Det Norske Veritas

Assessment of freight train derailment risk reduction measures:

Part A Final Report

Report for European Railway Agency
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MANAGING RISK DNV

Assessment of freight train derailment risk reduction measures:
Part A final report
for

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0.0 Executive Summary

0.1 Study Scope and Objectives

Det Norske Veritas is completing a study on behalf of the European Railway Agency (the Agency), the objective of which is twofold:

1. Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation within 5 to 10 years). This is to be achieved through the following schedule of activities:
    - Task A.1 - identification of existing operational and technical rules.
    - Task A.2 - description of the markets and technologies covered by the devices/systems in use or which may be used at medium term.
    - Task A.3 - description of the rules (inc. specific devices/systems used) in generic functional and performance terms.
    - Task A.4 - advice on innovative longer term measures (unlikely to be available within 10 years) which might be considered in a future R&D project.
2. Part B has the objective of analysing the measures identified in Part A with a view to establishing those that show the most promise from a risk reduction viewpoint. Part B addresses such measures which are available at the short and medium terms.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland. In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

This document is the Final Part A report.

0.2 Methodology

Part A has involved a series of consultation exercises, in particular:

1. We consulted with infrastructure managers (IMs) and railway undertakings (RUs) to establish:
    - The types of measures (technical, operational, organisational or human) they currently use to either reduce the frequency or mitigate the consequences of freight train derailments.
    - The effectiveness of these measures.
    - Their plans for introducing additional measures in the short term and beyond.
    - Where an IM or RU had indicated the use of a technical measure, we asked them in a subsequent round of communication for their experience of the reliability performance and effectiveness of these measures.
2. Having established, from the consultation above, a full list of existing and potential future measures, we embarked on a further round of consultation. This further consultation was limited to suppliers of technical measure (defined as a device or a system) , for which we sought information on, but not limited to:
    - The reliability, availability and maintainability (RAM) performance for their technical measures.

- False alarm rates and failure mode information.
- The way in which these technical measures may influence the risk of freight train derailment.
- Cost and life cycle questions, such as special disposal requirements, the requirement for preventative maintenance etc.
- Finally, we asked suppliers for their views of how technology might evolve and new products that may be available in the future.

This consultation work has been supplemented by complementary research and information searches to provide a through analysis of the areas of this project's scope. We have also considered and report on:

1. The regulatory framework in which the identified measures operate in Section 2.1.
2. The derailment problem, causes and influencing factors in Section 3.0.
3. An initial review of freight train derailments accidents in Section 8.0 (to be finalised and updated throughout Part B).

0.3 Results

0.3.1 Measures to Reduce Freight Train Derailment Risk and Consultation

As part of this consultation and other complementary research we identified:

- 43 measures in place to reduce the likelihood of a freight train derailment.
- 8 measures that could be introduced in the future reduce the likelihood of a freight train derailment.
- 13 measures in place to reduce the consequence following a freight train derailment.

For each measure within the study scope we assessed, or proposed a method for the assessment of, the performance of each measure. This is reported in detail in Section 7.0 for all measures identified.

We also discuss the way in which a measure will be used, together with its performance assessment, within Part B. We summarise this in the diagram below. In this diagram we show the failures that may lead to derailment in a logical construct, together with the measures that may be applied to reduce the contribution from that cause. This barrier model is to be further developed during Part B and populated with data for all failure causes contributing to freight train derailments.

0.3.2 Market Considerations

Finally, for a technical measure, it will be an important to carefully consider the market implications that may result should a measure be recommended, in terms of whether such a recommendation may provide a competitive advantage to one supplier. This is reported in terms of our market analysis at Section 6.0 and will be further addressed in Part B.

0.4 Summing Up

We have undertaken a large body of work to establish the measures in the study scope, involving significant industry consultation and research. We have also presented these measures to a large workshop arranged by the Agency, and held 6th May 2011. These are discussed in the body of this document.

We also present our initial findings arising from an evolving accident analysis of freight train accidents. This work will form a significant input to our Part B work, the structure of which is outlined in Section 8.0.

Contents

1.0 Introduction

1.1 Background

In 2009 the European Railway Agency (the Agency) issued a recommendation (ERA/REC/01-2009/SAF) [1] on a specific proposal[1] for a new harmonised rule aimed at reducing the consequences of freight train derailments, potentially involving dangerous goods. The recommendation concerned the potential use of a specific Derailment Detection Device[2] (DDD, a device which automatically acts on a freight train when a derailment of a wagon equipped with that device is suspected).

Although the Agency's recommendation was that the EDT-101 type devices should not be adopted in the RID, the Joint meeting of RISC and Inland TDG EU regulatory committees agreed that, considering the low potential benefit expected with the EDT-101 type devices, as well as some other problems related to the operation of trains equipped with these types of detectors, more efficient prevention measures should be further explored before deciding on imposing, by law, measures base on the derailment detection.

Therefore recognising that freight train derailments remain a safety and operational concern, and following a request of the above mentioned EU committees, the Agency has commissioned Det Norske Veritas (DNV) to undertake a follow-on study. This follow-on study is divided into two distinct research stages, Parts A and B and the results of Part A are summarised in this document.

1.2 Part A Project Scope and Objectives

Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation within 5 to 10 years). This is to be achieved through the following schedule of activities:

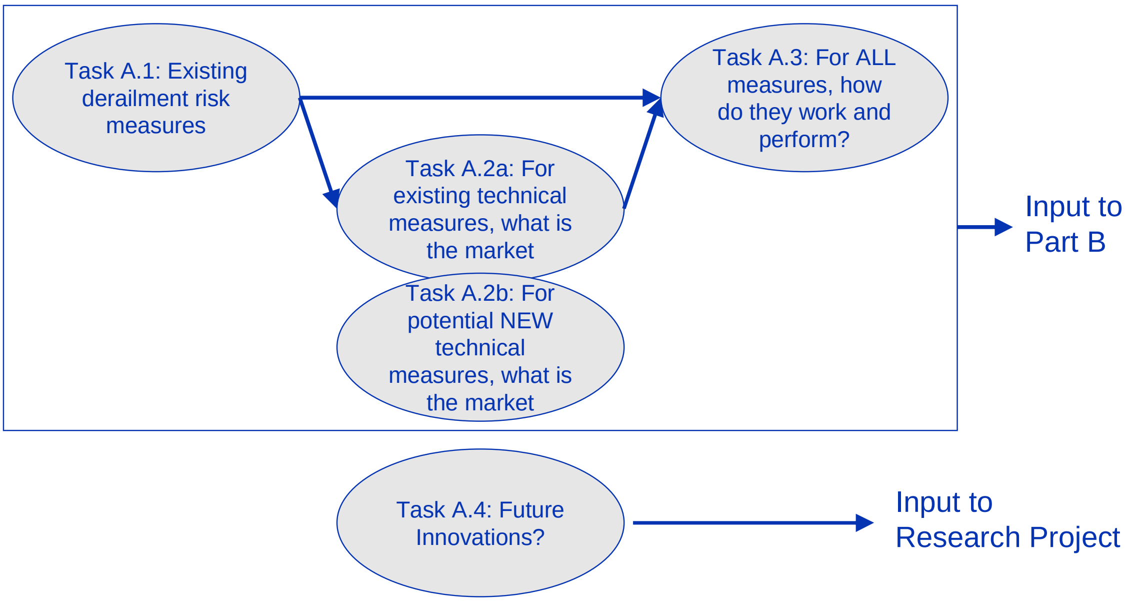
- Task A.1 - identification of existing operational and technical rules.
- Task A.2 - description of the markets and technologies covered by the devices/systems in use or which may be used at medium term.
- Task A.3 - description of the rules (inc. specific devices/systems used) in generic functional and performance terms.
- Task A.4 - advice on innovative longer term measures (unlikely to be available within 10 years) which might be considered in a future R&D project.

(Note that Task A4, which makes no further contribution to this project, is reported in a separate document [47]).

The linkage between tasks is shown below.

[1] The proposal was made by the RID Committee of Experts
[2] The specific device is the Knorr Bremse EDT 101

Figure 1: Part A Task Linkage



The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland[3]. In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

1.3 Part B Project Scope and Objectives

Part B has the objective of analysing the measures identified in Part A with a view to identifying those that show the most promise from a risk reduction and efficiency viewpoint. Part B is scoped to include all prevention measures but is limited to mitigation measures based on derailment detection technology. Part B addresses such measures which are available at the short and medium terms.

Part B is to be achieved through the following schedule of activities:

- Task B.1 – construction of detailed fault and event trees describing freight train derailments and showing the action of the safety functions on derailment risks.
- Task B.2 - semi-quantitative assessment of benefits and drawbacks of existing safety rules, and of new or improved measures at short and medium terms, using data on actual/targeted performance as well as conservative assumptions.
- Task B.3 - top ten ranking of potentially efficient new safety measures or improvements at short and medium terms, including practical and legal implementation aspects.

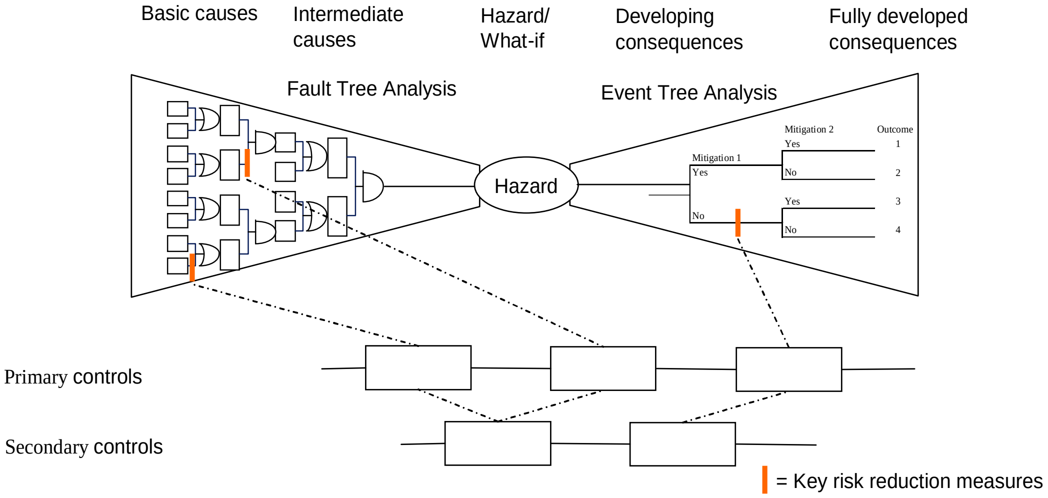
The assessment and ranking of these measures is take account of and suggest a possible implementation scheme designed to ensure the most efficient potential deployment of these measures (i.e. for all freight wagons, or a limited sub-set, for all infrastructure or only in highly populated areas etc).

However, and in keeping with the overall objectives of the Agency, any recommendations arising out of Part B work will be aimed at the harmonised international level.

[3] Hereinafter called the target countries

As a brief summary of the Part B structure, the figure below is provided. This figure shows a generic fault and event tree model which is to be developed in more detail during Part B.1.

Figure 2: Part B Structure



To the left hand side of the “bow-tie” model are the causes that may lead to the hazard (in this case freight train derailment). To the right hand side the model develops how the hazard may evolve into its potential outcomes. These may range from no significant consequence to loss of containment of dangerous goods, for example.

Shown pictorially in red are measures that may reduce the likelihood of freight train derailments (therefore appearing on the right hand side of the diagram) or mitigate the consequences (on the left). These measures are extracted from the A reports referenced above.

The models are populated with data extracted from various pertinent sources allowing the model to be used to identify a prioritised list of measures that show the most promise.

2.0 Background and Context

2.1 The Drive Towards a More Harmonised Rail Environment

2.1.1 Background

The various countries having an operational rail network all have a set of rules, regulations and operational procedures for design, construction and maintenance of the infrastructure and rolling stock, as well as for traffic operation[4].

Despite their being physical, technical, operational and regulatory differences between countries, cross border rail freight has been possible for more than 150 years and the railway has been an important medium for international freight transport in Europe during this period. This has been achieved through standardisation of the basic design of freight wagons through the works of UIC (Union Internationale des Chemins de Fer), International Union of Railways and the RIV (Regolamento Internazionale Veicoli), International Wagon Union, to suit interoperation of wagons from different countries.

More recently there has been a move towards a more competitive standardised and open approach to international rail traffic (freight and passenger). This has been achieved in the form of various directives and technical specifications.

We briefly summarise these below as it is important that this project does not make recommendations to the Agency that contravene the fundamental principles of harmonisation that is being strived for.

2.1.2 The European Railway Safety Directive

The European Railway Safety Directive (the Directive) [2] supports the development of open and transparent access to the European rail market. The Directive which was introduced in 2004, establishes a common regulatory framework designed to ensure that safety does not present a barrier to the establishment of a single market for railways.

The key measures introduced by the Railway Safety Directive 2004 [2] are listed below:

- The requirement for each Member State to notify the European Commission of all of their relevant National Safety Rules.
- The establishment of Common Safety Indicators (CSIs) which are high level indicators of significant risks to the mainline rail network (e.g. signals passed at danger and broken rails).
- The establishment of Common Safety Methods (CSMs) which are harmonized approaches to risk management, the exchange of safety relevant information and the evidence resulting from the application of a risk management process.
- The establishment of Common Safety Targets (CSTs) which define the minimum safety levels and safety performance that must at least be reached by the system as a whole in each Member State, expressed in risk acceptance criteria for individual risks to passengers, employees, level crossing users, 'others' and unauthorized persons on the railway.
- The requirement for Safety Authorizations and Certificates which requires the Member States' National Safety Authority to grant safety authorizations to Infrastructure Managers (IMs) and safety certificates to Railway Undertakings. The purpose of safety

[4] Rules, standards and instructions as discussed in this section provide some degree of control against derailments, but cannot cover all eventualities, failures and sub-standard conditions that may lead to derailment.

authorizations/certificates is to provide evidence that railway undertakings have established suitable Safety Management Systems (SMS) and are operating in accordance with them.

- The Investigation of Accidents.

2.1.3 Interoperability Directives

The European Commission has prepared a range of regulations to improve the interoperability of the European railways, not only with regard to hauling of freight and passenger cars, but regarding the overall operation of the railways.

In order to achieve this, a number of Interoperability Directives for the railway system have been developed and enforced by the European Community.

- The Trans-European High-speed Rail System [3] covered the development of the high speed rail system, mainly for passenger transport. The first Directive of 23 July 1996 was later amended as specified below:
  - The Interoperability Directive (2008/57/EC) [4] for the Community Rail System sets out a number of essential requirements to be met for interoperability, which include safety, reliability and availability, health, environmental protection and technical compatibility along with others specific to certain sub-systems. This also requires the production of mandatory Technical Specifications for Interoperability (TSIs) which define the specifications required to satisfy those essential requirements.

2.1.4 Technical Specifications for a Harmonised European Rail System

The TSIs are specifications drafted by European Railway Agency Working Groups to ensure the interoperability of the trans-European rail system. The TSIs outline the essential requirements and basis for design of an interoperable railway system in Europe. Table 1 below specifies the TSIs applicable for conventional rail infrastructure and freight trains that may influence the risk of derailments.

Table 1: Overview of TSIs with Relevance to Derailment

Reference:	Document Title	Status:
ERA IU-INF-090902-TSI 4.0	Trans-European Conventional Rail System – Subsystem Infrastructure	Final Draft TSI; dated 18/09/2009.
EUR-Lex – Official Journal – Vol 49 – 2006 - L 344. Vol 52 – 2009 – L 45	Technical specification of interoperability relating to the subsystem rolling stock — freight wagons of the trans-European conventional rail system	Commission decision of 28th July 2006; amended by commission decision of 23rd January 2009
08/57-ST05 10.06.2010	Draft Commission Decision concerning Technical Specification for Interoperability relating to the rolling stock sub-system – "Locomotives and Passenger rolling stock" of the trans-European conventional rail system	Final draft issued for approval of European Commission
ERA IU-RST-19112009-TSI Report	Trans-European conventional Rail System – Locomotives and Passenger Rolling Stock[1]	Comment report to Final Draft TSI; dated 19/11/2009
EUR-Lex – Official Journal – Vol 49 – 2006 L 359. Eur-Lex – Official Journal – Vol 53 - 2010 L-280, page 29 – 58.	Technical specification of interoperability relating to the subsystem Traffic Operation and Management of the trans-European conventional rail system.	Commission Decision 2010/640/EU amending Decisions 2006/920/EC and 2008/231/EC (26 Octobre 2010) Annex P5: Decision 2009/107/EC of amendment Decision 2006/861/EC and 2006/920/EC (23 January 2009) Decision 2006/920/EC (11 August 2006)

Reference:	Document Title	Status:
EUR-Lex – Official Journal – 2006 – L 284	Technical specification for interoperability relating to the control-command and signalling subsystem of the trans-European conventional rail system	Decision 2009/561/EC - Amendment of Decision 2006/679/EC; Decision 2008/386/EC - Command Subsystem ERTMS modifying Annex A to 2006/679/EC and Annex A to 2006/860; Decision 2006/860/EC - Control and command subsystem ERTMS modifying Annex A to 2006/679/EC; Decision 2006/679/EC
EUR-Lex – Official Journal – Vol 51 – 2008 – L 64	Technical specification of interoperability relating to safety in railway tunnels in the trans-European conventional and high-speed rail system.	Decision 2008/163/EC
EUR-Lex – Official Journal – Vol 49 – 2006 – L 13	Technical specification for interoperability relating to the telematic applications for freight subsystem of the trans-European conventional rail system	Regulation 62/2006/EC

2.1.5 European Standards

The documents listed in Table 2 include a list of standards and other documents relevant to the design and conformity assessment of subsystems and interoperability constituents. For each TSI, two groups of documents are listed:

- The standards or other documents (or parts thereof) which are specifically referred to in the TSIs and which are therefore mandatory.
- The standards or other documents (or parts thereof) that are not referred to in TSIs are not mandatory.

Table 2: Standards lists for TSIs

Standard lists of relevance to High Speed TSIs	
Publication date	Title
08-12-2008	Standards in HS Control command signalling TSI (2006/860/EC)
08-12-2008	Standards in HS Energy subsystem TSI (2008/284/EC)
08-12-2008	Standards in HS Infrastructure subsystem TSI (2008/217/EC)
08-12-2008	Standards in HS Operation TSI (2008/231/EC)
08-12-2008	Standards in HS Rolling stock subsystem TSI (2006/232/EC)
Standards lists of relevant to Conventional Rail TSIs	
Publication date	Title
08-12-2008	Standards in CR Control command and signalling TSI (2006/679/EC)
08-12-2008	Standards in TSI for noise in aspects of conventional rolling stock (2006/66/EC)
08-12-2008	Standards in CR Operation TSI (2006/920/EC)
08-12-2008	Standards in CR Rolling stock – Freight wagons TSI (2006/861/EC)
Standards lists of relevance to transversal TSIs	
Publication date	Title
08-12-2008	Standards in TSI relating to persons with reduced mobility in the trans-European conventional and high speed rail systems (2008/164/EC)
08-12-2008	Standards in TSI relating to safety in railway tunnels in the trans-European conventional and high-speed rail systems (2008/163/EC)

2.1.6 National Rules and Regulations and Voluntary Rules

2.1.6.1 National Rules and Regulations

As discussed in the opening of this section, national rules have always existed and will still exist – at least for the foreseeable future - despite the introduction of a more harmonised framework for international rail traffic.

These notified national rules are used in addition to the TSIs and describe nationally binding conditions that must be met. However, these national rules must ensure that the railway system is interoperable and must ensure that current safety levels are not eroded.

According to Article 8(1) of the Railway Safety Directive [2], Member States shall establish binding national safety rules. Article 8(2) required the Member States to notify these safety rules to the Commission before April 30 2005. After this date, Article 8(4) requires the notification of any amendment (including repeal) to these notified rules and also of any new national safety rules.

Annex II of Railway Safety Directive [2], describes the national safety rules that shall be notified. These are:

1. Rules concerning existing national safety targets and safety methods.
2. Rules concerning requirements on safety management systems and safety certification of railway undertakings.
3. Common operating rules of the railway network that are not yet covered by TSIs, including rules relating to the signalling and traffic management system.
4. Rules laying down requirements on additional internal operating rules (company rules) that must be established by infrastructure managers and railway undertakings.
5. Rules concerning requirements on staff executing safety critical tasks, including selection criteria, medical fitness and vocational training and certification as far as they are not yet covered by a TSI.
6. Rules concerning the investigation of accidents and incidents.

It should be noted that rules, which wholly concern requirements set out in TSIs in force, do not need to be notified.

2.1.6.2 Company and Voluntary Rules

Company / voluntary rules are those controls that are put in place by an organization, usually in addition to national rules. Their purpose is normally to improve business or safety performance, or to otherwise secure some benefit from their adoption.

2.1.7 Regulations for Transport of Hazardous Materials

2.1.7.1 RID Regulations

The RID regulation specifies under what conditions various materials are allowed for international transport by rail. The conditions comprise:

- Classification of goods.
- Packaging requirements.
- Tank usage including filling of tanks.
- Information and marking requirements.
- Requirements regarding testing and approval of packaging materials and tanks.
- Use of transportation modes (including loading, co-transportation and unloading).

The RID regulations are not concerned with railway technology and railway operation apart from tank design, and information and marking requirements.

2.1.7.2 National and Company Regulations

In addition there can be stricter regulations and requirements relating to transport of dangerous goods at a national and company level for instance with regard to shunting restrictions on wagons with dangerous goods including tank wagons with hazardous materials.

Chemical companies or train operators might have stricter regulations with regard to various form of shield protection of tank wagons. IMs and RUs might have restrictions on shunting operations. For example, in Scandinavia and Central Europe very dangerous goods are excluded from shunting humps, for instance chlorine whereas this is admitted in some Baltic countries.

3.0 Description of the Train Derailment[5] Problem

3.1 Railway System Elements

The railway transport system consists of:

- A fixed infrastructure comprising train formation yards, track, power catenaries, signalling and telematics system for communication.
- A number of transport units consisting of traction equipment and load carrying units (rolling stock) normally coupled into trains of a certain length.
- Operational personnel in an organizational structure that ensures qualified personnel as well as appropriate operational procedures and information management for handling the trains on the relevant infrastructure in a safe manner.

The essence of a safe railway operation is to manage the following tasks:

1. Ensure structural and functional integrity of the infrastructure and its subsystem,
2. Ensure structural and functional integrity of the rolling stock,
3. Control of the infrastructure – train interface in terms of wheel – rail guidance.
4. Train operation and management necessary for a safe and effective operation.

The management of all four tasks is important and we will address each of them briefly below.

3.2 Structural and functional integrity of the infrastructure

Important elements to avoid derailments are the integrity and functionality of the track and the provision of a free train profile as well as the functionality and safety of the signalling system. This includes:

- Integrity of the substructure, e.g. integrity of bridges and tunnels avoidance of subsidence etc.
- Integrity of the superstructure including track, rails, points (turnouts), sleepers, rail fastening equipment etc. Safety critical failures can be track buckles, rail ruptures, worn rails, broken sleepers, lost or damaged rail fastenings, etc.
- Functionality and safety of the signalling system with regard to clear and correct train driving information, movement allowances and operational speed along the line.

Each of the above groups is briefly described below:

3.2.1 Substructure Failures

The substructure consists of the structural earthworks for the railway, bridges and tunnels and provides a basis for the rail superstructure. It also includes the side terrain as far as is necessary to ensure the safety of the rail infrastructure. Substructure failures which can cause derailments are:

- Structural earthworks eroded and washed away due to flooding of rivers and streams crossing or running parallel to the railway.

[5] According to the EU definition of Common Safety Indicator a derailment occurring after a collision is allocated to the collision category. Consequently measures preventing the occurrence of collisions are not considered further in this report. For this reason measures P-3, P-4, P-5 and P-17 are no longer considered.

- Subsidence of earthwork and superstructure ballast due to water accumulation and high water level in the earthworks due to insufficient drainage.
- Structural collapse of bridges and tunnels.
- Frost heave in cold countries.

Protection against external hazards as well as inspection and maintenance of track drainage and side terrain are important activities to avoid derailments.

3.2.2 Superstructure Failures

The superstructure consists of the top ballast layer, the sleepers, rail fastenings and the running rails. Points and rail crossings also belong to the superstructure. Superstructure failures that can cause derailments are among others:

- Ruptures and excessive wear of main rails, switch rails and joint bars.
- Broken or missing rail fastenings.
- Point geometry failures.

Derailments due to track geometry failures are often an interface problem between track and rolling stock are discussed in Section 3.4.

3.2.3 Signalling and Train Control Equipment

Failure and insufficient functionality of the signalling and train control equipment can also be a cause of derailment with ambiguous signalling information or points being allowed to operate while a train is passing or located on top of the point.

3.3 Structural and Functional Integrity of the Rolling Stock

Important elements to avoid derailments are the integrity and functionality of the rolling stock. This includes:

- Integrity of the rolling stock running gear including wheelsets (wheels, axles and bearings), suspension and bogie structure. Typical safety critical failures are ruptures of axles and wheels, suspension failures in terms of broken or locked springs or sheared bearings.
- Integrity of the wagon or load carrying units, frame and load bearing capability. Typical safety critical failures are wagon frame twist, failure of load bearing elements, buffer failure.
- Integrity of train braking equipment. Typical safety critical failures in relation to derailment are: brakes are that non-operational or partly operational only, brakes that do not release and overheat the wheels or braking equipment falls off the wagon.

3.3.1 Wheelsets and Bearing Failures

The most critical components in relation to train derailment are wheelsets and bearings, and the following types of failures may occur:

- Sheared or increased friction in bearing causing overheating of the axle box and rupture or shearing of the axle journal (i.e. the parts of the axle that are outside of the wheel). This type of failure can be discovered by trackside detectors (hot axle box detectors or acoustic bearing failure detectors). If a bearing is damaged a hot axle box can develop very quickly.
- Rupture of axle shaft or axle journal due to fatigue. This type of failure is often initiated by a mechanical scratch to the axle material or a corrosion attack due to a fault or mechanical damage to the corrosion protection layer of the axle. The crack initiation is slow but maybe difficult to detect unless it has a visible cause. Once the crack has grown to a size that can

easily be detected, the further growth can be fairly rapid. Detection and correction of possible crack initiation points are therefore essential.

This type of failure will normally not be detected by hot axle box detectors or any other type of trackside detectors at the moment, at least not if the crack is located in the axle shaft (i.e. between the wheels). Thorough NDT-inspection of the axle is necessary.

- Wheel failure. The most common type of wheel failure that may cause derailment is various out of roundness failures such as wheel flats, wheel tread wear and shelling, oval wheels, wheel profile failure etc. By themselves they seldom cause derailments, but wheel flats, wheel tread failures and out of roundness of wheels may increase the load on the bearing whilst wheel flats may also rupture rails, in particular under cold weather conditions. Wheel profile failures in combination with difficult track geometry is a common contributor to derailments.
- Wheels can be of two types either monoblock wheels where the entire wheels is forged in one piece, or as a composite wheel with a separate rim and an outer tyre which is shrink fitted on the wheel.
    - For composite wheels the tyre can come loose and move sideways on the rim affecting the wheel width of the axle and cause derailment, or it can break and fall off or come loose entirely with the same result. Wheel tyre heating due to strong braking action can cause the tyre to move on the wheel rim. Composite wheels have therefore been removed from operation in some countries with mountainous lines where prolonged braking action is required. Rim and tyre wheels should normally be marked so that any relative movement between the wheel and rim can easily be discovered.
    - For monoblock wheels a rupture of the entire wheel may occur either due to a material failure or mechanical defect initiating a crack. Heating of the wheel tread by strong braking action can contribute to wheel rupture.

Figure 3: Example of a Bearing Failure[6]

[6] Picture from Eisenbahn-Unfallsuntersuchungsstelle des Bundes Jahresbericht 2009 (pdf/671-KB) Jahresbericht 2009

3.3.2 Wagon Frame and Wheel Suspension Failures

The twisting flexibility of a wagon frame and the suspension is important in order to avoid unloading of a wheel in a twisted track in transition curves. There are requirements relating to the flexibility of railway wagons and suspension to ensure that the wheels are not unloaded under normal track conditions. Further the suspension shall dampen forces to the track from wagon movements.

Failures that can cause derailments are ruptured suspension springs or wagon frame twist. In particular wagon frame twist can be difficult to discover during visual inspection.

3.3.3 Brake Failures

Failures of train brakes and inappropriate brake actions can cause derailments of freight trains. The most obvious is if the train cannot be braked and is unable to adhere to signals or speed reduction signs along the line, and if the train is in a steep descent a runaway train may be the result. In order to avoid such situations there are requirements for brake testing prior to departure in all railway operations.

Failures of brake action of a single wagon is not considered critical and hence it is not uncommon that brakes of a single wagon are closed off if there are some failures with the brake equipment e.g. brake blocks missing or brake blocks not meeting minimum thickness. Further, if the brakes of a wagon do not release properly it is a cause for closing the brakes of the wagon as locked wheels can cause wheel flats that can damage the rails.

The braking force of the individual wagons is adjusted according to the loaded condition of the wagon, either by automatic weighing valves or by a manual handle. The speed of brake application and the braking profile according to train speed can also be adjusted by manual handles on the side of the wagon with 3 possible positions G, P & R. Normally the brakes of wagons in freight trains are operated in position P apart from the locomotive and first wagons in long trains that have to be operated in brake position G.

Application of the brakes of a freight train is controlled by manipulating the drivers brake valve in the front of the trains and reducing the pressure in the brake pressure line. The speed of brake signal transmission is governed by the speed of sound in the pressure main and the minimum transmission speed according to UIC 540 is 250 m/s. Freight train length of approximately 800 m are allowed in some countries e.g. Denmark. Hence, the brake application in the front may occur more than 3 seconds prior to the brake application in the rear of the train. This will cause strong compression forces in the train that can cause derailment in sharp curves or if brakes are applied in deviated train routes across stations. The requirement for putting the brakes of the locomotive and the forward wagons in brake position G is thus often used to limit the compression forces as G is a slow brake action position.

3.4 Control of the Interface between Train and Infrastructure

Track geometry failures are the most frequent group of infrastructure caused derailments.

A rail vehicle basically consists of a body supported by secondary suspension on bogies in which the wheel sets are mounted and dampened by means of primary suspension. Track guidance of the wheel is achieved in principle by the following two provisions.

- The wheel surface contacting the rail is conical which means that in straight track a centring force is exerted on the wheel set if there is a slight lateral displacement. The centring effect promotes a better radial adjustment of the wheel set tyres of the wheel. This leads to more rolling, less slipping and hence less wear.
- The running surface of the rail wheel has flanges on the inside of the track to prevent derailment. In case of more considerable lateral displacement both in curves and on

switches, the lateral clearance between wheel set and track is not sufficient to restrict lateral displacement adequately by means of the restoring mechanism previously discussed. Should the wheel flange touch the rail head face high lateral forces and wheel and rail wear will occur and steep flanges may be a cause of derailment.

3.4.1 Derailment due to Track Twist

A derailment due to track twist occurs when there is a high horizontal guiding force between wheel and rail and a reduced vertical load that is insufficient to prevent the wheel flange from climbing the rail. A horizontal guiding force always occurs in curves and a reduced vertical load can occur due to track twist or insufficient torsional flexibility of the wagon frame and suspension (springs).

Track twist occurs as a designed and constructed feature of the railway track in transition curves leading into and out of a circular canted curve or due to uncorrected faults in the trackbed. Factors that contribute to unloading of wheels in twisted tracks are:

- Increased horizontal guiding force due to tight curve.
- Low wheel loads due to empty or partly loaded vehicles.
- Torsionally stiff vehicles in particular if they have a long wheel base.
- Skew loaded vehicles:
  - Low train speed.
  - High friction conditions associated with dry rails.
  - Another unfavorable factor can be compression forces in the train due to uneven braking along the train and strong braking in the front of the train.

Derailment due to track twist is therefore complex phenomena not always easy to control under all operational conditions, but generally it is most likely to occur at low speed.

3.4.2 Derailment due to Height Failure (cyclic tops)

Height failures in the track can cause derailments, in particular if there are regular undulations in the track causing excitation of the wagon suspension. Such failures may not be discovered by local static measurements. A derailment due to height failure (cyclic top) can also be caused by single dip followed by a top. Such conditions may develop in track passing one or more points if the substructure is weak. Derailments due to height failures or cyclic tops normally occur at high speed. Speed reduction is a relevant risk reducing measure.

3.4.3 Derailment due to Excessive Track Width

If the dynamic track width becomes excessive one of the wheels can fall below the rails. This occurs most often where the track superstructure and rail fastening is weak, either with lost fastenings or old wooden sleepers not giving good support for the fastening. This is most likely to occur on track that has not been given sufficient priority in maintenance, either on sidelines or in sidetrack at the stations. Speed reduction may decrease the derailment risk.

Figure 4: Example of a Track Width Failure[7]

3.4.4 Derailment due to Heat Buckles

Heating of the track may cause sudden buckles (heat buckles or sun curves) of a continually welded track. They occur abruptly, often while train is passing, and can cause very serious derailments. They occur most likely in curves and close to a fixed point in the track. It is mitigated by controlling the track temperature or track stresses during construction and the position of the track. Rail creep due to braking and/or traction can contribute to developing heat buckles.

Figure 5: Example of a Heat Buckle[8]

3.5 Train and Infrastructure Operation

Operational actions and omissions by RUs, train operating staff, rolling stock operators as well as infrastructure traffic controllers can influence the risk of derailment in many ways as indicated below:

[7] Picture from SHT Report 2009/05: Derailment of train 5505 25.07.2008 between Hval & Hønefoss
[8] Picture from SHT Report 2007/11: Derailment at Råde on Østfoldbanen

- By inappropriate loading of wagons, i.e. skew loading or insufficient fastening of transported loads.
- By unfortunate train composition with uneven train load and train brake distribution.
- By insufficient train inspection and brake testing.
- Switching of points whilst the point is occupied by a train.
- By mishandling of train on route by train driver.

The derailments classified as operational failures include a very wide variety of causes by different actors. Inappropriate loading is one common derailment contributory factor and is discussed in more detail below.

3.5.1 Loading Failure

Restrictions apply in every country with regard to maximum allowed load of a wagon as well as lateral and longitudinal load distribution.

Among the applicable restrictions are:

- Maximum axle load, both in relation to rolling stock and infrastructure limitations.
- Longitudinal and lateral load distribution in the wagon, in particular is the lateral load distribution important and an allowable restriction with respect to load distribution.
- Requirements for securing of loads against movement along the route.

According to the regulations of most RUs the loading should be controlled by adequate means before train departure. However, an increased use of containers and swap bodies makes it difficult to control the load distribution. An increased use of large front wheel loaders for loading of hopper wagons also represents a new challenge with regard to controlling against skew loading, as loading of hopper wagons by front wheel loaders can cause significant skew loading. Due to a high centre of gravity this can be particular critical under certain track conditions. Below is a picture of a skew loaded hopper wagon which is a typical example

Figure 6: Example of a Skew Loaded Wagon[9]

[9] Picture from http://versa.bmvit.gv.at/uploads/media/17.11.2008_Entgleisung_Z47107_in_Unter_Purkersdorf_02.pdf

3.6 Organisational Failures

Finally, underpinning the causes discussed above, and influencing their likelihood, is the organisational structure of IMs, RUs and other actors. We have mentioned the types of controls in place in Section 2.

Failures of these organisational controls may include:

- Inappropriate adherence to operating procedures.
- Lack of / inappropriate maintenance.
- Failure to learn lessons from previous incidents.
- Poor safety culture.

Whilst such failures are difficult to quantify numerically, they contribute to many of the derailment causing failures described above.

4.0 Existing Measures Addressing the Derailment Problem

4.1 Methodology and Definition

A measure is something that is in place to either reduce the likelihood or minimise the consequences of a freight train derailment.

A measure is existing if it is *"...applied for implementing a given regulation requirement, or applied on a voluntary basis."* [5]. For a measure to be existing it must therefore be applied in at least one of the target countries.

We have identified these existing measures through a diverse range of activities that has included:

1. A first round of direct consultation with IMs, RUs, National Safety Authorities (NSAs), railway associations and other stakeholders.
2. A second round of direct consultation with research organisations and rail market suppliers regarding technical measures supplied to the market.
3. Internet research and review of journals to identify specific examples of applied measures.
4. Review of network statements, accident reports and other information sources.

We report specifically on the consultation at Section 4.2 below as this is an important aspect of this work, and an essential requirement of the Agency work remit.

4.2 The Consultation

4.2.1 IMs, RUs and Other Actors

DNV has identified organisations representing IMs, RUs, and trade associations, inviting them to participate through responding to questionnaires. The full questionnaires are presented in Appendix II for RUs and Appendix III for IMs. We summarise the question categories below.

Table 3: Measures Consultation Question Categories

Railway Undertakings and Wagon Owners	Infrastructure Managers
• What is currently done to prevent or mitigate freight train derailments: – What measures are currently applied and why do you apply them? – Are the measures you apply effective?	• What is currently done to prevent or mitigate freight train derailments: – What devices are used to supervise trains (hot axle box detectors etc) and what is their density? Are these installed to meet a requirement (international, national or company)? – How is the information provided by these devices used? – Are the condition monitoring measures you apply effective? – Do you use some form of speed supervision on your freight lines? – What type of speed supervision is used?
• Maintenance: – Who performs maintenance on your wagons and locomotives? – What controls and competency standards are in place to ensure that maintenance is performed correctly?	• Design and Maintenance: – For mixed traffic, are the track parameters optimised for passenger or freight? – What is the maximum axle load/speed? – What is your preventative maintenance philosophy? – How is maintenance funded and are freight lines given equal priority? – How are conflicts of interest dealt with? – What controls and competency standards are in place to ensure that maintenance is performed correctly?
• Current performance / short term measures: – What is your experience and what are your views	• Current performance / short term measures: – What is your experience and what are your views on

Railway Undertakings and Wagon Owners	Infrastructure Managers
on your own performance with regard to freight train derailments? – Where do you consider improvements are most needed? – Are you aware of any new measures that could be applied in the short term to improve the situation and what are your views on the costs that might be associated with these measures? – Are there any changes that could be made to instructions such as TSIs that you consider would be beneficial?	your own performance with regard to freight train derailments? – What is the approximate division between derailment causes by rolling stock, infrastructure and operational failures? – Are you aware of any new measures that could be applied in the short term to improve the situation and what are your views on the costs that might be associated with these measures? – Are there any changes that could be made to instructions such as TSIs that you consider would be beneficial?
• Future advances: – Are you aware of/have plans to test new technology that could form the basis of a longer term solution to the problem of freight train derailments – What are your views of the provision of electrical power to wagons/	• Future advances: – Are you aware of/have plans to test new technology that could form the basis of a longer term solution to the problem of freight train derailments
• Other comments	• Other comments
	• What is the size and nature of your network: – Proportion TEN classified? – Proportion mixed traffic/freight only/passenger only?

The consultation exercise has been conducted on a confidential basis, and we are not able to identify the specific individuals or organisations responding to the questions, however we can provide the following details relating to responses received.

Table 4: Consultation Question Categories

Country	RUs / Wagon Owner	IMs	Country	RUs / Wagon Owner	IMs
Austria	Yes	Yes	Luxembourg	Yes	
Belgium		Yes	Macedonia		
Bulgaria	Yes		Netherlands		Yes
CER	Yes	Yes	Norway	Yes	Yes
Croatia		Yes	Poland		Yes
Czech Republic		Yes	Portugal		Yes
Denmark	Yes	Yes	Romania		
Estonia			Slovakia	Yes	Yes
Finland	Yes	Yes	Slovenia	Yes	
France		Yes	Spain	Yes	
Germany	Yes		Sweden	Yes	
Greece			Switzerland	Yes	Yes
Hungary		Yes	Turkey		
Ireland			UIP	Yes	
Italy			UNIFE	Yes	Yes
Japan			United Kingdom	Yes	Yes
Latvia	Yes	Yes	United States	Yes	Yes
Lithuania	Yes	Yes			

In some cases the responses from trade associations provide the views of a number of their members, some of whom have chosen not to respond individually. The combined coverage (based only on individual country responses, not trade associations) covers approximately 80% of the total freight traffic volume in the target countries.

4.2.2 Suppliers and Research Organisations

DNV has sought input from research organisations and organisations supplying the rail market regarding existing measures, and also market developments and potential future advances. The mechanism for this has been through questionnaires and targeted interviews.

The full questionnaires are presented in Appendix IV. We summarise the question categories below.

Table 5: Supplier Consultation Question Categories

Question Category	Question Detail (Summary)
Interviewee	Details of the role, responsibility of the respondent and the Company they are responding for
Organisation and products	Details relating to the range of products marketed and previous products
Future developments	What other types of technical measures are you currently developing? When will these be available in the market place? Are you aware of other future developments with respect to technical measures for preventing/mitigating derailment?
Market	What is the primary function / technology associated with the products offered? Where are they installed? Are the products employed primarily for passenger traffic, primarily for freight traffic or both? What is the existing and potential future market for the products? What is the market share (financial or quantity)?
Costs and benefits	What is the indicative price of a single product? What are the life cycle costs / requirements for the products? How should the products be deployed to maximise their benefits? What operational aspects need to be considered in order to reap the benefits of the product?
RAM	What is the estimated lifetime of the products? What is the estimated Mean Time Between Failure or other reliability measure of the products? What is the estimated Mean Time To Repair or other maintenance measure of the products? How will failures of the products be detected? Will all failures of the product be detected? If not, are these failure modes dangerous? What is the estimated rate of False Alarms of the product? What is the in-service reliability performance of this equipment? What is the actual measured rate of false alarms? Has the product been approved by relevant safety authorities?

The consultation reported here received over 30 detailed responses for technical measures.

4.3 Results – What are the Existing Preventative Measures?

4.3.1 Definitions and Clarifications

In the following tables various existing measures to prevent derailments are listed. When some individual countries are mentioned as employing the measure it does not mean that they are the only countries (or companies) applying the measure.

We use the term “general railway knowledge” to describe measures that we believe are well known and accepted in the industry, and would be acknowledged by rolling stock or infrastructure engineers as having a positive effect on reducing the probability of derailment.

Some general measures, like hot axle box detectors and various type of wheel load detectors have several suppliers and use different technologies. In such cases only the generic type is mentioned.

Table 6: Infrastructure Preventive Measures

Type of measure	P#	Measures and motivation:	Where applied:	Source for Information:
Technical infrastructure	P-1	Installation of check rails to prevent derailments, in particular in sharp curves, as it will hinder flange climbing on outer rail in sharp curves. Check rails are also used in other conditions and have a wear reducing effect also. For further info see 4.3.2.1	In points in most countries. In line track with sharp curves GB and republic of South Africa.	Network Rail Track construction standard, NR/SP/TRK/102
	P-2	Installation of track and flange lubrication in front of track sections with narrow curves to reduce rail flange friction and limit the risk of flange climbing on rail with subsequent derailment consequences. For further info see 4.3.2.2. See also flange lubrication measure on rolling stock (locomotives) 4.3.5.1.	Several countries including Austria. Great Britain	Ref. [6]
	P-3	No longer used		
	P-4	No longer used		
	P-5	No longer used		
	P-6	Use of ground penetration radars (Geo radars). Ground penetration radars are used to survey conditions of track bed superstructure with regard to quality and water content. This is mainly used through ad hoc baseline runs to provide information for planning of maintenance and renewal, but permanent installations can also be considered. For further info see 4.3.2.3.	Several countries including US and Norway.	Ref. [7]
	P-7	Rolling stock mounted equipment for monitoring of rail profile conditions. For further info see 4.3.2.6.	Mermec supplied equipment	Mermec brochure [8]
Infrastructure; Control Command and Signalling	P-8	Track circuit as part of signalling system may detect rail ruptures. For further info see 4.3.2.4	Most countries	General railway knowledge
	P-9	Interlocking of points operation while track is occupied. This is not fully implemented at shunting yards. Hence a number of derailments occur due to points being operated while it is occupied by a train. This action very often causes derailment. Extend use of interlocking of remote controlled points to include tracks at shunting yards used for train movements. Interlocking of switch movement if the switched is occupied by rolling stock. For further info see 4.3.2.5	The protection measure is utilised and applied in most countries. The degree of application of point interlocking at shunting yards varies.	Several derailments reported due to shifting of point while occupied by train.
Trackside rolling stock supervision	P-10	Installation of hot axle box (hot bearing) detectors for detection of faulty and hot bearings and axle journals in order to remove them from train prior to derailment. For further info see 4.3.3.1.	Several European countries.	Questionnaire responses
Trackside installations to supervise	P-11	Installation of acoustic bearing monitoring equipment (This is partly an alternative to hot axle box detectors). The purpose of the installation is to detect faulty bearings by sound analysis and implement bearing maintenance prior to bearing seizure and hot temperature development. For further info see 4.3.3.2.	US, GB, Norway (installation plans)	Questionnaire responses & Ref [9]

Type of measure	P#	Measures and motivation:	Where applied:	Source for Information:
rolling stock	P-12	Installation of hot wheel and hot brake detectors. For further info see 4.3.3.3.	Several countries.	Network statement, Questionnaire responses
	P-13	Installation of wheel load and wheel impact load detectors. For further info see 4.3.3.4.	Several countries.	Network statement, Questionnaire responses
	P-14	Installation of dragging object and derailment detectors. For further info see 4.3.3.5.	US and other countries	Ref [9]
	P-15	Bogie performance monitoring/Bogie lateral in-stability detection (bogie hunting). For further info see 4.3.3.6.	US and other countries, including Turkey.	Ref [9]
	P-16	Wheel profile measurement system / Wheel profile monitoring unit. For further info see 4.3.3.7.	US and other countries	Ref [12]
	P-17	No longer used		
Infrastructure Operational/ organisational	P-18	Make sure available maintenance resources are sufficient in relation to network extent and traffic levels. If not possible to ensure sufficient resources a measure could be to close low traffic lines or take little used tracks out of operation. Lines and tracks where the minimum infrastructure safety requirements cannot be maintained should be closed down. For further info see 4.3.4.1	Low traffic line closure has been common in several countries.	General railway knowledge
	P-19	Ensure that the track/train clearance gauge including the flange groove is free of obstructions that can cause collisions or derailments. Special focus to flange groove in level crossings. For further info see 4.3.4.2.	Normal inspection and maintenance in most countries.	A1 final draft report reviewer
	P-20	Perform ultrasonic rail inspection of track at sufficient frequency in order to detect rail cracks before dangerous ruptures occur. This is an activity carried out by most infrastructure managers with frequencies dependent upon rail age and traffic loads. For further info see 4.3.4.3.	The activity is performed by most infrastructure managers. Frequency varies according to track loading.	General railway knowledge
	P-21	Perform track geometry measurement **of all tracks** in order to detect track sections requiring maintenance actions. Regular track geometry measurements are carried out by most infrastructure managers. The completeness of the measurements with respect to track coverage at stations as well as intervals may vary. Frequency normally dependent upon traffic load and allowable speed level of track. For further info see 4.3.4.4.	Most infrastructure managers but frequency may vary. Mixed coverage of sidetracks.	Accident investigation reports
	P-22	Establish EU-wide intervention and/or immediate action limits for track twist. The final draft TSI for CR Infrastructure specifies safety limits for track twist but intervention limits are left to the NSA or infrastructure managers of the various countries and they vary to a certain extent. Since the rolling stock are to be interoperable across all infrastructures the track intervention limits should also be corresponding. For further info see 4.3.4.5	Lack of consistency between countries, e.g. GB & Norway with regard to track twist intervention limits.	Final draft TSI CR Inf. Ref.[10] & RGS GC/RT5021 [11]
	P-23	Establish EU-wide intervention and/or immediate action limits for variation of track gauge.	Variation in maximum gauge	Final draft TSI CR Inf.

Type of measure	P#	Measures and motivation:	Where applied:	Source for Information:
		Present limits varies among infrastructure managers and the intervention limit specified in the final draft TSI for CR Infrastructure is less stringent than what is presently applied in many countries. For further info see 4.3.4.6.	width between countries and towards TSI CR INF.	Ref. [10] & RGS GC/RT5021 [11]
Infrastructure Operational/ organisational	P-24	Establish EU-wide intervention and/or immediate action limit for cant variations. In addition it should be considered to introduce a limit for excessive cant in track positions where trains are likely to stop or operate at low speed. Many derailments occur in track sections with narrow curves and high cant at low speed. For further info see 4.3.4.7.	Swiss & Norwegian track regulations	Swiss & Norwegian track regulation, [12, 13, 14]
	P-25	Establish EU-wide intervention and/or immediate action limit for height variations and cyclic tops which does not exist in Final draft TSI for Conventional rail infrastructure. For further info see 4.3.4.8.	GB and Norway at least.	RGS GC/RT5021 [11] and Norwegian track regulation [15]

Table 7: Rolling Stock Preventive Measures

Type of measure	P#	Measures and motivation:	Where applied:	Source for information:
Rolling stock technical or structural	P-26	Flange lubrication of locomotives. Requirement for installation of onboard lubrication of locomotive flanges to be able to provide necessary track/flange contact lubrication. The measure must be seen in relation to the application of trackside installed lubrication in curves. Reduces friction available for wheel flange climbing. For further info see 4.3.5.1.	US, Austria, Switzerland, Norway and others	Requirement specified in Network Statement of SBB [16] & BLS [17]
	P-27	Replace composite wheels with monoblock wheels. Composite wheels have a more complex inspection and maintenance requirements and seems to have a higher failure rate causing derailments. For further info see 4.3.5.2.	Several countries or companies are prohibiting use of composite wheels for new and existing rolling stock.	General knowledge
	P-28	Replace metal roller cages in axle bearings by polyamide roller cages. For further info see 4.3.5.4.	CargoNet & DB Schenker freight wagons.	SHT Investigation report [18]. EUB Jahresbericht 2009 [19].
	P-29	Replace existing axles for stronger axles or axles with improved material properties with regard to crack initiation and crack propagation. For further info see 4.3.5.3.	VTG exchanges axles for tank wagons	Railway Gazette International [20].
	P-30	Increase the use of central coupler between wagons in fixed whole train operation. With an integrated draw gear and buffer function in a central coupling the rolling stock side buffers becomes superfluous. This will reduce side buffer loads and reduce risk of derailment due to buffer locking and couples that are too loose or too tight between wagons. For further info see 4.3.5.5.	Australia, US, former USSR including Baltic states in EU. 1520/24 mm gauge lines in Eastern Europe. Train for iron ore transport from Kiruna	General railway knowledge

Type of measure	P#	Measures and motivation:	Where applied:	Source for information:
			towards Narvik and Luleå	
	P-31	Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis. For further info see 4.3.5.6.	US & Europe	General railway knowledge
	P-32	For new rolling stock install disc brakes instead of wheel tread brakes. Major motivation may be less noise in relation to Noise TSI, but also less heat activation of wheels, which may reduce derailment risk. For existing rolling stock, exchange wheel tread brakes with disc brakes for existing rolling stock. For further info see 4.3.5.7.	Employed for many new wagons and is the dominating brake type for new passenger rolling stock	General railway knowledge
	P-33	Rolling stock should be designed to operate safely over a track twist of up to 17 per mille over a 2.7 m base, and up to 4 per mille over an 11.2 m base. This will reduce derailment frequency due to track twist. Further info in 4.3.5.8.	Republic of Ireland and Northern Ireland	TSI for freight wagons Specific case item 7.2.2.4.5. Ref. [21]
	P-34	Secure brake gear located in the underframe of the wagon to ensure that braking components that become loose does not fall to the ground and cannot provoke a derailment. For further info see 4.3.5.9.	Sweden, Norway and Germany and possibly other countries	Questionnaire response
	P-35	Regular greasing and check of fastening of rolling stock buffers to reduce risk of a buffer falling off and causing derailment. Alternatively, strengthen fastening elements. For further info see 4.3.5.10	Routinely greased and inspected in most countries	A1 final draft report reviewer
Rolling stock Operational / organisational	P-36	Wheel set integrity inspection (ultrasonic) programs. For further info see 4.3.6.4.	Most wagon owner and train operating companies.	Company inspection and maintenance standards.
	P-37	Derating of allowable axle loads for type A-I and A-II axle designs. For further info see 4.3.6.3.	Applicable countries, ref recommendation from ERA JSSG.	Ref [22]
	P-38	Inspect axles of freight train rolling stock according to EVIC (European Visual Inspection Catalogue). For further info see 4.3.6.2.	Most European countries Program implemented by ERA JSSG	Ref [23]
	P-39	Requirement for double check and signing of safety-classified (S.-marked) maintenance operations. For further info see 4.3.6.5.	Norway	Questionnaire response

Table 8: Preventive Measures applied to Train Loading and Operation

Type of measure	P#	Measures and motivation:	Where applied:	Source for information:
Train loading / human	P-40	Qualified and registered person responsible for loading. The person must show sufficient competence and be registered by the train operator. For further info see 4.3.7.1	Spain & Bulgaria	Questionnaire response
Pre-departure inspection and brake settings/ human	P-41	Locomotive and first wagons of long freight train in brake position G (Lange locomotive). For further info see 4.3.7.2 Various countries have operational requirements that the locomotive and the first wagons of a train shall be put in brake position G to limit the compression forces of the train when braking with the pneumatic activated train brakes.	Germany, Austria and Switzerland, as well as Norway and Sweden to a lesser degree.	DB Netz AG; Richtlinie Züge fahren und Rangieren [24] Accident reports
Train operations/ human:	P-42	Limitations on use of brake action in difficult track geometry, particularly at low speed, to avoid high compression forces of train that could cause buffer locking and derailment (includes re-generative braking). For further info see 4.3.7.4.	Switzerland, Austria & possibly other countries	Austrian Accident report into derailment at 8th of April 2009 [25]. Swiss FDV [26].
	P-43	The ATP-system of some countries including Norway, Sweden and Finland, called ATC, has a function to perform a dynamic brake test on the route to get actual test information with regard to the train braking performance. For further info see 4.3.7.3.	Sweden	Trafikstyrelsen JvSFS 2008:7 bilaga 11 [27].
	P-44	Saw tooth braking should be applied when using pneumatic brakes to limit speed in long and steep descents in order to limit heat exposure to wheels. For further info see 4.3.7.5	Switzerland	Schweizerische Fahrdienstvorschriften [28]
	P-45	When passing a signal showing a reduced speed, the driver should initiate the braking or speed reduction action prior to passing the signal. This could reduce the risk of over-speeding in track deviations. For further info see 4.3.7.6	Switzerland	SBB Regulation; Infrastruktur R 301.11 Bremsen 300.14 - Punkt 14.2.
	P-46	Trafikverket in Sweden (former Banverket) has recently issued a new regulation for how various alarms should be handled. Traffic controllers and drivers should not be allowed to override detector alarms. For further info see 4.3.7.7.	Sweden	BV regulation BVF 592.11 [29].
	P-47	Wagons equipped with a balance to detect overload in visual inspection.	Switzerland	Questionnaire response

4.3.2 Infrastructure Installed Technical Measures to Limit Derailment Risk

4.3.2.1 Application of Check Rails in Narrow Curves

Check rails are installed to guide the wheels in rigid crossings and point crossings. Check rails may also be installed in sharp curves to prevent derailments as it will hinder flange climbing on the outer rail in sharp curves, In some countries (e.g. Germany) check rails may also be used to give an additional safety against derailment when the track is passing safety critical installations such as supports of overhead bridges.

A picture from the Republic of South Africa taken from Voest Alpine web page shows how check rails can be applied in curved line sections [30].

Figure 7: Example from RSA showing Check Rail installation in Curved Track

RSSB's Railway Group Standard GC/RT5021 [11] Track system Requirements specifies that track in passenger lines with a radius of 200 metres or less should be fitted with a check rail to reduce the risk of derailment.

Other infrastructure managers also install check rails in difficult track geometries, but the degree of application varies. Check rails can also be a cause of derailment in some circumstances, in particular with an excessive track width, so check rails require tight control of the track width.

Check rails should not be confused with guard rails (M-5) that are installed to limit the consequences of a derailment, see Section 4.4.1.

4.3.2.2 Application of Track or Flange Lubrication at Selected Track Positions

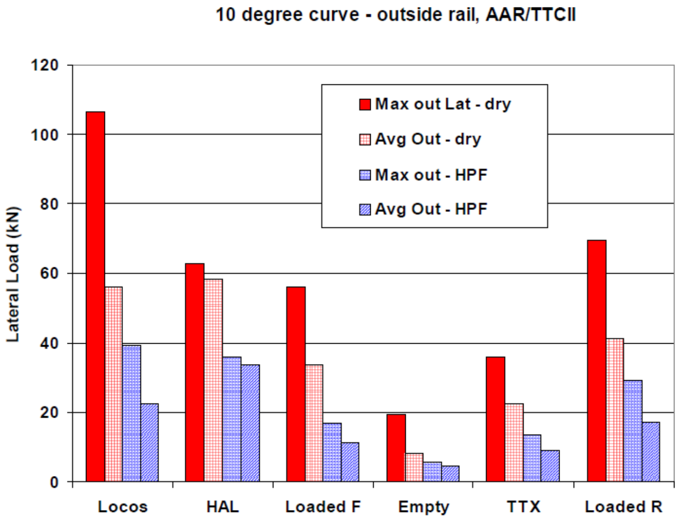
Lubrication of the flange and track contact point is an important measure to reduce the friction between rail and wheel flange and hence reduce the risk of derailment in difficult track geometries, i.e. in narrow curves or track sections with high cant and/or high twist. Normally the lubrication is obtained by lubrication of the wheel flange of traction units.

For track sections where this is not deemed sufficient, for instance in deviated routes at turnouts, trackside flange or track lubrication points can be installed to provide the necessary lubrication. Lubrication can also be provided by special track lubrication train runs at regular intervals or under dry weather or hot temperature conditions.

Below is a picture of a track installed lubrication installation [31], and test results [32] showing the effect of lubrication of the track flange contact point.

The reduced lateral track force in narrow curves should cause less wear, less noise and less risk of derailment.

Figure 8: Track mounted lubrication installation and test results from narrow curve



4.3.2.3 Subsidence and Ground Instability Detection

Ground penetration radars are used to survey conditions of trackbed superstructure with regard to quality and water content [7] and [33] This is mainly used through ad hoc baseline runs to provide information for planning of maintenance and renewal, but permanent installations can also be considered in places where the railway is located on unstable ground that is considered exposed to high water level in substructure, subsidence or landslides. Certain types of ground instability detectors can be installed which will detect high water levels subsidence and landslides outside of acceptable limits.

4.3.2.4 Track Circuits to Detect Rail Ruptures

Track circuits are applied in the signalling system of most IMs. Track circuits will detect some type of rail ruptures and prevent signals from being set for a track section with a ruptured rail, hence preventing derailments. However, supervision for rail ruptures is not the main purpose of the track circuit and there are several types of rail ruptures the track circuits cannot detect. Track circuit systems for detection of track occupation are to an increasing degree being replaced by axle counters of many IMs. Axle counters are not able to detect track ruptures.

4.3.2.5 Interlocking of Points Operation while Track Occupied

Points at main lines and at main tracks at stations are normally interlocked to prevent operation of the point while the point section of track is occupied by rolling stock. This is not fully implemented at shunting yards even at tracks being used for train movements. Hence a number of derailments occur due to points being operated while occupied by a train. This action very often causes derailment. An existing measure is interlocking of remote controlled points to include track at shunting yards used for train movements in such a way that the switch can not be moved while the switch is occupied by rolling stock.

4.3.2.6 Rolling Stock Mounted Equipment for Rail Profile Measurement

Suppliers are marketing rail profile measurement systems that can be mounted on commercial rolling stock and used for continuous supervision of track geometry and measurement of rail wear. According to the supplier the monitoring results are equally good as those that can be obtained by special measurement cars and trains with the advantage of more frequent measurements.

This technology incorporates the latest laser and video camera technology to provide accurate and immediate report on the profile and wear condition of the rail whilst travelling at track speeds. The video cameras capture full cross-sectional rail profiles from the base/web fillet area up to the top-of-rail surface to allow comprehensive and accurate rail measurements [8].

The equipment installed on commercial rolling stock is an alternative to separate measurement runs by inspection wagons.

4.3.3 Trackside Installations to Supervise Rolling Stock

4.3.3.1 Hot Axle Box/Bearing Detector (HABD)

High temperature in the axle box or the bearing of an axle may be a sign of a mechanical structural defect under development. This can be in the form of high friction in the bearing or a developing rupture in the axle journal. By monitoring the temperature of axle boxes, a failure state of the bearing may be detected and an alarm raised either to the train driver or to the train control centre. Hot axle box detectors for freight trains are normally located along the track monitoring the temperature of axle box of all passing trains. Axle box monitoring devices can also be located on the vehicle, continuously monitoring the temperature of the axle boxes, but this is normally not applied on freight trains as the individual freight wagon does not have any electricity to power such monitoring equipment. Wayside detectors usually consist of one or more thermal sensors continuously measuring infrared radiation, and should be capable of detecting both normal temperature and high temperature axle boxes.

Combined with an axle counting feature it can identify which train axle has an excessive temperature and once the train has passed the detector it transmits this information to the train control centre or the train driver directly. If the hot axle box detector is combined with a vehicle identification system the information about axle temperature can also be transmitted to the RU or owner. This is mainly useful if the detectors are networked and a temperature trend can be identified. Some systems will calibrate measurements with the ambient temperature.

Normal requirements to the site localisation for a hot axle box detection installation are:

- Track to be level, avoiding inclines.
- Track to be straight, avoiding curved area.
- Away from tunnel and cuttings.
- Ease of access for construction and maintenance.

- Suitably located to permit train regulation on alarm activation, i.e. to allow trains to be stopped at a siding were possible so it does not affect mainline traffic.

Hot axle box detectors are commonly used in the European railways. The number of axle box detectors installed can be quite high. Here are some approximate figures taken from questionnaire responses, network statements and other sources:

- US: around 6000 detectors.
- Germany: around 460 detectors.
- GB: around 200 detectors.
- Switzerland: around 80 detectors.

Hot axle box detectors are also frequently installed in Austria, Sweden and Finland.

Not all countries use them with similar frequency. They are not installed in Slovakia nor are they particularly frequently installed in the Netherlands or Denmark. In Denmark they are only installed in front of the Great Belt tunnel and in the Netherlands they are installed on the new high speed line from Amsterdam towards Antwerpen and in the new Betuwe freight route from Rotterdam to the German border.

In the TSIs developed for harmonisation of the European railways it is only the TSI for Safety in Railway Tunnels that makes hot axle box detectors mandatory. They require that "line-side hot axle box detection or predictive equipment shall be installed at strategic positions on networks with tunnels so that there is a high probability of detecting a hot axle box before the train enters a tunnel and that a defective train can be stopped ahead of the tunnel(s)". Other TSIs specifies the geometrical features of a hot axle box detector, i.e. where the detectors should look for increased temperature.

Hot axle box detectors are not a foolproof measure. Firstly, the damage and the associated temperature development can be so fast that a derailment occurs prior to the development being detected by a hot axle box detector. Secondly, when an alarm is raised, the train has to slow down and stop at a convenient location to let the driver inspect the situation and a derailment may occur before the train has stopped. Thirdly, when the train is stopped it may take some time until the driver is able to move to inspect the axle box in question and the temperature might have dropped in the meantime and nothing is detected and the journey is continued. Once the train is moving again the situation reappears and a derailment occurs.

4.3.3.2 Acoustic Bearing Detectors

Acoustic bearing detectors are, like hot axle box/bearing detectors, used to detect developing mechanical structural defects associated with wheel bearings. They are however not based on temperature measurement, but on the analysis of the sound as wheel sets pass by. The major advantage over hot axle box detectors is that acoustic bearing detectors are able to detect developing defects much earlier as such defects will result in increased noise. Acoustic bearing detectors are placed wayside and consists of a microphone array and a system unit which analyses the sound and raises an alarm if dangerous defects are detected. Used in combination with vehicle identification systems, the system may also be used to store information on individual vehicles and wheel sets in a central database, allowing for trend analysis and preventive maintenance.

The amount of noise produced by the bearing during deterioration may depend on the design of the bearing and acoustic bearing detectors may not work equally well for all types of bearings.

Such systems are used widely on heavy haul railways in China and USA, where such devices have been a standards requirement for many years.

4.3.3.3 Hot Wheel and Hot Brake Detectors

Braking can increase the temperature of the wheels and brake pads. In particular this can be a problem with brakes that have not released and continuously apply braking action. The rise of temperature may itself be a problem if it leads to structural changes in the wheel material. If the wheel becomes completely stuck it may skid along the rail resulting in wheel flats etc. Hot wheel detectors are positioned wayside and use the same technology as hot axle box/bearing detectors, i.e. thermal sensors measuring the temperature of passing wheels. Used in combination with axle counting devices or vehicle identification systems, the system is able to identify the vehicle and wheel of any higher than normal temperatures and raise an alarm.

Cold wheel detectors may in some situations (e.g. if positioned at the bottom of a downward slope) indicate that brakes have not been applied where they should have been, i.e. that brakes are defective or working poorly. However, non-operating brakes on a single wagon are normally not a problem and often wagons may have the brakes locked out if a fault with the brakes of the wagon has been detected in the train brake test.

Railways that have installed hot axle box detectors often combine them with hot wheel and hot brake detectors. They are not mandatory by any TSI.

4.3.3.4 Wheel Load Detectors & Wheel Impact Load Detectors

Several different types of wheel load detectors exist. They are installed at various locations in many countries. In The Netherlands they are used as input for calculation of load dependent track access charges for rail operators in their “quo Vadis system”.

Wheel load and wheel impact load detectors can be used to detect a range of different faults with a wagon or its loading:

- By measuring the wheel loads of an axle it can detect overloading of the wheels and axles or skew loading of the wagon either due to a wrongly applied load in the longitudinal or transversal direction, a shifted load or due to a wagon or bogie frame twist, suspension or spring failure.
- Wheel load detectors can also detect wheel failures in terms of general out of roundness or more specifically wheel flats and wheel tread damages due to shelling and spalling. As the wheel moves around this causes wheel impact load on the rail, which again cause damage to rails (including rail breaks) or increase the temperature of bearings and lead to a hot axle box.

Wheel load detectors are wayside detectors measuring the size and variations of the load of wheels as they pass by. Several different technologies are employed depending on the various faults to be detected. Some use strain gauges, others analyse sound or measure the deflection of rails between sleepers as trains pass using optical sensors. Accelerometers can also be used.

If the situation is severe an alarm is raised and the train has to be stopped to check the wagon(s) that have triggered the wheel load detector alarm, or the train speed may be adjusted. Used in combination with vehicle identification systems, the RU and/or wagon owner may receive a message about the out-of-limit characteristics in order for rectifying actions to be implemented prior to further operation of the wagon.

Wheel load detectors can be combined with hot axle box detectors, but are often installed in departure tracks from train formation yards. Alternatively, they are installed in main tracks immediately after train formation yards in order to detect the situation as soon as possible. Faults can also occur along the route. In general there are fewer trackside wheel load detectors than hot axle box detectors.

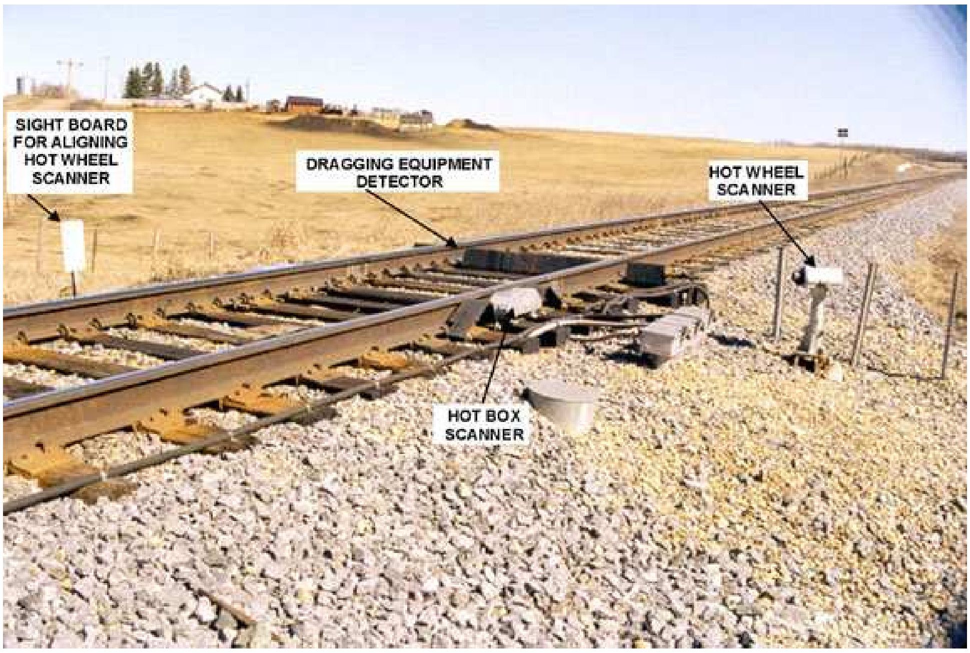
4.3.3.5 Derailment and Dragging Object Detectors

Derailment and dragging object detectors can be installed to identify if a train has a derailed axle, or equipment that has come loose from a wagon and is being dragged along the track between the rails. Such detectors may be installed in front of large stations or structures where the situation may cause major damage. They are extensively used in the US.

Early dragging equipment detectors were of the "brittle bar" type. Fixed elements between and beside the rails would break when struck by foreign objects. Their breakage would interrupt an electric circuit that formed part of the reporting system, and the train would be stopped and inspected. The introduction of "self-restoring" dragging equipment detectors, which are hinged and sprung so they return to position after impact, have reduced maintenance requirements for such installations. Figure 9 shows a typical derailment and dragging object used in the US. If employed in Europe one has to modify the design to avoid being hit by hanging screw couplers.

The derailment and dragging object detectors will also detect derailments and are also included as a mitigating measure.

Figure 9: Typical US derailment and dragging object (and other) detectors[10]



4.3.3.6 Bogie Steering Performance Detectors/Lateral Instability Detection (bogie hunting)

This wayside defect detection system is capable of detecting and identifying train bogies that exhibit poor performance. This system monitors safety performance in several dimensions such as: potential of flange climb derailment, gauge spreading, and rail over. This state-of the-art system has the capability to benchmark bogie performance on a fleet-wide basis. They are used in the US and at least in Turkey.

[10] Picture from Transportation Safety Board of Canada Report Number R99T0031, http://www.tsb.gc.ca/eng/rapports-reports/rail/1999/r99t0031/r99t0031.asp

4.3.3.7 Wheel Profile Measurement System / Wheel Profile Monitoring unit

Damage to the wheel profile may be a contributing cause to derailments. Whereas wheel impact load detectors can detect some wheel profile problems, wheel profile measurement systems provide a more complete picture. They are also based on other technology: analysis of wayside digital camera images highlighting the profile using lasers or strobe light. A number of wheel profile parameters are captured, e.g. flange height, flange width, flange slope, tread hollow and rim thickness. Some measurement systems can operate with trains passing at high speeds (e.g. up to 140 km/h).

4.3.4 Infrastructure Applied Operational and Organisational Measures

4.3.4.1 Closure of Lines and Tracks

If the available resources are not sufficient to maintain lines and tracks at stations to minimum safety requirements it is from a derailment and safety viewpoint better to close the lines or tracks rather than trying to keep lines operational in a state where all safety margins are removed.

Accident investigation reports from various countries have shown that many accidents occur due to known infrastructure failures, where there are insufficient resources to make the required repair, or alternatively that the repair has not been prioritised within available resources. Such conditions increase the risk of freight derailment and if hazardous materials are transported on such lines it might be a public risk.

4.3.4.2 Inspection and Maintenance to Ensure Free Clearance Gauge

The clearance gauge should be kept free of obstructions when trains are due to arrive. This is a general inspection and maintenance task carried out by all IMs. Special focus should be given to the flange groove at level crossings. If the flange groove is obstructed by hard solid objects it can cause derailments. Level crossings with rubber elements (Strail) can reduce the risk.

In countries with severe winters snow or ice can pack in the flange groove and around the rail during periods of frost during night and thaw during daytime. In particular this can be a risk if free water seeps over the track, for instance in level crossings. The risk is most severe for passenger trains.

4.3.4.3 Ultrasonic Rail Inspection Wagon

IMs provide for ultrasonic inspection through the use of various forms of inspection wagons in order to detect cracks and fractures that can cause rail ruptures. Either the IM owns the inspection equipment or the inspection is done by contractors. The ultrasound inspection provides the IM with information with regard to the quality of the rails and the need for rail replacements.

The frequency of ultrasonic rail inspections is determined by the IM based on the rail age and traffic loads on the actual line accounting for available resources and equipment performance.

4.3.4.4 Track Geometry Measurements

Regular track geometry measurements are carried out by most IMs. In order to be reliable they should be carried out under dynamic load conditions. The track geometry of railway lines is regularly measured by track inspection wagons or trains which provide dynamic loading to the track while doing the measurement. Among the geometric parameters measured are:

- Track gauge variations.
- Track cant.
- Track twist.

- Track height variations.
- Track lateral position faults.

In addition modern measurement wagons can inspect rail surface conditions in terms of rail wear and various rail surface defects. The completeness of the measurements with respect to track coverage at stations as well as intervals may vary. Frequency is normally dependent upon traffic load and allowable speed limit of track.

The frequency of inspection is based on local conditions and environmental factors, ground stability, line speed and traffic loads accounting for available resources and equipment performance. Normal frequencies can be 2 to 6 times a year with increased frequency for lines with more traffic and higher allowable speed.

4.3.4.5 Track Twist Intervention Limits

Excessive track twist is among the most frequent derailment causes often in combination with other causes such as skew loading, wagon frame twist and low speed in narrow curve with high cant etc. In many cases where track twist is a major factor leading to derailment the actual track twist exceeds allowable twist limits, and in some cases the situation has also been known to those responsible for track maintenance.

Track twist requirements must be looked at in combination with requirements and limitations for rolling stock flexural stiffness. The ORE B55 RP8 document has analysed the conditions for derailment, Ref [34].

The final draft TSI for Conventional Rail Infrastructure specifies safety limits (or immediate action limits) for track twist as follows:

> "All TSI Categories of Line
>
> (1) The immediate action limit for track twist as an isolated defect is given as a zero to peak value. Track twist is defined as the algebraic difference between two cross levels taken at a defined distance apart, usually expressed as a gradient between the two points at which the cross level is measured. The cross level is measured at the nominal centres of the rail heads.
>
> (2) The track twist limit is a function of the measurement base applied (l) according to the formula:
>
> Limit twist = (20/l + 3)
>
> (a) where l is the measurement base (in m), with 1.3 m l 20 m,
>
> (b) with a maximum value of 7 mm/m.

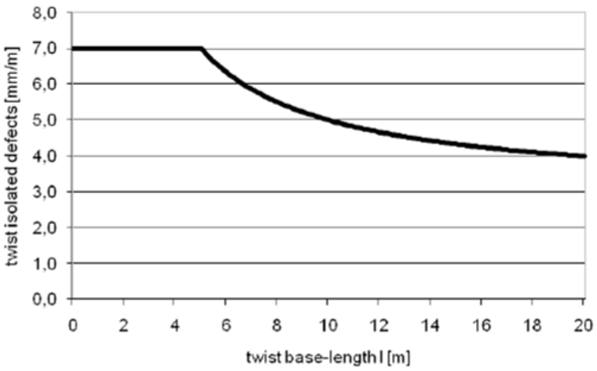


Figure 3: Limit for track twist for all TSI Categories of Line

(3) The Infrastructure Manager shall set out in the maintenance plan the basis on which it will measure the track in order to check compliance with this requirement. The basis of measurement shall include at least one measurement base between 2 and 5 m.

TSI Categories of Line IV-F, IV-M, V-F, V-M, VI-F, VI-M, VII-F and VII-M

(4) If the radius of horizontal curve is less than 420 m and cant D > (R – 100)/2, track twist shall be limited according to the formula: Limit twist = (20/l + 1.5), with a maximum value between 6 mm/m and 3 mm/m depending on the twist base length as shown in Figure 4.

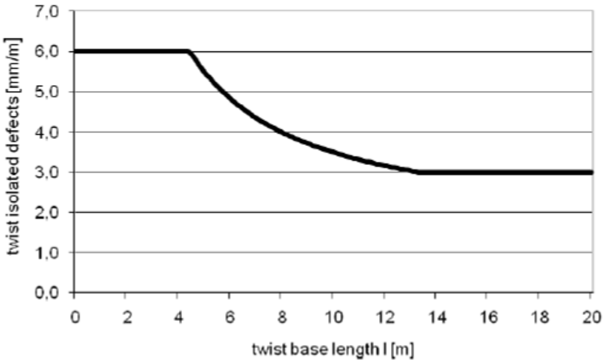


Figure 4: Limit for track twist for freight and mixed lines on small curves

”

The above limits specified in the TSI are safety limits that require immediate traffic shut down. According to recent accident investigation reports several derailments have occurred due to track twist in tracks within the safety limits specified above.

The TSI specifies that intervention limits shall be developed by IMs or NSAs. Today’s intervention and safety limits for track twist varies somewhat between different countries within EU.

An existing measure adopted by some IMs has been to impose more stringent limits for these parameters which suggest a more widespread adoption of harmonised limits may be beneficial. The reason for this is that rolling stock meeting the TSI for freight wagons is interoperable through the European Union and hence criteria for track maintenance activities should be harmonised in order to be able to maintain a high level of safety against derailment due to track twist. The intervention and safety limits should be viewed in relation to the lubrication status of the track.

Further, one should make sure that the developed criteria can handle allowable skew loading conditions of wagons with a certain margin.

4.3.4.6 Immediate Action Limit for Variation of Track Gauge

The immediate action limits for variation of track gauge are set out in the final draft TSI for Conventional rail are as follows:

Speed [km/h]	Dimensions [mm] - Nominal track gauge to peak value	
	Minimum track gauge	Maximum track gauge
V 80	-9	+35
80 < V 120	-9	+35
120 < V 160	-8	+35
160 < V 200	-7	+28

The above immediate action limit is significantly less rigorous than today's action limit for many countries as for instance GB [11] and Norway [15]. A review of the limits may be warranted if there is a strategy to reduce derailment frequencies. The argument for harmonised limits is as for 4.3.4.5.

4.3.4.7 Immediate Action Limit for Variation in Cant and Excessive Cant

Action limits for variation in cant relative to design cant is specified in the final draft TSI for Conventional Rail Infrastructure.

> TSI Categories of Line IV-F, IV-M, V-F, V-M, VI-F, VI-M, VII-F and VII-M (Requirements for passenger lines (P-lines) are excluded as they are not open for freight traffic.)
>
> (1) The in service cant shall be maintained within +/- 20 mm of the design cant, but the maximum cant permitted in service is 170 mm.

Additional to the above some countries, such as Norway and Switzerland, have general limitations of allowable excessive cant, specifically at locations where trains are expected to stop at a signal or drive slowly [13] and [14]. This requirement is of special importance at locations with narrow curves where trains may have to stop in front of signals and where there also is high track twist when leaving from transition curves.

4.3.4.8 Immediate Action Limitation for Track Height Variation

Among others, the railways of Norway and Great Britain have intervention limits for variation in track height. The intervention limits specified in Britain and Norway are relatively consistent, but with some minor variations. Variations in track height and cyclic tops may cause derailment, in particular if there are cyclic variations. A report issued in January 2006 as a result of a research work financed by Rail Safety & Standards Boards identified height variations and cyclic tops to be one of the most frequent high speed derailment causes [6].

A measure could be that the Final draft TSI for Conventional Rail infrastructure is modified to include quantitative limitations on height faults. An interoperable rolling stock fleet will benefit from harmonised track intervention and safety limits.

4.3.5 Rolling Stock Applied Technical Measures

4.3.5.1 Flange Lubrication at Locomotives

In some countries, in particular countries with a high proportion of curved tracks, there is a requirement to fit main traction units with flange lubrication to reduce the friction of the contact between wheel flange and rail. Specification for flange lubrication requirement for traction units and type of lubrication is found in the Network statements of SBB [16] and BLS [17].

Reduced friction between wheel flange and track also reduces the necessary traction force and energy use on curvy track sections [32]. Other countries with less narrow curves and a more level network do not apply flange lubrication to the same degree.

The Austrian railways ÖBB has the following specification for flange and track lubrication as introduced in the software of locomotive type “Taurus” [35]:

- “< 20 km/h: no flange lubrication.
- v > 20 km/h normal flange lubrication.
- v in range 73 – 90 km/h for more than 2 minutes: increased flange lubrication (Mode Berg 2).
- v in range 30 – 72 km/h for more than 3 minutes: strongly increased flange lubrication (Mode Berg 1)”.

Recent accident investigations in Austria [35] have found that the above lubrication programme may not give sufficient lubrication at localised difficult track geometries at low speed e.g. at track with reduced speed or in sparsely used tracks at stations. Added lubrication might therefore be required at curvy track in the above mentioned speed classes.

According to the TSI for locomotives and traction units there are no requirements for flange lubrication.

In order for track lubrication to be effective across Europe it should be considered whether it should be required that freight train traction units employed in international traffic should be equipped with flange lubrication.

4.3.5.2 Replace Composite Wheels of Freight Wagons with Monoblock Wheels

A composite wheel consists of a wheel rim with an outer shrink fitted ring comprising the wheel tread and the flange. A tyre retaining ring helps to keep the assembly in place. Composite wheels have the advantage that the ring can be replaced once it is worn down. A disadvantage with composite wheels is that the wheel ring can come loose and be displaced, in particular due to heating in prolonged braking actions. A wheel with a displaced or lost wheel ring is likely to derail.

Monoblock wheels are forged or rolled from one block and have fewer failure modes, however, also for these wheels prolonged and excessive heating due to braking can cause material failure and wheel rupture with consequential derailment. Some RUs, in particular those with very mountainous lines, favour monoblock wheels and have completely exchanged all their composite wheels with monoblock wheels.

An existing measure with extended application is therefore to replace composite wheels with monoblock wheels.

4.3.5.3 Replace Existing Axles with Higher Strength Axles

The private wagon owner VTG with a large fleet of tank wagons recently made a decision to replace axles in most of their rolling stock to axles with higher strength according to a notice in Railway Gazette International of December 2009 [10]. According to the notice all their rolling stock axles are to be replaced by 2015.

The allowable axle load of the rolling stock is not expected to be increased and the main reason for the replacement is an increased safety against axle ruptures and derailments.

4.3.5.4 Replace Metal Roller Cages in Axle Bearings by Polyamide Roller Cages

The Norwegian rail freight operator CargoNet decided approximately 10 years ago to exchange their axle bearings from using brass roller cages to polyamide roller cages [36]. The implementation of the decision has been by replacement when the wagon and axle boxes are in for overhaul. The rationale for the replacement was a number of derailments due to hot axle boxes and shearing of axle journals prior to the decision being made. The cause of many of the failures was wheel damage. The polyamide cages were considered less prone to failures due to vibration impact.

The same measure has recently been recommended by the German National investigation body, Eisenbahn-Unfallsuntersuchungsstelle des Bundes (EUB) towards Eisenbahnbundesamt (EBA), the German NSA and the relevant railway undertaking, and has been accepted [19].

Figure 10: Fractured Outboard Roller[11]

4.3.5.5 Increase Use of Central Couplers for Wagons in Block Trains

Central couplers are commonly used across the world in North America including USA and Canada, Australia as well as the Commonwealth of Independent States (former Soviet republics) including the Baltic Countries. Central couplers are also commonly used in Finland as Russian rolling stock is often used. In the rest of Europe central couplers are mainly used for fixed train units for passenger transport, or for freight transport in heavy haul operations, e.g. the iron ore transport from the Swedish iron ore mines to the ports of Narvik and Luleå. In rail freight transport operations by fixed block trains with bogie wagons with uniform loading, central couplers will reduce curve forces and ensure that compression forces occur centrally in the train. This will reduce the derailment risk.

An existing measure that could be given wider usage is therefore the introduction of central couplers of 4 axle rolling stock with bogies in block train operation.

4.3.5.6 Increase Use of Bogie Wagons instead of Single Axle Wagons

The rolling stock of the European railways consist of a mixture of single or coupled 2 axle units with single axles or bogie wagons with 2 or 3 2-axle bogies. Normally, bogie wagons have better riding quality and a lower derailment rate.

[11] Picture from report into the derailment of a Tara Mines freight train at Skerries on the 10th of January 2008

An exchange of single axle wagons for bogie wagons could therefore be a measure to reduce the number of derailments. This is already applied for most heavy bulk transport applications. For the transport of light weight goods and lightly loaded containers and swap bodies this is not the case. For such transport operations, wagons based on single axle wheel allows for a long loading basis to be obtained with a minimum of weight and cost; whilst this is advantageous commercially it is not beneficial with respect to minimising derailment risk.

A review of accident reports indicates that these types of cars have an increased derailment frequency, often in combination with high track twist.

4.3.5.7 Exchange Wheel Tread Brakes with Disc Brakes

Existing fleets of freight wagons are to a large degree equipped with wheel tread brakes utilising cast iron brake blocks (shoes). Some modern wagons are equipped with composite brake blocks or disc brakes, mainly due to new noise criteria.

To move the brake action away from the wheel tread, as is the case with disc brakes, also has a safety advantage as the wheel tread material is less heat affected and increased braking force can be applied without the risk of overheating the wheels. This may reduce the failure rate for both composite and monoblock wheels. Application of disc brakes will increase the torsion loads on axles and the strength of existing axles must be checked before implementing it on existing wagons.

Disc brakes also have some disadvantages as they does not clean the wheel tread for rub that may form in the wheel-rail contact if the wheel is locked for a short period.

The measure is applied for some new freight wagons, mainly to limit noise from train braking.

4.3.5.8 Increase Requirement to Twist Flexibility of Rolling Stock

The WAG TSI (TSI for rolling stock freight wagons) as a specific case for the Irish railways (Republic of Ireland and Northern Ireland) in § 7.7.2.2.4.5 allows a stricter requirement to twist flexibility for freight rolling stock on that network than for the rest of Europe. The relevant paragraph reads:

> “Rolling stock should be designed to operate safely over a track twist of up to 17 per mille over a 2.7 m base, and up to 4 per mille over an 11.2 m base”.

This will make the rolling stock much less likely to derail due to track twist and should be considered also for the rest of Europe. However, it is unlikely that all existing RIV marked freight wagons will satisfy such a requirement.

4.3.5.9 Apply Safety Slings of Steel Wire on Underframe brake gear

In order to prevent brakes falling from a wagon and possibly causing a derailment, parts of the brake rigging that could come loose should be secured by safety springs of steel wire. This is a requirement in some countries or done by some RU.

4.3.5.10 Regular Check and Greasing of Buffer Fastening

Rolling stock buffers can be lost and be a cause for train derailment. Various preventive measures are normally in place to control this possible derailment cause such as: inspection of buffer fastenings and regular greasing of buffer plates as well as buffer cylinder contact parts. If considered necessary fastening elements should be strengthened.

4.3.6 Rolling Stock Applied Operational and Organisational Measures

4.3.6.1 Task Force (TF) made up of Experts in the field of Freight Wagon Maintenance and Railway Axles

A task force under administration by the Agency has been set up, following the Viareggio accident, to investigate what action can be taken to reduce the risk of such accidents.

The objective of the first phase of the work was to address and develop urgent measures as a follow-up to information on problems with broken axles (cases in AT, DE, IT). For this purpose the sector set up a Joint Sector Support Group (JSSG) and focused on the following tasks:

- Investigate further and with urgency the width and character of the problem with broken axles, based on information from NSAs and RUs and study the need to reduce the maximum permitted axle load for wagons with certain types of axles that may have been overloaded without adequate maintenance supervision.
- Review the relevant actions in the sector action plan and develop the necessary accompanying measures (European Visual Inspection Catalogue – EVIC, etc.).
- Review ongoing standardization activities and identify further areas for standardization and/or the need for review of standards.

4.3.6.2 Implementing the European Visual Inspection Catalogue for Axle Inspections

Since 01.04.2010 a European-wide voluntary program of wagon owners for visual examination of axles and wheels has started. The purpose of the inspection is partly to identify surface marks and scratches in wheels and axles that can act as crack initiators.

The EVIC can be considered as a reference manual for RUs and keepers providing the criteria to freight wagon maintenance staff to visually identify, during light maintenance in workshops (i.e. without disassembling from the wheel-sets), axles with a potentially increased risk for safe operation. A wheel-set/axle which doesn’t meet the EVIC-criteria will be discarded from service and undergo non-destructive tests (NDTs). Additionally, a sample of axles fulfilling the EVIC-criteria will also be subject to NDT.

This program runs over the next 4 years for rail tank cars and 6 years for other railway wagons. The examination according to the EVIC-catalogue will be done from April 2010 on each wagon, which enters a workshop for repair (operational maintenance) outside from revision. The inserted wheel-sets are examined and the workshop will inform the wagon owner about the result. Results with regard to inspection progress are to be reported to the Agency.

A catalogue document describing the defects to be looked for has been developed.

4.3.6.3 Derating of Allowable Axle Load for Certain Axles

Investigations by the Agency JSSG indicates that an increase of the axle load of types A-I and A-II axles has been allowed nationally for some countries even though this exceeds the intended design load. The JSSG has recommended that maximum operational axle load limitations for A-I and A-II axles are limited to 20 tonnes. A-III axles are allowed a continued operation with 22.5 tonnes axle load provided strengthened inspection and maintenance routines are introduced [22].

Type A axles comprises more than 75 % of existing wheel axles in European rolling stock.

4.3.6.4 Wheel Integrity Inspection (Ultrasonic)

Wheel ruptures and damage to the wheel profile may be a contributing cause to derailments. Whereas wheel impact load detectors can detect some wheel profile problems, wheel profile measurement systems and wheel ultrasonic integrity inspection with respect to cracks can provide a more complete picture. They are also based on other technology: analysis of lasers and digital camera images highlighting the profile using lasers or strobe light. In addition wheels have to be inspected for material cracks that can cause ruptures.

Various NDT methods can be used for crack detection including ultrasonics. Technology exists for supervision stations in depots that can do the necessary inspections while the train passes the supervision station at low speed. Measurements can be stored in a central database for monitoring of trends and planning of maintenance.

4.3.6.5 Requirement for Double Check and Signing of S-marked Maintenance Operations

CargoNet, the largest freight rail operator in Norway, has classified their maintenance activities according to whether the maintenance operation is safety critical or not. The safety critical maintenance operations, called S-marked activities, have to be double checked and signed out by 2 persons. This is considered to reduce the likelihood of faults and omissions in the maintenance work of safety critical items of the rolling stock.

4.3.7 Train Operational Measures

4.3.7.1 Qualified Persons Responsible for Loading Safety

In Spain it is required by law to have a qualified and certified person responsible for supervising the loading of trains. In the recent national legislation in Spain companies performing loading and unloading tasks are required to designate a responsible person. The person designated must demonstrate sufficient knowledge in order to be deemed qualified, and the designated person is registered with the train operator. Also in Bulgaria a qualified person is to be responsible for correct train loading.

Figure 11: Inappropriate Train Loading[12]

[12] Picture from http://www.eisenbahn-unfalluntersuchung.de/cln_033/SharedDocs/Publikationen/EUB/DE/Untersuchungsberichte/2010/60____Tornesch,templateId=raw,property=publicationFile.pdf/60__Tornesch.pdf

4.3.7.2 Locomotive and First Wagons of Long Freight Train in Brake Position G ("Lange locomotive")

When operating long freight trains in brake position P the delayed application of pneumatic train brakes in the rear of the train compared to the front of the train causes significant compression forces. In order to limit train compression forces when operating pneumatic brakes of a freight train in position P the locomotive(s) and the first wagon(s) of a long freight train shall be put in brake position G to limit the compression forces of the train when braking with the pneumatic activated train brakes.

In Germany the requirements are specified in [24] and for freight trains weighing 800 – 1200 tonnes the locomotive should be placed in brake position G. For freight trains weighing 1200 tonnes or more, the locomotive and the 5 first wagons are to be placed in brake position G. The above train weight values are exclusive of locomotives.

4.3.7.3 ATP-system for Testing of Braking Performance of Train Mechanical Brakes

The ATP-systems of some countries including Norway, Sweden and Finland called ATC, has a function to perform a dynamic brake test on the route to get actual test information with regard to the train braking performance.

In Sweden it is mandatory to test the train brake performance by this system as soon as possible after departure from a train formation station. Specifications in JvSFS 2008:7 bilaga 11 [27].

4.3.7.4 Limitations on Use of Brake Action in Long Freight Trains

Regardless of type of brake activation it is important to restrict brake actions in difficult track geometries at low speed. In particular this applies when freight trains are routed through deviated point settings with narrow curves across stations. The traffic operation regulations of Austria [25], Switzerland [26] and other countries, specify limitations.

<u>Electro-dynamic braking</u>

Operational braking of freight trains is mainly carried out by using electro-dynamic brakes at the locomotive. This produces compression forces in the train and the brake force at the locomotive has to be limited in difficult track geometries in order not to jeopardize safety against derailment. Train operators therefore have specified limitations with regard to allowable use of electro-dynamic brakes, in particular at low speed. Here are some examples:

- CargoNet (Norway): 150 kN.
- ÖBB (Austria): 100 kN for speeds < 40 km/h and 150 kN for 50 km/h=/< speed > 150 km/h
- SBB (Switzerland): 150 kN.

For older locomotives such limitations have to be adhered to by the driver. For modern locomotives the limitations are programmed into the brake and traction control computers.

<u>Use of pneumatic brake</u>

The Swiss traffic operation regulations [26] specifies that when passing deviated point settings with speed limitations to 40 km/h the application of pneumatic brakes should be limited to 0,5 bar pressure reduction unless during emergency.

Further, the regulations specifies that after an emergency braking at above specified track conditions the train should be inspected before continued operation.

4.3.7.5 Saw Tooth Braking Applied when Pneumatic Brakes used in Long Descents

When pneumatic brakes have to be applied to restrict the speed in long descents the Swiss traffic regulations (Fahrdienstvorschriften) [28] specifies that saw-tooth braking should be applied. This means that during a brake application of approximately 60 seconds the speed should be restricted so much that there can be an interval of minimum 90 seconds without brake application until the next pneumatic brake application. By such actions the heat exposure to the wheels is limited and the risk of wheel damage is reduced and hence reducing the risk of derailment.

If necessary, the speed should initially be reduced so the above specified brake actions are sufficient to maintain allowable speed during the descent.

4.3.7.6 Initiate Braking Prior to Passing Signal or Sign Requiring Braking Action

When passing a signal showing a reduced speed, the driver should initiate the braking or speed reduction activities prior to passing the signal. This is a requirement of the Swiss operating rules [37]. For a number of reasons this may reduce the risk of over-speeding and derailment in track deviations:

- The braking action is initiated earlier and a gentler braking will ensure sufficient speed reduction according to signals and signs.
- There is less chance of the driver forgetting the speed reduction signal if the braking action is initiated immediately.

4.3.7.7 Improved Handling of Trackside Detector Alarms

It is not uncommon that hot axle box alarms are acted upon too late so the derailment has already occurred when the train stops or reduces the speed. Further, there are several examples of accidents that seem to have occurred due to overriding of a hot axle box alarm, either because the time taken for the driver to inspect the axle box has taken too long (thus cooling has occurred), or possibly because there is not a convenient location to stop and inspect the train without delaying other traffic, etc..

Trafikverket in Sweden (former Banverket) has recently issued a new regulation for how various alarms should be handled (BVF 592.11) [29]. The document specifies the actions to be carried out after a detector alarm registration is received and restricts the traffic controller's and train driver's possibility to override detector alarms.

4.4 Results – What are the Existing Mitigation Measures?

In the following table the various existing measures to mitigate the consequences of derailments are briefly presented.

Table 9: Mitigation Measures applied to Train Loading and Operation

Category:	M#	Measures and motivation:	Where applied:	Source
Rolling stock	M-1a	Derailment detection detectors (valves) to avoid derailed wagons from being dragged along for long distances – these devises apply train brakes automatically. For further info see 4.4.3.	By train operators in Switzerland & Slovenia. Similar system in use in RWE Rheinbraun	Questionnaire info A2 final draft report reviewer
	M-1b	Derailment detection detectors to provide an alarm to the train driver indicating a suspected derailment – these devises do not apply train brakes automatically. For further info see 4.4.3.		At the request of ERA, no specific devices of this type have been identified.
	M-2	Equip tank wagons with impact shield to protect tank against penetration (US-requirement also used in Sweden). For further info see 4.4.4.	RID requirement for some materials, e.g. chlorine. Country requirements: US, Sweden	RID [38] & RSSB [39]
	M-3	Install emergency warning lights on locomotive to warn train on neighbouring track going in opposite direction. For further info see 4.4.5.	Switzerland	BAV Fahrdienstvorschriften [40] Accident report Mühlehorn
	M-4	Attach mechanical guides at the bogie structure or on wagon support at appropriate position to ensure that a derailed wagon most likely is kept along the track and does not overturn or become hit by other wagons. For further info see 4.4.6.	High speed trains in France, Sweden and Japan. Similar system in use in RWE Rheinbraun	Document received from ERA [41] A2 final draft report reviewer
Infrastructure	M-5	Existing requirement for safety rails (guard rails) at bridges and in tunnels. For further info see 4.4.1.	Several countries for bridges. Denmark for to tunnels	General railway knowledge
	M-6	Battering rams in front of safety critical pillar supports of roof structures and overbridges in order to prevent derailed rolling stock damaging such safety critical structures. For further info see 4.4.8.	Germany	A1 final draft report reviewer
	M-7	Installation of dragging object and derailment detectors. The detector will detect both dragging objects and derailments. For further info see 4.3.3.5.	US and other countries	Ref [9]
	M-8	Installation of deviation points leading to a safe derailment place in strongly descending tracks from marshalling yards and train formation stations. For further info see 4.4.2.	Norway, Sweden, United Kingdom etc.	Preliminary Accident investigation report [42] & Press news from JBV [43]
	M-9	Radio or cell phone communication installations like GSM-R in order to transfer emergency stop orders to trains. For further info see 4.4.7.	To be implemented as part of Interoperability directive and TSIs command, control and signalling.	Part of ERTMS specification in TSI command, control and signalling
Operational	M-10	Separate passenger and freight traffic to separate lines to a larger degree (which is also EU-policy). For further info see 4.4.9.	High speed lines for passenger traffic. Betuwe route (NL) for dedicated freight	EU-programme
	M-11	Restrictions on freight traffic in general or hazardous materials transport in special through certain busy passenger terminals and/or underground stations to restrict traffic and limit the consequences of a derailment. For further info see 4.4.10.	Examples are banning of general freight traffic through airport train stations (e.g. Oslo and Schippol)	NL - Prorail Network Statement 2010 [44]
	M-12	Develop and apply a checklist for dangerous goods transport as the Swiss checklist for dangerous goods transport by freight trains. For further info see 4.4.11	Switzerland	BAV Checklisten – Checkliste Gefahrgut.

	M-13	Requirement for activating of warning lights in driving end of train. For further info see 4.4.11.	Switzerland	BAV Fahrdienstvorschriften [40]

4.4.1 Installation of Guard Rails between Running Rails

The European railways in general install guard rails between the running rails at bridges to limit the movement of a derailed wagon. In some countries and railway lines (e.g. Øresund tunnel in Denmark) guard rails are also fitted in tunnels. The measure could be given a wider application in order to limit the free movement of a derailed wagon and hence may limit the consequences of a derailment.

Guard rails should not be confused with check rails (P-1) that are installed to limit the consequences of a derailment.

4.4.2 Installation of Deviation Points leading to a "Safe" Derailment Places

In order to handle runaway rolling stock in strongly descending tracks from marshalling yards controlled derailment points may be provided to avoid runaway rolling stock accelerating in the descending tracks and causing large consequence collisions or derailments or other accidents further down the line. Such trap points are frequently used in many networks and are derailment devices to limit consequences if other safety measures have failed or are not sufficient.

Severe accidents due to a lack of safety trap points have recently occurred March 24th 2010 at Alnabru/Sjursøya in Oslo Norway [42] causing 3 fatalities and 4 serious injuries, and December 3rd 2005 at Salerno in Italy [45] causing one fatality and 3 injuries. Pursuant to the Alnabru/Sjursøya accident Jernbaneverket in Norway has installed deviated points leading to a safe derailment location [43].

In addition, a derail or derailer is a device used to prevent fouling of a track by unauthorized movements of trains or unattended rolling stock. It works (as the name suggests) by derailing the equipment as it rolls over or through the derail.

4.4.3 Installation of Derailment Detector Valves

The purpose of a derailment detector is to detect that a derailment has occurred and to either automatically employ brakes to bring the train to a halt or to warn the driver and allow the driver to take appropriate action. The technology employed is typically a spring mass valve measuring vertical acceleration. Acceleration above a certain threshold activates the emergency brake valve. The derailment detector valve is installed on rolling stock in Slovenia and Switzerland (tank wagons), and is provided by tank car hire wagon companies.

It is also reported that similar systems are used by RWE Rheinbraun trains operating in Germany.

4.4.4 Crash Protection of Tank Cars

Tank wagon hire companies have available for hire rail tank wagons with a large number of elements for improving the safety of hazardous goods transport services.

The rail tank wagons are fitted with special buffers with additional deformation elements and structural protection to prevent damage for impact speeds up to approx. 35 km/h depending upon the size of the train. It is a requirement for transport of many types of hazardous materials that the wagon is equipped with protection against buffer locking (Überpufferung) to prevent structural damage to the tank and wagon frame in an accident. RID specifies the minimum requirement for wagons used for various type of materials [38].

The unit also features protective shields on both ends of the tank serving as a crumple zone and protecting the tank bottom from perforation in the event of buffer locking and overriding. Design improvements on the fittings dome provide added protection against leakage if the vehicle overturns or rolls over. The additional optional safety elements increase the tare weight by only approx. 1.2t.

The CPR tank car (Crash Protected Rail Tank Car) meets the valid rail standards (e.g., UIC, RIV) and European standards for rail tank cars EN12561. In terms of design and technology, the wagon is optimal for cross-border transport services.

4.4.5 Install Warning Lights in Driving End of Train

In Switzerland it is a requirement that locomotives are equipped with warning lights in the front that can be lit to warn trains on the neighbouring track in the opposite direction about possible dangers in terms derailed wagons etc. Installation of such warning lights can be extended to other countries.

These warning lights (red flashing lights) should be activated if the train driver suspects that the neighbouring track could be blocked or interfered by a derailment or other obstruction. See also 4.4.11.

4.4.6 Derailment Guides on Bogies and Wagon Supports

A number of high speed passenger trains are equipped with structures or equipment in the bogie which ensures that the wagon is kept along the track if a derailment of one axle occurs. Examples of such trains are TGV in France, X-2000 in Sweden and Shinkansen in Japan. In many cases the guiding devices has been installed for other purposes and for other functions, but their guiding effect has been proven in accidents [41].

It is also reported that similar systems are used by RWE Rheinbraun trains operating in Germany.

4.4.7 Emergency Communication Equipment

Emergency communication connection between trains and traffic control can reduce the time from derailment to train stop and hence reduce consequences. GSM-R is a cell phone based communication system that is specified as part of ERTMS and will be the standard system in the EU-countries.

4.4.8 Battering Rams/Structural Protection

Safety critical structural supports of platform roofs, large overbridges located between tracks or close to tracks may be given additional protection in the form of battering rams or other forms of structural protection to limit the risk of damage from derailed rolling stock. The measure is used to protect special safety critical structures but is not very commonly used.

4.4.9 Separation of Freight and Passenger Traffic by Route or Time

In order to minimise the risk of hazardous materials rail transport, hazardous materials trains should as far as possible be separated from heavy passenger rail traffic by route or time of operation in order to minimize the consequence. Hazardous material trains should if possible also be routed around high population density residential areas.

4.4.10 Restrictions on Freight Traffic through busy City Terminals and/or Underground Stations

Restrictions on freight traffic in general or hazardous materials transport in particular through certain busy passenger terminals, city centres and/or underground stations to restrict traffic and limit the consequences of a derailment.

Examples are banning of general freight traffic at busy lines around Rotterdam and Amsterdam or through airport train stations as Oslo Airport and Schipol in Amsterdam [44].

4.4.11 Develop and Use a Checklist for Dangerous Goods Transport

The Swiss "Bundesamt für Verkehr" has developed a checklist for use by freight train transport of dangerous goods [46]. The checklist is meant as an operational aid in controlling freight train transports of dangerous goods. The checklist could be adopted for use in the EU and other countries.

4.4.12 Requirements for Activation of Warning Lights in Driving End of Train

In Switzerland it is a requirement that safety warning lights (red flashing lights) in the front of the train are activated if there is a suspicion that a derailment has occurred and there is a chance that the neighbouring track is blocked by the derailment or other obstruction [40].

Improved communication systems by GSM-R required by ERTMS can be an alternative to the above measure.

4.5 Existing Measures allocated to Short, Medium and Long Term Categories

There is a further consideration associated with measures, and that relates to when they could be introduced into EU regulation (see Section 1.2.) The Agency definition regarding this is:

- A measure is short term if it can be introduced into EU regulation and largely implemented before 1st January 2013.
- A measure is medium term if it can be introduced into EU regulation and largely implemented within 5 to 10 years.
- A measure is long term if it is likely to require more than 10 years for it to be introduced and largely implemented.

We present the results of the allocation applied, and the reasons for the allocation in the table below.

Table 10: Time Categorisation of Existing Preventative Measures

Measure Number	Description	Category	Comment
P-1	Check rail	Medium	The adoption of such measures, where not currently applied, would require consideration of the application parameters, surveys of IMs' infrastructure to identify installation locations and then engineering work to implement this measure. It is not considered this could be achieved in the short term.
P-2	Track and flange lubrication installed on track	Medium	The adoption of such measures, where not currently applied, would require consideration of the application parameters, surveys of IMs' infrastructure to identify installation locations and then engineering work to implement this measure. It is not considered this could be achieved in the short term.
P-3	Not used		
P-4	Not used		
P-5	Not used		
P-6	Geo radars	Medium	The technology exists, and is already implemented in some locations. However, the time to procure, install, train personnel and test such equipment is unlikely to be achievable in the short term.
P-7	Rolling stock mounted equipment for monitoring of rail profile conditions.	Medium	The technology exists, and is already implemented in some locations. However, the time to procure, install, train personnel and test such equipment is unlikely to be achievable in the short term.
P-8	Track circuit	Medium	This is implemented already in many countries. However, where it is not implemented changes to the signalling system may be required which is not likely to be achievable in the short term.
P-9	Interlocking of points operation while track is occupied	Medium	This is implemented already in many countries. However, where it is not implemented changes to the signalling system may be required which is not likely to be achievable in the short term.

Measure Number	Description	Category	Comment
P-10	Hot axle box (hot bearing) detectors	Medium	The technology exists, and is already implemented in some locations. However, the time to procure, install, train personnel and test such equipment is unlikely to be achievable in the short term.
P-11	Acoustic bearing monitoring equipment	Medium	The technology exists, although is not implemented (other than in test locations) in the target countries. It may require a lengthy implementation programme, although it is considered to be achievable within 5 – 10 years.
P-12	Hot wheel and hot brake detectors	Medium	These are often provided as a function of hot axle box detectors, and for the purposes of this assessment are jointly considered with P-10.
P-13	Wheel load and wheel impact load detectors	Medium	The technology exists, and is already implemented in some locations. However, the time to procure, install, train personnel and test such equipment is unlikely to be achievable in the short term.
P-14	Dragging object and derailment detectors		Derailment detectors considered at M-7. Regarding dragging object detectors these devices would have to be fitted at a very high frequency along the track, with high installation costs and maintenance costs. On the basis that the cost would be prohibitive and we have not considered these further.
P-15	Bogie performance monitoring/Bogie lateral instability detection (bogie hunting)	Medium	The technology exists, although is not implemented (other than a small number of locations) in the target countries. It may require a lengthy implementation programme, although it is considered to be achievable within 5 – 10 years.
P-16	Wheel profile measurement system / Wheel profile monitoring unit	Medium	The technology exists, and is already implemented in some locations. However, the time to procure, install, train personnel and test such equipment is unlikely to be achievable in the short term.
P-17	Not used		
P-18	Sufficient availability of maintenance resources	Short	This is a matter of recruitment and training. It is considered that this could be achieved within the short term.
P-19	Clearance of obstructions from flange groove (particularly at level crossings)	Short	This is a matter of potentially increasing inspections at certain locations. It is considered that this could be achieved within the short term.
P-20	Ultrasonic rail inspection	Short	This is a matter of potentially increasing inspections at certain locations. It is considered that this could be achieved within the short term.
P-21	Track geometry measurement of all tracks	Short	This is a matter of potentially increasing inspections at certain locations. It is considered that this could be achieved within the short term.
P-22	EU-wide intervention/action limits for track twist	Medium	Such measures would involve extensive consultation with IMs, and possibly a revision to existing TSIs. This is unlikely to be achievable within the short term.
P-23	EU-wide intervention/action limits for track gauge variations	Medium	Such measures would involve extensive consultation with IMs, and possibly a revision to existing TSIs. This is unlikely to be achievable within the short term.
P-24	EU-wide intervention/action limits for cant variations	Medium	Such measures would involve extensive consultation with IMs, and possibly a revision to existing TSIs. This is unlikely to be achievable within the short term.
P-25	EU-wide intervention/action limits for height variations and cyclic tops	Medium	Such measures would involve extensive consultation with IMs, and possibly a revision to existing TSIs. This is unlikely to be achievable within the short term.
P-26	Flange lubrication of locomotives	Medium	The adoption of such measures, where not currently applied, would require consideration of the application parameters, surveys of IMs' infrastructure and RUs' locomotives to identify lubrication locations and then engineering work to implement this measure. It is not considered this could be achieved in the short term.
P-27	Replace composite wheels with monoblock wheels	Medium	This is likely to be integrated with the maintenance cycle of wheel sets and be implemented on an opportunistic basis. Therefore it would not be achieved within the short term.
P-28	Replace metal roller cages in axle bearings by polyamide roller cages.	Medium	This is likely to be integrated with the maintenance cycle of axles / wheel sets and be implemented on an opportunistic basis. Therefore it would not be achieved within the short term.
P-29	Replace existing axles for stronger axles or axles with improved material	Medium	This is likely to be integrated with the maintenance cycle of axles / wheel sets and be implemented on an opportunistic basis. Therefore it would not be achieved within the short term.

Measure Number	Description	Category	Comment
	properties with regard to crack initiation and crack propagation		
P-30	Increase the use of central couplers between wagons in fixed whole train operation	Medium	The equipment / technology exists, although would require substantial re-engineering of wagons to implement. Therefore it would not be achievable within the short term.
P-31	Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis.	Medium	The equipment / technology exists, although would require substantial re-engineering / procurement to implement. Therefore it would not be achievable within the short term.
P-32	Install disc brakes instead of wheel tread brakes for new wagons.	Medium	A requirement to install disc brakes on new wagons could be developed in the short term (although the time to have a wagon fleet fitted with disc brakes would depend on the procurement programmes of RUs, wagon owners etc).
P-33	Rolling stock design for track twists	Long	A requirement to have more fault tolerant rolling stock design could be applied for new wagon purchases. The benefits of this measure however not be realised until long term however and be governed by the time (and investments) necessary for the renewal of the targeted wagon scope.
P-34	Secure brake gear underframe	Medium	This requires a special design for new wagons or retrofitting existing wagons; retrofitting requires some form of rebuilding. It is not likely to be achievable within the short term.
P-35	Regular greasing and checks of rolling stock buffers.	Short	Measures of this type could be introduced quickly, in the form or recommendation or other formal notification. These could be applied rapidly by RUs, IMs etc.
P-36	Wheel set integrity inspection (ultrasonic) programs	Short	This measure largely exists and is applied by all RUs and wagon owners.
P-37	Derating of allowable axle loads	Short	Measures of this type (introducing a maximum axle load for these types of axles) could be introduced quickly, in the form or recommendation or other formal notification. These could be applied rapidly by RUs.
P-38	EVIC (European Visual Inspection Catalogue)-based inspection of freight train rolling stock axles	Short	Measures of this type could be introduced quickly, in the form or recommendation or other formal notification. These could be applied rapidly by RUs, subject to suitable training.
P-39	Double check and signing of safety-classified maintenance operations	Short	Measures of this type could be introduced quickly, in the form or recommendation or other formal notification.
P-40	Qualified and registered person responsible for loading	Medium	Measures of this type could be introduced quickly, in the form or recommendation or other formal notification. However, the development and roll-out of a qualification scheme is unlikely to be achievable in the short term.
P-41	Locomotive and first wagons of long freight trains in brake position G	Short	Measures of this type could be introduced quickly, in the form or recommendation or other formal notification.
P-42	Limitations on use of brake action in difficult track geometry	Short	Measures of this type could be introduced quickly, in the form or recommendation or other formal notification, subject to suitable training and rule book updates.
P-43	Dynamic brake test on the route	Medium	This requires an ATP system with this functionality. The introduction of such technology, or adaption of existing technology, is not achievable in the short term.
P-44	Saw tooth braking to limit heat exposure to wheels	Short	Measures of this type could be introduced quickly, in the form or recommendation or other formal notification, subject to suitable training and rule book updates.
P-45	Initiation of braking or speed reduction prior to passing signal showing reduced speed	Short	Measures of this type could be introduced quickly, in the form or recommendation or other formal notification, subject to suitable training and rule book updates.
P-46	Not allowing traffic controllers and drivers to override detector alarms	Short	Measures of this type could be introduced quickly, in the form or recommendation or other formal notification, subject to suitable training and rule book updates.
P-47	Wagons equipped with a balance to detect overload in visual	Medium	This measure may require investigation of installation location and fitting of appropriate devices. This is unlikely to be achievable in the short term.

Measure Number	Description	Category	Comment
	inspection.		

Considering measures to mitigate the consequences of derailments, this project has only the objective of assessing measures related to the detection of derailments. We have therefore considered only M-1, with the following categorisation:

- **M-1**: The technology exists, and is already implemented on some freight wagons. However the time to procure, install on a wider range of wagons is unlikely to be achievable in the short term. We therefore classify this as a **medium** term measure.

5.0 Possible Future Measures Addressing the Derailment Problem

5.1 Methodology and Definition

We have defined an existing measure as something that is *"...applied for implementing a given regulation requirement, or applied on a voluntary basis."* [5]. For a measure to be existing it must therefore be applied in at least one of the target countries.

Future measures are therefore:

- Measures that exist, but which are not applied in the target countries, or
- Measures that are under development.

We have identified these future measures through a diverse range of activities that has included:

1. A first round of direct consultation with IMs, RUs, NSAs, railway associations and other stakeholders.
2. A second round of direct consultation with suppliers to the rail market.
3. Internet research and review of journals to identify specific examples of applied measures.
4. Review of network statements, accident reports and other information sources.

We have reported on these approaches in Section 4.0.

Further, with reference to Section 4.5, measures are further classified as short, medium and long term. In this document we report only on **short** and **medium** term measures, as these are to be taken forward to Part B of this project. **Long** term measures require consideration of what the future railway might look like and an explanation of how the identified long term measure may fit into the derailment problem.

In order to keep this report manageable in terms of length and detail, we have produced a separate stand-alone report addressing potential long term future measures, to which the reader is referred, [47].

5.2 Results – What are the Potential Future Short and Medium Term Measures?

As part of our work we have identified eight categories of potential future measures intended to prevent or reduce the likelihood of freight train derailments. These are tabulated below.

We note that the information and assessments that follow for measures that have less operational experience within Europe and therefore may be subject to more variation and uncertainty.

Table 11: Potential Future Measures

Measure Number	Description	Category	Comment
F-1	**End-of-train device (brakes)**. In the USA & Canada freight trains are installed with "end of train devices" that are in radio contact with the driver, and by radio signal to the unit the driver can apply brakes on the train in an emergency situation. This can be an essential safety measure in situations where the brakes of substantial rear parts of the train cannot be applied immediately from the driver's position. Application of brakes through an end of train device can also speed up the brake application in an emergency situation, and also may reduce compression forces in a train. Note: This measure is not to prevent collisions but to allow a better quality of brake application, limiting the possibility to induce a derailment due to a non-uniform application of the brakes especially in the case of long trains. This measure should be distinguished from the brake tests before departure which have the objective to ensure that the brake performance is correct and therefore to help to prevent over-speed which can lead both directly to a derailment and to a collision.	Medium	The introduction of such devices would require complementary tests and agreement regarding issues such as the transmission of signals between the driver and the end of train device. Such work is likely to require a timeframe within the 5-10 year window relating to the definition of medium term.
F-2	**Awareness program and improved maintenance**. A concern expressed to us by several IMs was regarding the quality of freight wagons from some countries. In particular that maintenance as well as supervision of national authorities of this maintenance is of varying standards.	Short	This is an issue relating to the safety management systems and culture of RU / keepers / wagon owners as well as the supervision of this by NSAs. It is certainly the case that renewed emphasis on this matter could be recommended in the short term, although a full implementation of this may take longer.
F-3	**Hot Axle Box Indication**. The use of thermo-sensitive paint / chalk or similar to check for hot axle boxes. This may provide visual indication to train driver of the presence of a hot axle box. (Possibly a hot axle box alarm may have been triggered, but on inspection some minutes later the axle box has cooled – this may provide indication that the alarm was genuine, and avoid accidents where the driver continues.) We understand that this measure is applied in at least one RU within the target countries.	Short	This is a simple measure which is likely to be quick and relatively easy to implement.
F-4	**Machine vision devices**. These products are designed to detect faults that may occur on freight vehicles when they run pass the detection site. Such devices are installed at trackside and employ hi-speed cameras to grab images of the vehicles. These images are sent to a computer for processing, comparison and analysis so any fault on the vehicle can be distinguished and detected. They detect mechanical failures of the bogie, dragging objects, coupler faults and may also detect temperature variations etc. This measure is applied in countries which include the USA and China, but not within the target countries.	Medium	The introduction of such devices would require complementary tests. Such work is likely to require a timeframe within the 5-10 year window relating to the definition of medium term.
F-5	**Telematics**. Devices that allow receipt and transmittal of information from / to rail freight vehicles. Using this technology it is possible to inform the Entity in Charge of Maintenance of defects for rectification. A number of the measures described in this document require the positive identification of a train in order for emerging issues to be identified (for example acoustic bearing monitoring). Other benefits include verification of train consist and operational parameters.	Medium	The scale of the implementation programme, and the supporting infrastructure required to collate the information would mean this was not achievable within the short term.

Measure Number	Description	Category	Comment
	This measure is partly implemented in some target countries.		
F-6	**Anti-lock device.** Systems of this type reduce locking of the wheels and associated wheel damage during braking on railway freight cars. In turn this may reduce maintenance costs associated with re-profiling wheel sets, improve safety with reduced risk of wheel cracking or major tread damage that could increase derailment risk, reduce impact forces to track with the wheel sets, reduce noise generated with the wheel sets. The control system concepts are similar to passenger Wheel Slip Protection, but the application to freight cars has 2 principle differences:- • The absence of electrical power, which is overcome by integrated generators driven from the axle ends • Much less compressed air available to control slide activity – this is a particular constraint with “single-pipe” braking used almost exclusively within the EU. They may also provide a local power source for other monitoring systems. Currently a system of this type is being tested in one of the target countries.	Medium	The scale of the implementation programme would mean this was not achievable within the short term.
F-7	**Sliding wheel detectors**. These systems detect wheels that are not rotating correctly and raise an alarm, with similar benefits to the antilock device for freight wagons described above. They are currently used in at least Australia, although a GB demonstration is planned for 2011.	Medium	The introduction of such devices would require complementary tests. Such work is likely to require a timeframe within the 5-10 year window relating to the definition of medium term.
F-8	**Handbrake interlock.** This would prevent a freight train moving off with the handbrake applied and therefore reduce the likelihood of subsequent issues like wheel flats, overheating and track damage.	Medium	The scale of the implementation programme would mean this was not achievable within the short term.
F-9	**Harmless infrastructure.** This relates to the removal of obstructions on or near the track that may make penetration of a dangerous goods wagon less likely.	Medium	The scale of the implementation programme would mean this was not achievable within the short term.

6.0 Markets for Technical Measures

6.1 Methodology and Definition

A technical measure is defined as "…*a measure based on the use of a specific device or system.*" [5]

With regard to these technical measures, it is a project requirement to "*…provide data on markets related to 'technical measures'. The volume of existing market and sales, in and outside EU, shall be described as well as the respective shares of key designers, manufacturers, suppliers.*" [5]

Against these objectives, our first task was to establish from the list of measures P-1 to P-47, M-1 to M-13 and F1 to F-8, those to be considered for market assessment. The results and rationale for this activity are presented in the table below for both existing and potential future measures.

Table 12: Existing Technical Measures Subjected to Market Assessment

Measure Number	Description	Market Assessment[13]	Comment / Discussion
P-1	Check rail	No	Check rails are a well established mechanical measure with many suppliers.
P-2	Track and flange lubrication installed on track	No	Track and flange lubrication systems are installed primarily as technical measures to reduce track wear, although they are thought to contribute to reducing derailments in certain cases. However, as derailment mitigation is not their primary purpose we have not considered them here.
P-3	Not used		
P-4	Not used		
P-5	Not used		
P-6	Geo radars	Not Applicable	Geo radars. IMs currently employ such technical measures / techniques for the identification of track superstructure faults. Further, track superstructure faults appear (based on our preliminary accident review – this hypothesis is to be further checked in Part B) to make only a minor contribution to freight train derailments.
P-7	Rolling stock mounted equipment for monitoring of rail profile conditions.	Not Applicable	Rolling stock equipment for rail profile monitoring. This technical measure / technology allows for quicker and more efficient inspection of rail profile conditions (compared with the use of specialist vehicles) The main benefits of such systems are cost and efficiency, rather than safety
P-8	Track circuit	No	Track circuits are part of a normal signalling system and although they may also help detect rail ruptures, are generally not for used for this purpose on its own. They are not considered here.
P-9	Interlocking of points operation while track is occupied	No	This is part of a normal interlocking system. Interlocking of points operation is a question of the design of the interlocking system and is not a product bought off the shelf.
P-10	Hot axle box (hot bearing) detectors	Yes	
P-11	Acoustic bearing monitoring equipment	Yes	
P-12	Hot wheel and hot brake detectors	No	These are often provided as a function of hot axle box detectors, and for the purposes of this assessment are jointly considered with P-10.
P-13	Wheel load and wheel impact load detectors	Yes	
P-14	Dragging object and derailment detectors	No	Derailment detectors considered at M-7. Regarding dragging object detectors these devices would have to be

[13] "No" means that a market assessment is not performed for the reasons provided in the comment / discussion column. Not Applicable means that a market assessment is not performed as measures in support of human / organisational failures are not required to be assessed by this project (as defined by the Terms of Reference).

Measure Number	Description	Market Assessment[13]	Comment / Discussion
			fitted at a very high frequency along the track, with high installation costs and maintenance costs. On the basis that the cost would be prohibitive and we have not considered these further.
P-15	Bogie performance monitoring/Bogie lateral instability detection (bogie hunting)	Yes	
P-16	Wheel profile measurement system / Wheel profile monitoring unit	Yes	
P-17	Not Used		
P-18	Sufficient availability of maintenance resources	Not Applicable	This is an operational/organisational measure.
P-19	Clearance of obstructions from flange groove (particularly at level crossings)	Not Applicable	This is an inspection and maintenance activity
P-20	Ultrasonic rail inspection	Not Applicable	This is an inspection and maintenance activity
P-21	Track geometry measurement	Not Applicable	This is an inspection and maintenance activity
P-22	EU-wide intervention/action limits for track twist	Not Applicable	This is an operational/organisational measure.
P-23	EU-wide intervention/action limits for track gauge variations	Not Applicable	This is an operational/organisational measure.
P-24	EU-wide intervention/action limits for cant variations	Not Applicable	This is an operational/organisational measure.
P-25	EU-wide intervention/action limits for height variations and cyclic tops	Not Applicable	This is an operational/organisational measure.
P-26	Flange lubrication of locomotives	No	Track and flange lubrication systems are installed primarily as measures to reduce track wear, although they are thought to contribute to reducing derailments in certain cases. However, as derailment mitigation is not their primary purpose we have not considered them here.
P-27	Replace composite wheels with monoblock wheels	No	Wheels are a part of any locomotive or wagon. It is a simple mechanical measure. Both types of wheels have existed for a long time and constitute alternative technologies. Most suppliers of wheels will provide both types of wheels.
P-28	Replace metal roller cages in axle bearings by polyamide roller cages.	No	Roller cages in axle bearings are a part of any rolling stock. Different types of cages have existed for a long time and constitute alternative technologies.
P-29	Replace existing axles for stronger axles or axles with improved material properties with regard to crack initiation and crack propagation	No	Axles are a part of any locomotive or wagon. It is a simple mechanical measure. Different types of axles have existed for a long time and constitute alternative technologies. Most suppliers of axles will provide different types.
P-30	Increase the use of central coupler between wagons in fixed whole train operation.	No	Couplers are a part of any locomotive or wagon. Different types of couplers have existed for a long time and constitute alternative technologies. Mandating a new type of coupler will raise a number of problems in the transitory period – except for isolated transportation routes.
P-31	Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis.	No	This is a wagon design / mechanical issue applicable to new wagons only.
P-32	Install disc brakes instead of wheel tread brakes.	No	Brakes are a part of any locomotive or wagon. Different types of brakes have existed for a long time and constitute alternative technologies. Most suppliers of brakes will provide different types.
P-33	Rolling stock design for track twists	No	This means buying new types of wagons – it is not a measure that can be applied to old rolling stock. It is a mechanical measure and therefore not considered from a markets perspective.
P-34	Secure brake gear underframe	No	This requires a special design for new wagons or retrofitting existing wagons; retrofitting requires some form of rebuilding, i.e. it is not a product bought off the shelf.

Measure Number	Description	Market Assessment[13]	Comment / Discussion
P-35	Regular greasing and checks of rolling stock buffers.	Not Applicable	This is an operational/organisational measure.
P-36	Wheel set integrity inspection (ultrasonic) programs	Not Applicable	This is the normal wheelset inspection program carried out by all RUs to ascertain that the wheels and axles are free of safety critical wear damage and cracks. This is normally carried out by visual inspection as well as ultrasonic or other NDT-methods while the train is in a depot. As a largely existing measure, we have not performed a market assessment.
P-37	Derating of allowable axle loads	Not Applicable	This is an operational/organisational measure.
P-38	EVIC (European Visual Inspection Catalogue)-based inspection of freight train rolling stock axles	Not Applicable	This is an operational/organisational measure.
P-39	Double check and signing of safety-classified maintenance operations	Not Applicable	This is an operational/organisational measure.
P-40	Qualified and registered person responsible for loading	Not Applicable	This is a human/operational/organisational measure.
P-41	Locomotive and first wagons of long freight trains in brake position G	Not Applicable	This is a human/operational/organisational measure.
P-42	Limitations on use of brake action in difficult track geometry	Not Applicable	This is a human/operational/organisational measure.
P-43	Dynamic brake test on the route	Not Applicable	This is a human/operational/organisational measure.
P-44	Saw tooth braking to limit heat exposure to wheels	Not Applicable	This is a human/operational/organisational measure.
P-45	Initiation of braking or speed reduction prior to passing signal showing reduced speed	Not Applicable	This is a human/operational/organisational measure.
P-46	Not allowing traffic controllers and drivers to override detector alarms	Not Applicable	This is a human/operational/organisational measure.
P-47	Wagons equipped with a balance to detect overload in visual inspection.	Not Applicable	This is a human/operational/organisational measure.
M-1	Derailment detection devices	Yes	
M-7	Dragging object / derailment detectors	No	In the context of derailment detection these devices offer an alternative to M-1. To be comparable however these devices would have to be fitted at a very high frequency along the track, with high installation costs and maintenance costs. On the basis that the cost would be prohibitive (compared to M-1) we have not considered these further.
M-2 to M-6 and M-8 to M-13	These measures are excluded from the scope of future assessment during Part B [5] and hence are not required to have an effectiveness assessment allocated to them.		

Table 13: Potential Future Measures Subjected to Market Assessment

Measure	Description	Market Assessment	Comment / Discussion
F-1	End of train device (brakes)	No	Based on the summary accident review completed to date, lack of braking effort / application speed has not been seen to be a significant contributory factor to freight train derailments (this hypothesis is to be tested in Part B). This measure is considered unlikely to show significant benefit.
F-2	Awareness programme for rolling stock maintenance	Not Applicable	This is not a technical measure
F-3	The use of thermo-sensitive	Not Applicable	This is not a technical measure

Measure	Description	Market Assessment	Comment / Discussion
	chalks or similar to check for hot axle boxes		
F-4	Machine vision devices	Yes	
F-5	Telematics	No	Many of the devices providing these functions are readily available from many existing suppliers. A market assessment is not considered necessary
F-6	Antilock device for freight cars.	Yes	
F-7	Sliding wheel detectors.	Yes	
F-8	Handbrake interlock.	No	We have found no suppliers of this measure, and assume it is an engineered system.
F-9	Harmless infrastructure	No	This is an engineering / layout solution.

To establish data on market and market share, we approached IMs, RUs and suppliers as we have reported in Section 4.2. This primary research activity was supported by internet research and other information sources where appropriate to deal with data shortfalls.

It is also possible to infer market conditions from information, including:

- The number of suppliers to a particular market.
- Previous research work on this subject. In this regard two reports have been particularly helpful:
    1. Rail Safety and Standards Board (2008), Identification of existing and new technologies for wheelset condition monitoring, RSSB Report for Task T607, July [48].
    2. TTCI (2010), 15th annual AAR Research Review, Presentation from March 2-3, 2010 [49].

The consultation reported here received over 30 detailed responses for technical measures.

6.2 Results of Market Research

The findings of our research in this area are presented in the following tables.

Table 14: Market Assessment Results for Existing Measures

Measure	Description	Quantity of Suppliers	Market Size	Market Conditions
P-10 and P-12	Hot axle box (hot bearing) detectors / Hot brake detectors	There are at least 10 suppliers in the market with each supplier producing at least one device.	We estimate the existing market size to be around 1,500 installed devices in the target countries, and around 8,000 world-wide. The potential market size / growth is likely to be in countries which do not currently use these devices.	This is a mature market with a good range of suppliers and devices. It is an existing European requirement that devices of this type are used in certain locations and hence possible further regulation is unlikely to provide one supplier with a competitive advantage. Pricing levels are likely to be stable.
P-11	Acoustic bearing monitoring equipment	There are at least 3 suppliers of device of this type.	There is no existing market in the target countries, although at least one country is testing this technology. It is known that at least 80 such installations operate in the USA and China. The potential market size is not considered to be very large due to high cost and (relatively) low installation density	The small number of existing suppliers may enjoy a dominant position if regulation were introduced regarding these measures. Prices are currently high, but more volume and new entrants may force prices down.
P-13	Wheel load and wheel impact load detectors	There are at least 10 suppliers in the market with each supplier producing at least one device.	We estimate the existing market size to be around 150 installed devices in the target countries. In the USA there are at least 130 installations. The potential market size is not considered to be very large due to high cost and (relatively) low installation density	This is a mature market with a good range of suppliers and devices. Regulation in this area is unlikely to provide one supplier with a competitive advantage. Pricing levels are likely to be stable.
P-15	Bogie performance monitoring/Bogie lateral instability detection (bogie hunting)	There are at least 5 suppliers in the market with each supplier producing at least one device.	We estimate the existing market size to be very small at present in the target countries – probably in single figures. In the USA there are at least 30 installations. The potential market size is not considered to be very large due to high cost and (relatively) low installation density	The small number of existing suppliers may enjoy a dominant position if regulation were introduced regarding these measures. Prices are currently high, but more volume and new entrants may force prices down.
P-16	Wheel profile measurement system / Wheel profile monitoring unit	There are at least 9 suppliers in the market with each supplier producing at least one device.	The size of the existing market is difficult to estimate due to the varying technologies and different functions offered by such systems, however we consider the market to be relatively small. Few IMs / RUs indicated they use such systems. We estimate the size of market in the target countries to be in double figures, but not significant. One supplier estimates the total market size to be fewer than 500.	This is a niche market, although we have noted that solutions and prices can vary significantly. However, this is not likely to be a high volume market.
M-1	Derailment detection devices	There are at least 4 suppliers in the market with each supplier producing at least one device.	We estimate that about 2,000 wagons are fitted with devices of this type. The potential market size is large, potentially every freight wagon operating in the target countries.	This is a market that is expanding in terms of the numbers of suppliers, although one supplier has a dominant position. Costs are relatively low and as the supplier base grows may reduce further, especially if larger volume sales are anticipated.

Table 15: Market Assessment Results for Potential Future Measures

Measure	Description	Quantity of Suppliers	Market Size	Market Conditions
F-4	Machine vision devices	There are at least 2 suppliers in the market with each supplier producing at least one device.	We are aware of no installations within the target countries. Systems exist outside of these countries however and we are aware about 120 of these devices installed in China. The potential market size is not considered to be very large due to high cost and (relatively) low installation density.	This is a new market based on new and evolving technology. The small number of existing suppliers may enjoy a dominant position if regulation were introduced regarding these measures. Prices are currently high, but more volume and new entrants may force prices down.
F-6	Antilock device for freight cars.	We are aware of only 1 supplier of devices of this type (although other devices converted from passenger train applications and which require a battery of electrical power are thought to be available).	We are aware of no installations within the target countries, except for one which is currently being tested. The potential market size is large, potentially every freight wagon operating in the target countries.	This is a new market. The existing supplier would enjoy a dominant position if regulation were introduced regarding this measure, although new market entrants would be likely. Prices are relatively modest, and more volume and new entrants may force prices down.
F-7	Sliding wheel detectors.	We are aware of only 1 supplier of devices of this type.	It is likely that deployment of such devices would be limited to exits from freight loading bays / routes such that defective braking could be identified prior to entering service which will define the potential market share.	This is a new market. The existing supplier would enjoy a dominant position if regulation were introduced regarding this measure, although new market entrants would be likely. Prices are relatively modest, and more volume and new entrants may force prices down.

7.0 Functional and Performance Assessment of Freight Train Risk Reduction Measures

7.1 Methodology and Definition

To avoid confusion, the "assessment" reported relates to the intrinsic performance of the measures assessed, in terms of their RAM characterises and other pertinent data; this is not a cost-benefit assessment of the effectiveness of these measures. This later objective is the purpose of Part B. The task definition for this work is [5]:

> *The task A.3 will describe each technical and operational measures in generic functional terms associated with the description of both intrinsic performance level and actual performance (for example, based on RAMS analysis for technical measures) as well as relevant life cycle costs (investment, operation, maintenance, repair, refurbishment, dismantling...). The description shall contain the necessary and sufficient level of details compatible with the part B of the study (development of scenario tree, semi-quantitative assessment of efficiency) and also with the necessary inputs for detailed impact assessments carried out by the Agency.*
>
> *Concerning the 'technical' measures, the related devices/systems will be described with the help of information provided by the designer(s), manufacturer(s), and/or, supplier(s) about the expected performances and by users for the actual performances.*

In undertaking this research:

1. We consulted with IMs and RUs to establish:
   - The types of measures (technical, operational, organisational or human) they currently use to either reduce the frequency or mitigate the consequences of freight train derailments.
   - The effectiveness of these measures.
   - Their plans for introducing additional measures in the short term and beyond.
   - Where an IM or RU had indicated the use of a technical measure, we asked them in a subsequent round of communication for their experience of the reliability performance and effectiveness of these measures.
2. Having established, from the consultation above, a full list of existing and potential future measures, we embarked on a further round of consultation. This further consultation was limited to suppliers of technical measures, for which we sought information on, but not limited to:
   - The RAM performance for their technical measures.
   - False alarm rates and failure mode information.
   - The way in which these technical measures may influence the risk of freight train derailment.
   - Cost and life cycle questions, such as special disposal requirements, the requirement for preventative maintenance etc.

Our approach is reported in more detail at Section 4.2.

7.2 Results for Functional and Performance Assessment

We present the results of our assessment in the following tables.

Table 16: Performance Assessment for Existing Infrastructure Preventive Measures

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	**Observed**	**Purchase and Installation**	**Life Cycle**	
P-1	An installed check rail is expected to be at least 90 % effective in avoiding derailment due to track geometry faults in curves with radius less than 250 m.	Installation cost € 250/m of track. The lifetime is at least equal to the lifetime of the rest of track construction.	Added track maintenance and tamping cost: + 20 %	The installation is assumed restricted to curves of radius < 250 m.	Checkrails may also be installed with the joint aim of reducing track wear.
P-2	Track and flange lubrication systems are installed primarily as measures to reduce track wear. These systems do however have secondary benefits and are thought to be contribute to reducing derailments in certain cases (as reported to us during our consultation exercises), hence their inclusion here. However, as their installation is generally for track wear considerations, we have not considered them as measures in the context of derailment prevention. Further, as derailment reduction is a benefit rather than a primary function of these measures, there are unlikely to be any no specific derailment reduction effectiveness data. We will review this situation during Part B.				
P-3	Not used				
P-4	Not used				
P-5	Not used				
P-6	Geo radars. IMs currently employ techniques for the identification of track superstructure faults. Further, track superstructure faults appear, based on our accident review, to make only a minor contribution to freight train derailments. We have not considered these further at this stage. We will review this situation during Part B				
P-7	Rolling stock equipment for rail profile monitoring. This technology allows for quicker and more efficient inspection of rail profile conditions (compared with the use of specialist vehicles). The main benefits of such systems are cost and efficiency, rather than safety. These are not considered further at this stage.				
P-8	Track circuits are installed for train detection purposes, as part of the signalling system. These systems do however have secondary benefits in that they may detect rail ruptures and thus contribute to reducing derailments in certain cases. However, because the primary function is train detection rather than derailment reduction, we have not considered them further. We will review this situation during Part B				
P-9	Interlocking to prevent movement of points while the relevant track section, inclusive of point, is occupied by a train, is a common feature of railway signalling installations. The interlocking feature in railway signalling systems is normally very reliable. The technology is very reliable in performing this function and would be considered to eliminate most derailments occurring due to this cause.		A track circuit costs approximately € 6000 – 10 000. If the point is electrically operated centrally from a signal box interlocking can be made locally or centrally depending upon cost.	Operating cost can vary depending upon the technical solution: Coarse estimate € 1000,- per track circuit.	Interlocking functionalities are normally introduced when installations are renewed. To what extent and at what cost interlocking functions can be added to an existing installation depends on the age of the installation.
P-10	Manufacturer's claim is for 10,000 hours MTBF for mechanical parts and 500,000 hours MTBF for electrical parts. Repair times of 5 minutes are claimed (excluding travel	Claimed by one IM to achieve an availability of >99%. A repair time of 1 day (mostly travel) was also quoted together with a false alarm rate of 40% All other IMs answering this	Costing information is confidential The cost is dependent on the type of device, as some hot axle box detectors are multi-purpose.	Manufacture's recommend a fortnightly inspection. Estimated by one IM at 5% of purchase cost.	We have reported at various points within the Part A work that alarms can be ignored (or possibly thought to be a false alarm) and the train allowed to continue leading to derailments. This issue would need to be addressed if the full benefit of the increased use of these systems were

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
	time). False alarm rate of less than 40% quoted.	question stated that the devices they used were "effective" or similar qualitative judgement, and that they saw increased coverage as a good derailment reduction option.			to be realised.
P-11	Manufacturer claims are that these offer very similar characteristics to hot axle box detectors (P-10). The rate of estimated false alarms is less than 2%	The systems in service have an average of 98% full system availability.	Costing information is confidential Installation claimed to take 3 days.	Manufacture's recommend a fortnightly inspection. A second supplier suggests that hardware maintenance is restricted in general to a six monthly periodic inspections and a system calibration as a 12 monthly routine.	Can be linked with telematics to provide effective feedback to appropriate parties.
P-12	In most cases, these devices are integrated with hot axle box detection to provide a single solution. The data for P-10 applies.				
P-13	Manufacturer claims between 85 and 95 % with 5% false alarm rate. Alternative supplier claims MTBF of 3 years with a 2 day repair time. False alarm rate of 1 per 100,000 trains.	One IM indicated that the detection of wheel anomalies through a system of this type had almost completely eliminated hot axle box problems for one passenger train operator.	Costing information is confidential	Costing information is confidential	There is a significant variance in cost depending on the functionality of the devices in this category.
P-14	See mitigation measure M-7 for dragging object/derailment detector.				
P-15	Manufacturer's claim is for track and sensors to have an MTBF 8 to 10 yrs	In-service estimates show achieved levels of over 20,000 hours MTBF (manufacturer's claim)	Costing information is confidential	Maintenance requirement less than 15 hours per year with a repair time of 30-90 minutes.	Although similar systems are used in Turkey, we are not aware of other installations outside of the USA, Canada, Australia and India
P-16	Manufacturer's claim is for track and sensors to have an MTBF > 10 yrs, and computer systems 5-10 yrs	Availabilities range between 85 and 95 % depending on the operators skills and environmental influences	Costing information is confidential Installation into the track 100 man hours (1- 2 days duration). Setup 160 man hours (2 weeks duration) (+ handover & staff training).	Regular maintenance: weekly visual check / cleaning 2hrs. = 104 hrs/year Annual inspection and maintenance: 40 hrs. False alarm rate claimed to be between 5% and 8%. A weekly test measurement using a master wheel set is recommended	
P-17	Not used				
P-18	Many derailments are caused by substandard track that does not meet minimum standards and where speed has been reduced, either in freight only lines or in sidetracks at stations. Examples can be found in many countries, e.g. Norway, Sweden, Finland, Switzerland, Hungary. In order to reduce the frequency of derailments such lines should be closed for traffic operation until		The cost to upgrade and maintain track to a safe standard can be substantial.		The consequences of derailments at such tracks depend on the traffic performed. If it is only for timber traffic in rural areas the consequence risk are small. However, if substandard tracks also exist in freight only lines or station sidetracks in urban

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	**Observed**	**Purchase and Installation**	**Life Cycle**	
	the standard has been upgraded. The effectiveness of this measure depends on the degree to which improved maintenance is carried out, but if maintenance is carried out to levels similar to main lines, then performance matching main line performance should be possible.				areas, the consequences may be severe.
P-19	This measure relates to the frequency of derailments caused by failure to clear the flange groove. The potential benefit and costs of a revision of this measure can only be judged when the frequency of freight train derailments which are caused by these defects is known (i.e. during Part B).				
P-20	This measure relates to the frequency of rail inspections. The potential benefit and costs of a revision of this measure can only be judged when the frequency of freight train derailments which are caused by track defects is known (i.e. during Part B). (In particular the use of side tracks are often the cause of derailments due to poor track geometry and rail conditions.)				This measure is closely linked to others, for example P-18. If there are insufficient resources to act on the information provided by additional inspection then this measure will not be effective.
P-21	This measure relates to the frequency and coverage of track geometry inspections. The potential benefit and costs of a revision of this measure can only be judged when the frequency of freight train derailments which are caused by track defects is known (i.e. during Part B). (In particular the use of side tracks are often the cause of derailments due to poor track geometry and rail conditions.)				This measure is closely linked to others, for example P-18. If there are insufficient resources to act on the information provided by additional inspection then this measure will not be effective.
P-22	Excessive track twist, in particular in transition curves leaving a highly canted circle segment of a curve, is one of the most frequent contributions to derailments in many countries. Existing intervention and immediate action limits varies from country to country. In view of the interoperability of rolling stock across border this is not helpful in avoiding derailments. If adopted, this measure will be very effective (depending on the operating limits chosen) in reducing derailments caused by excessive track twist.		The direct track cost of reducing track twist might not be high, but a reduction in track twist might reduce allowable speed and hence have an influence on travel time and capacity.	Increased inspection and maintenance cost may be required to reduce frequency of excessive track twist conditions.	Derailments are in general low speed derailments with somewhat smaller consequences than derailments at high speed, but they often occur at stations or close to stations where the infrastructure damage can be higher.
P-23	Tight control of track gauge is important to reduce derailments, in particular for tracks with old wooden sleepers and old rail fastening equipment. The existing measures implied by the various EU countries vary significantly. The final draft TSI for conventional rail infrastructure specifies an immediate action limit only which is laxer than action limits by existing limits in some countries. If adopted, this measure will be very effective (depending on the operating limits chosen) in reducing derailments caused by excessive track width.		This is difficult to assess as tighter action limits will increase the maintenance cost and the need for sleeper exchange. However, since it is mainly track with wooden sleepers of a certain age that is exposed to this risk, the cost should be reasonable.		It is usual that track width derailments occur at track with aged wooden sleepers and at little used sidetrack at stations or on freight-only lines. In some cases the cause has been specified as a dynamic widening of the track gauge due to the train forces in curves. In some of the cases rail compression forces due to high rail temperatures could have contributed to the dynamic widening of the gauge.
P-24	A maximum allowed cant inclusive of any variations during operation is in TSI for conventional rail infrastructure is set at 170 mm for lines open for freight traffic.		Small costs, but track cant might have to be reduced to limit the maximum possible cant	Reduction in allowed train speed in curves in front of signals where freight trains may expect stop signals.	A very high track cant is unfortunate in positions where freight trains may have to stop, e.g. in front of signals. In particular if

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
	This is a very high cant in particular in curves where trains may need to stop regularly, e.g. in front of signals. This is particularly safety critical if some of the wagons are skew loaded within or just outside of specified limitations. If adopted, this measure will be very effective (depending on the operating limits chosen) in reducing derailments caused by excessive cant variation.		including allowed variations.		there is a narrow curve at the relevant track section which can be occupied of a train stopping in front of a signal. The TSI allows as much as 160 mm design cant for lines with freight train operation but limited to R-50/1.5 in curves of R < 290 m.
P-25	The overall derailment frequency reduction potential for a measure to reduce excessive track height variations is a function of the number of derailments which are attributable to this cause. This applies to a single height variation or more cyclic effects. The degree to which this reduction can be achieved in practice is dependent on the criteria adopted, and the level to which it is implemented.		This is a track maintenance issue once the track is installed. Short length height failures are fairly easy to detect but costly to correct as their cause are often due to insufficient water drainage of the substructure. However, a speed reduction will reduce derailment risk. Long wave cyclic height failures are more difficult to detect, but once detected they can be corrected by track geometry adjustment		Derailments due to track height variations are high speed phenomena and the speed reduction would be the least costly action. Due to the high speed the cost associated with derailments cause can be high.

Table 17: Performance Assessment for Existing Rolling Stock Preventive Measures

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
P-26	Flange lubrication for locomotives – see P-2.				
P-27	An analysis of accident reports suggest twice as many derailments caused by composite wheels as for mono-block wheels. Whether one type of wheel can be said to have a higher failure rate than the other depends upon the number of wheels of each type and the traffic performance of each type of wheel. If we assume there is an equal number and equal traffic performance of each type of wheel the derailment rate could be approximately halved for the rolling stock with composite wheels if the wheels were exchanged with mono-block wheels.		The cost of such a measure to replace composite wheels for mono-block wheels depends upon how it is carried out. The most cost-effective approach would be to make the replacement when existing wheel tyres are worn out, or when the entire wheel including both rim and tyre has to be replaced.	The cost of a new wheel tyre is assumed to be lower than the cost of a new mono-block wheel. The operational cost of a fleet of railway cars with mono-block wheels might therefore be higher than for a similar sized fleet of wagons with composite wheels, but this depends upon the time between tyre and wheel replacement and the actual cost and time of doing the replacement.	If it can be verified without significant doubt that mono-block wheels have a lower failure rate than composite wheels one could make mono-block wheels mandatory for wagons for hazardous materials.
P-28	Selection of roller cage material can influence the failure rate of bearings. Information searches on the internet seems to indicate that polyamide roller cages are less exposed to failure due to vibrations, and hence may be a better material then brass in the roller cages of railway wagon bearings. Failure of roller cages of bearings is an important cause of hot axle boxes, and hot axle		The price difference between polyamide type roller cages and metal type roller cages is hardly important. If the replacement with a new roller cage material is done when the bearing has to	We do not know whether the material selection has an influence on the life time of the roller cage, but so far we have no such indication that it does. However, internet information indicates that polyamide roller cages make less	CargoNet the Norwegian freight train operator made a decision in 2000 to replace their brass roller cages with polyamide type roller cages. EUB of Germany has made the same recommendation to DB Schenker after a

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
	boxes are among the major causes of freight train derailments. A reduced roller cage failure rate may therefore have a significant influence on hot axle box events and also on freight train derailments. It is unclear at present the numerical difference in failure rates between polyamide and brass roller cages; however the maximum potential may be as much as a 10 % reduction in overall freight derailment frequency.		be opened and maintained in any case the cost is assumed to be marginal.	noise when failures occur, and hence they might be more difficult to follow-up by trackside acoustic bearing monitors.	derailment between Bruchmülen and Bunde in 2009 and the recommendation has been accepted by DB Schenker. We do not know to what extent polyamide roller cages are common in other countries.
P-29	Exchange of axles for stronger axle designs is assumed to influence the frequency of axle ruptures caused by hot axle boxes. As a working assumption, we will assume that 50% to 90% of axle ruptures may be avoided.		The cost of this measure is partly determined by the cost of new axles, but also to what extent the wagons has to be taken out of commercial operation during the replacement	With higher strength axles the inspection frequency might be reduced and hence the operating cost reduced, but the inspection frequency is mainly to be determined by the calculated fatigue life time of the axles, which might not be proportional to the strength.	Axle ruptures are mainly due to fatigue failures and the important factor is whether fatigue life of the axles is increased by an increased strength. If the extra strength is achieved by higher strength materials, the fatigue life may not be significantly affected.
P-30	Increased use of central coupler between wagons in fixed whole train operation with 4 axle cars are likely to reduce derailment frequency due to removal of buffer forcers, but heavy whole train operations are anyhow not exposed to high derailment risk from factors that can be influenced by the central coupling arrangement		The use of central coupler has to be motivated by other factors other than reduction in derailment risk.	Operating cost may be reduced and motivate the reduction.	
P-31	Bogie wagons are less prone to derailments than single axle wagons. In particular this applies to lightly loaded or empty single axle wagons with a long wheel base and long overhang. It is difficult to quantify the effect of a measure to replace single axle wagons with bogie wagons, but it is likely to have a significant influence of the derailment frequency of freight trains.		For tank cars, hopper wagons and wagons for bulk transport of heavy materials the trend is for bogie wagons and the cost may be in favour of bogie wagons.	If more axles are required for same loading capacity an increased inspection and maintenance cost may result but this depends upon the type of wagon and load.	For wagons for containers, swap bodies and light manufactured objects like automobiles single axle wagons can give a lower unit cost per m of loading basis and will be favoured on commercial reasons for some sort of operation. Even for timber transport we have seen that an increase in allowable axle load for heavy timber transport lines have favoured short coupled wagons with single axle running gear, as they give a higher loading capacity per m train length.
P-32	Installation of disc brakes reduces the heat load on wheels and may reduce the risk of catastrophic wheel failures, either in the form of mono-block wheel ruptures or due to displaced tyres of composite wheels. Hence, disc brakes may reduce the derailment risk somewhat. An analysis of accident reports indicates that as many as 8% of derailments are caused by catastrophic wheel failures		Exchange of brakes from tread brakes to disc brakes on existing wagons is very expensive and must be motivated by other benefits. A replacement of cast iron brake blocks by composite wheel	Probably not decisive in any way, but has to be investigated further.	Disc brakes also have some disadvantages as they does not clean the wheel tread for rub that may form in the wheel-rail contact if the wheel is blocked for a short period. Not being able to remove rub from blocked wheels may increase the risk of

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
	As a working assumption, we will assume that 50% to 90% of wheel ruptures may be avoided. The driving force behind a possible move from tread brakes to disc brakes may be the "TSI for railway system noise" that is difficult to meet by tread brakes with cast iron brake blocks.		blocks is a cheaper way of meeting the noise TSI for existing wagons.		hot axle boxes.
P-33	Apply Irish track twist limitations for rolling stock. This measure is a specific case for the Irish railways (Northern Ireland and Republic of Ireland) in the TSI for freight wagons and is probably granted due to the specific track gauge in Ireland and their captive rolling stock that is designed for such track twist conditions. It is not applicable for the rest of Europe unless changes are made to rolling stock specifications which are assumed very costly. This measure will not be investigated further.				
P-34	Secure brake gear located in the underframe. Based on a review of derailment accidents, approximately 2% could have been prevented by such a measure, if it was 100% effective.		The cost figure depends upon actual design of wagon brake system, but is assumed to be relatively small.	The lifecycle cost in terms of inspections and replacement of failed securing straps will increase, but we are not aware of any quantification.	
P-35	This measure relates to the frequency of derailments caused by buffer failure (lack of greasing etc). The potential benefit and costs of a revision of this measure can only be judged when the frequency of freight train derailments which are caused by these defects is known (i.e. during Part B).				
P-36	This is the normal wheelset inspection program carried out to by all RUs to ascertain that the wheels and axles are free of safety critical wear damages and cracks. This is normally carried out by visual inspection as well as ultrasonic or other NDT-methods while the train is in a depot. The effectiveness of this measure will be dependent on the safety culture of the organisation, amongst other things. A review of accidents during Part B may provide further information to support an effectiveness rating.				
P-37	Derating of allowable axle load for type Ai and Aii axle designs. This is a reversal of an exemption granted by some countries to allow higher axle loads than the intended design axle load, and a recommendation to revoke such higher loads has been issued by the JSSG of ERA. To what extent this will reduce axle ruptures due to fatigue is uncertain, but to remove this exemption will lead to replacement of those axles with new and stronger axles. As a working assumption, we will assume that 50% to 90% of axle ruptures may be avoided where this exemption applies.		No direct investment cost.	Probably a reduced life cycle cost for the wagons in question, but an increased no of wagons is required to do the same amount of transport, which will increase the train operating cost.	Axle ruptures are often high speed phenomena with a large accident potential as shown by the Viareggio accident, although we do not know whether the involved wagon in the Viareggio accident has been allowed a higher axle load than the intended design load.
P-38	Implement EVIC inspection programme for axles. From the number of derailments due to this cause the measure seems to have a potential for 5 % reduction in derailment frequency, but the reduction in derailment cost and consequence is likely to be higher as these accidents are normally high speed derailments. The effectiveness of this measure however needs to be judged based on the quantity of axle failures that may have been prevented by this programme. This information is not available at the present time.		No particular purchase or installation cost.	Increased inspection cost might apply, but the EVIC inspection program may be more cost- effective than previous inspection programmes.	Axle ruptures are often high speed phenomena with a large accident potential as shown by the Viareggio accident.
P-39	Like P-36, the effectiveness of this measure depends on the safety culture of the organisation, time allowed for the task and other factors. We have previously identified, from the ARAMIS method [50] the following relating to the use of human barriers: ▪ Where the human barrier is of a preventative nature or part of a normal operation, a probability of failure on demand of 10^{-2} is				

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
	suggested. ▪ Where the human barrier requires a specific intervention, a probability of failure on demand of 10^{-1} is suggested. These values perhaps provide a range, although following development of a risk model in Part B the context in which this measure applies will be clearer, allowing a better estimate of its potential effectiveness. Costs associated with a potential adoption of this measure will be relatively minor.				

Table 18: Performance Assessment for Existing Train Loading and Operational Preventive Measures

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
P-40	The discussion at P-39 applies.				
P-41	Brake position G for locomotive in G and "Lange Lokomotiv" depending on train weight. Identical or similar requirements exist in many countries to reduce compression forces when braking long and heavy freight trains. The effectiveness in terms of avoiding derailments are difficult to assess, particular since this measure to a large degree is an existing measure that is applied in most countries. However, we are aware of derailment accidents which partly can have been caused by not implementing this measure contrary to the requirements.		None.	None.	This measure is to a large degree already implemented in most countries.
P-42	Limitations on brake application at low speed in difficult track geometries. Abrupt braking of long freight trains at low speed in difficult track geometries, in particular in deviated track route across stations, may cause derailments due to buffer locking. Traction control of modern electric traction units might include speed dependent limitations on dynamic braking. Otherwise this is mainly a matter of good train handling. Uncontrolled application of brakes due to an active ATP-system either due to exceeding allowable track speed or from a locomotive not being in front and passing a signal at danger may be a cause for such derailments. The potential for overall derailment frequency reduction by removing this cause is, we believe, about 2-3 % based on an analysis of accidents resulting from this cause, factored by the effectiveness of the measure. The effectiveness of the measure is a human factors issue, and will be assessed in the context of the risk model to be developed during Part B.		None	None	This is low speed derailments where the brakes are already applied and the consequences are normally low, but as such derailments often happen at stations they might involve other trains which can increase the accident consequences severely. Strong regenerative braking through s-curves for instance at crossovers also applies. If the wagons are light behind the locomotive then derailments may occur. (In some few cases even the low regenerative brake force of today is still too high).
P-43	ATP Dynamic brake test on route to get information about brake		Embedded in ATP and ETCS-	None	The use of this measure is dependant

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
	performance. Normal brake tests before train departure does not give direct information on the actual performance of the train brakes. In order to improve the information to the driver the ATP-system that is used in Sweden, Finland, Norway and possibly France has a function to test the brakes and get feedback about the actual performance of the brakes. Train drivers in Sweden and Norway are obliged to use this test at the earliest convenience after train departure from the formation yard. A similar functionality is specified for the ETCS -system of Sweden and Norway which is additional to the general ETCS-functionality. The potential for overall derailment frequency reduction by removing this cause is, we believe, about 2-3 % based on an analysis of accidents resulting from this cause, factored by the effectiveness of the measure.		system. Actual cost of adding this functionality to the ETCS is unknown.		upon the functionality of the ATP-system. Existing ATP-systems of France, Sweden, Finland and Norway supports the functionality. The functionality is not included in the general ETCS functionality, but is included in the Swedish and Norwegian application. For each brake application the driver may get information about the functionality of the brakes and if it is lower than specified in the train dossier he has to adjust the train settings accordingly.
P-44	Apply saw-tooth braking. This is a Swiss requirement specified in their train operating rules, "Fahrdienstvorschriften" The measure is only of relevance in very long and steep descents and not a measure that has a general application outside of the Alpine countries or other countries with long and steep descents, such as Norway and Spain. The overall derailment potential is low, but the measure might be important in countries where it is applied. Human reliability assessment would be required to estimate the potential benefit		None	None	The effect of this measure is to reduce overall thermal load on the wheel. It is mainly applicable in long and steep descent or in trains with low dynamic braking capability.
P-45	Initiate braking prior to passing a signal which requires brake application. The potential for overall derailment frequency reduction by removing this cause is, we believe, about 2-3 % based on an analysis of accidents resulting from this cause, factored by the effectiveness of the measure. It can also reduce the collision risk. The potential risk reduction benefit needs to be factored by the effectiveness of the measure. The effectiveness of the measure is a human factors issue, and will be assessed in the context of the risk model to be developed during Part B.		None	Increased train running time	For a number of reasons this may reduce the risk of over-speeding and derailment in track deviations: • The braking action is initiated earlier and a gentler braking may be applied not risking derailment due to train compression at low speed. • Less risk of forgetting the speed reduction and running into an ATP brake application that might cause derailment.
P-46	The experience of one IM is that it is possible to reduce to almost zero the incidence of axle failures / hot axle boxes, with suitable equipment and suitable instructions concerning dealing with alarms.		The main cost associated with this measure is potential traffic disruption dealing with false alarms.		See also comments in P-10.
P-47	We are waiting additional information on this measure. However,				

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
	we believe that it would assist with visual inspection of wagons and possibly allow detection of incorrect loading during preparation.				

Table 19: Performance Assessment for Existing Mitigation Measures

M#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
M-1	Manufacturer's estimate between 500,000 and 1,000,000 MTBF operational hours per detector. No known failures (despite false alarms)	There have been no false alarms or known failures with latest device variant which has been in operation on 50 wagons (100 units) for about 5 years, hence 500 years of operation.	Some costing information is provided in the Agency Impact Assessment [51] Installation time on new wagons is negligible, on older wagons possibly 3 to 4 hours per wagon.	No field maintained parts, repair time is to remove and replace – about one hour per unit. Periodic test required – involving inducing shock (hitting with hammer) to check operational.	Training of driver required so that he is aware of the installation of the device and what to do in case brakes applied. The application of brakes may not be an appropriate mitigation in all cases, and may increase the risk of a more serious derailment.
M-7	Dragging object / derailment detectors. In the context of derailment detection these devices offer an alternative to M-1. To be comparable however these devices would have to be fitted at a very high frequency along the track, with high installation costs and maintenance costs. On the basis that the cost would be prohibitive (compared to M-1) we have not considered these further.				
M-2 to M-6 and M-8 to M-13	These measures are excluded from the scope of future assessment during Part B [1] and hence are not required to have an effectiveness assessment allocated to them.				

Table 20: Performance Assessment for Potential Future Mitigation Measures

Measure	Description	Effectiveness	Comments
F-1	End of train device (brakes)	The potential effectiveness of these devices is reduced in the area governed by EU regulation as freight trains are generally shorter than in the USA. However, we propose to establish potential effectiveness criteria based on a review of accidents and an assessment of those that such devices may have prevented. Should the measure show promise on this basis then additional information will be sought.	
F-2	Awareness programme for rolling stock maintenance	A review of accident reports will indicate the potential improvement that could be achieved through the implementation of a measure of this type (i.e. the reduction of derailments caused by poor maintenance of freight trains). A periodic safety check, setting of safety limits etc is a possible implementation method for this measure.	
F-3	The use of thermo-sensitive chalks or similar to check for hot axle boxes	This measure could be useful in visual examination by RUs to detect for hot axles.	
F-4	Machine vision devices	Costing information is confidential Claimed to have MTBF of around 10,000 hours for the mechanical parts and 500,000 hours for the electric parts and an MTTR of less than 10 minutes	
F-5	Telematics	The potential effectiveness of such measures will be assessed during Part B following a review of accidents. (Benefits may include for identification of train formation errors at check points, better communication of maintenance requirements etc).	
F-6	Antilock device for freight cars	Costing information is confidential Such devices may reduce the incidence of derailments resulting from locked / fractured axles and overheating axle boxes. Data on reliability / effectiveness not available at this time.	
F-7	Sliding wheel detectors	Costing information is confidential These systems are described as virtually maintenance free. One supplier stated that six units have been installed, the first in 2003 with no reported failures.	
F-8	Handbrake interlock	The potential effectiveness of such measures will be assessed during Part B following a review of accidents. This is likely to be an engineered solution and requires further assessment regarding the costs and effectiveness.	
F-9	Harmless infrastructure	Not assessed – this is a mitigation measure and is out of the scope of this project.	

8.0 Part A Conclusions and Part B

8.1 Regulatory Framework - Derailment

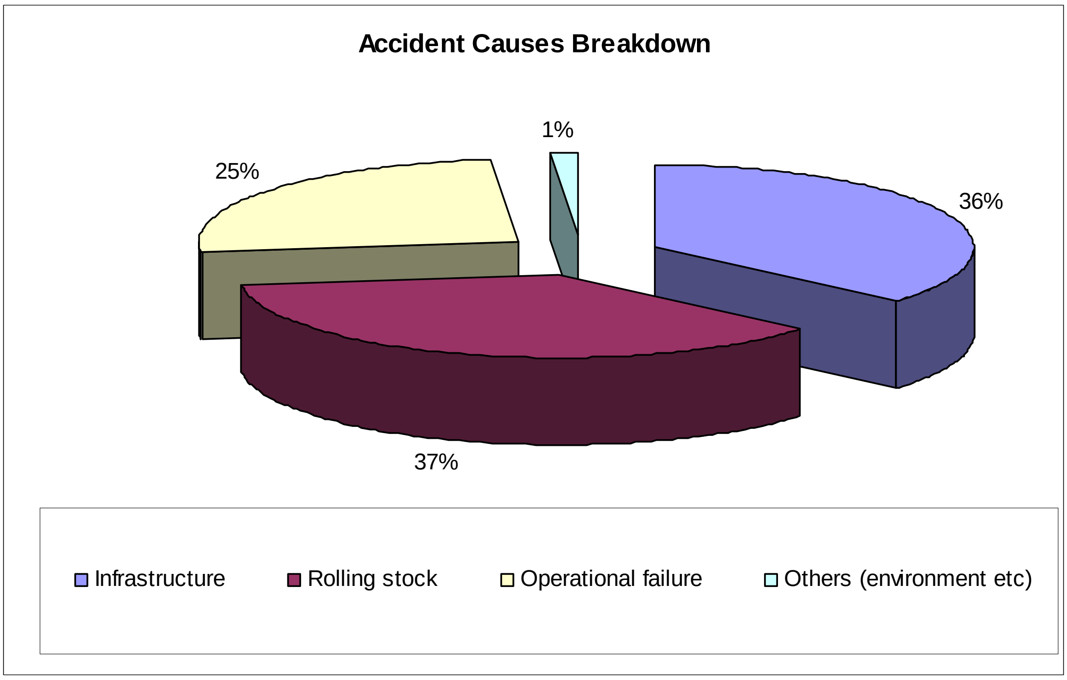
We have identified at Section 2.1 the historical and emerging framework in which freight train derailment risk reduction measures operate. In particular there is an increasing move towards a harmonised approach, comprising of uniform approaches to safety management, as well as a more standardised approach to technical requirements and the like.

This is an important initiative from a freight train derailment perspective, especially for international traffic. In this respect a harmonised infrastructure, rolling stock and operational rules will provide a more stable operating environment and less variability.

8.2 The Derailment Problem

We report in Section 3.0 the issues leading to, and therefore to be tackled if freight train derailments are to be reduced, or their consequences minimised. To support this analysis, we also present the emerging pattern from an analysis of previous derailments.

Figure 12: Approximate Breakdown of Freight Train Derailments by Category



It should be noted that human and organisational measures are not reflected in this breakdown; rather they are underlying causes that may lead to a derailment categorised as infrastructure / rolling stock and to a lesser extent operational failures. Measures identified that are address human / organisational failures include P-6, P-7, P-18 to P-25, P-35 to P-47, F-2 and F-3.

These divide into category causes as follows:

MANAGING RISK

Figure 13: Infrastructure Failures Leading to Freight Train Derailments

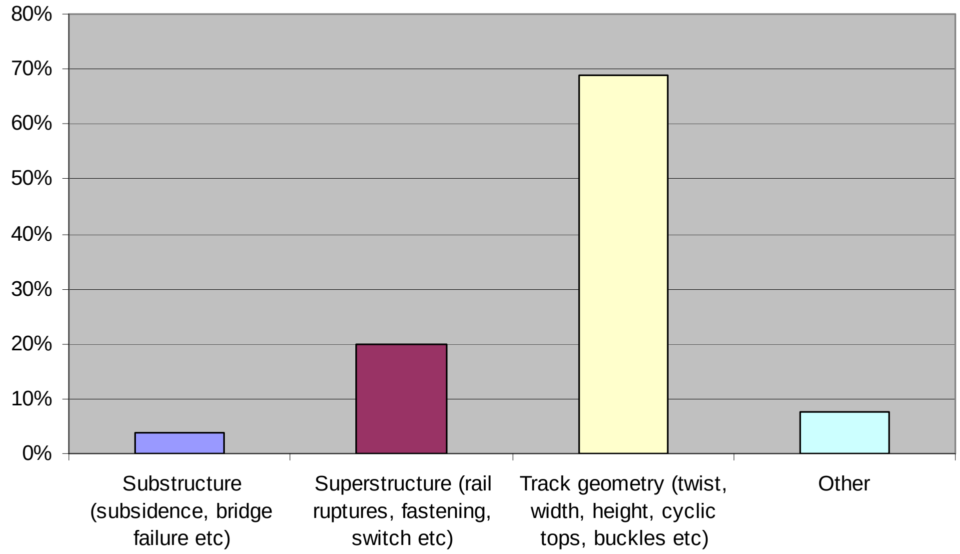


Figure 14: Rolling Stock Failures Leading to Freight Train Derailments

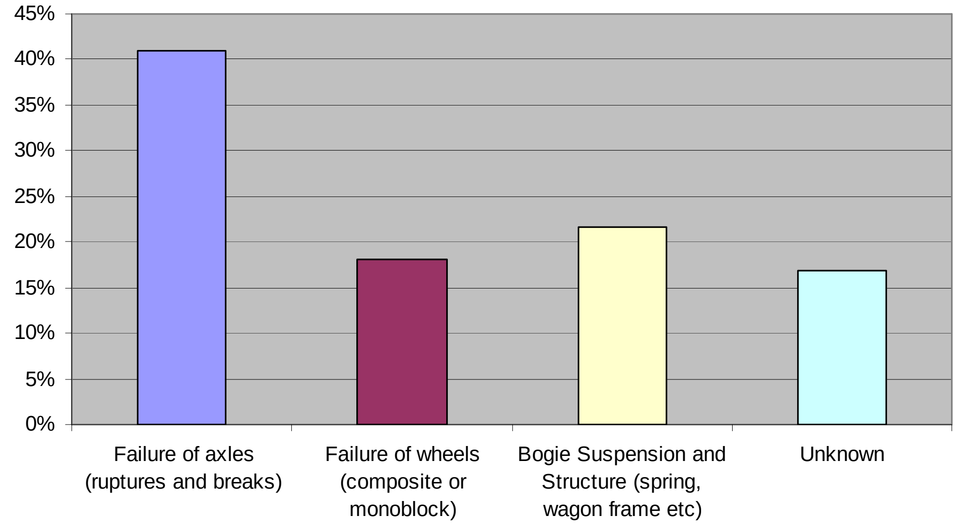
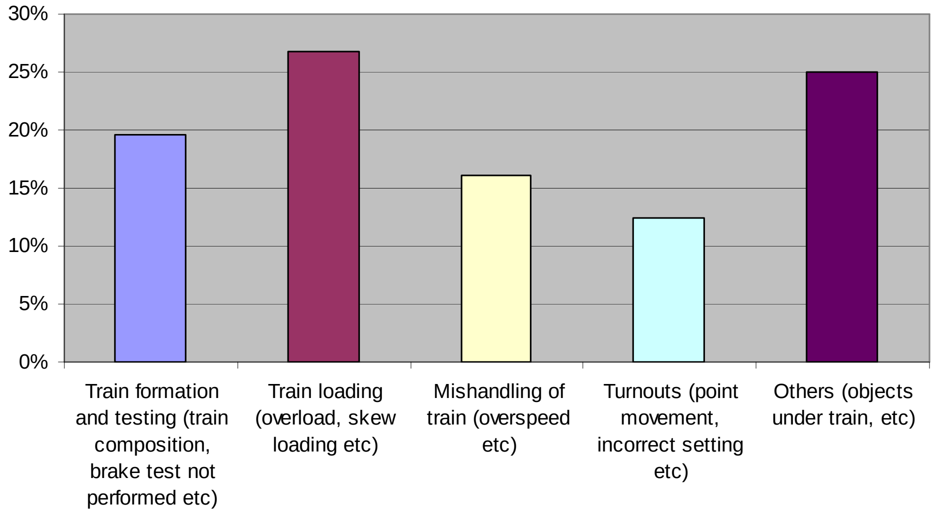


Figure 15: Operational Failures Leading to Freight Train Derailments



This analysis indicates that of the 36% of derailments caused by infrastructure failures, nearly 70% of those are caused by track geometry defects. (Therefore 36% x 68% = 25% of all freight train derailments across Europe are caused by, or have track geometry, as a significant contributory cause).

We are currently working on refining this analysis, which on completion will comprise the combined results and inputs from approximately 700 recent freight train derailments, and also provide a greater level of resolution.

8.3 Measures to Reduce Freight Train Derailment Risk and Consultation

In Section 4.0 we reported on a large consultation exercise, the objective of which was partly to establish what measures Infrastructure Managers (IMs) and Railway Undertakings (RUs) currently apply, or could be apply in the future, to manage freight train derailment risk. This consultation received responses from most major freight carrying countries. A second round of consultation was directed towards suppliers to the rail market, regarding the technical measures that were available, together with their performance and other parameters.

As part of this consultation and other complementary research we identified:

- 43 measures in place to reduce the likelihood of a freight train derailment.
- 8 measures that could be introduced in the future reduce the likelihood of a freight train derailment.
- 13 measures in place to reduce the consequence following a freight train derailment.

For each measure within the study scope we assessed (Section 7.0), or proposed a method for the assessment of, the performance of each measure

The measures identified and assessed map as following onto freight train derailment causes.

Table 21: Linkage of Derailment Cause and Preventive Measure

Derailment Cause	Safety Function	Measure	P/F#
Axle failure / seizure	Monitor axle bearing temperature	Hot axle box detectors	P-10
		Acoustic bearing monitoring	P-11
		Machine vision device	F-4
		Use of thermo-sensitive materials to detect axle temperature condition	F-3
	Prevent Axle Failure	Replace metal roller cages with alternative materials	P-28
		Use of stronger axles	P-29
		Derating of axle loads	P-37
		Inspect axles of freight train rolling stock according to EVIC	P-38
Track geometry defects / failures	Maintain track geometry within acceptable limits	Track geometry tests on all tracks	P-21
		Establish EU-wide limits for track twist	P-22
		Establish EU-wide limits for track gauge	P-23
		Establish intervention/immediate action limits for track cant	P-24
		Establish intervention/immediate action limits for track height	P-25
		Continuous supervision of track conditions via rolling stock mounted equipment	P-7
		Adequate maintenance resources for network	P-18
	Rolling stock to be more tolerant to geometry defects	Increase rolling stock tolerance to track twist defects	P-33
	Detection of potential superstructure	Ground penetration radar	P-6
Rail ruptures / failures	Detection of potential / existing rail ruptures	Continuous supervision of track conditions via rolling stock mounted equipment	P-7
		Track circuit to detect rail ruptures	P-8
		Ultrasonic inspection of rail to detect onset of rupture conditions	P-20
Flange climb	Prevent flange climbing	Check rail in sharp curves	P-1
		Track and flange lubrication (infrastructure)	P-2
		Bogie performance monitoring equipment	P-15
		Flange lubrication of locomotives	P-26
Collision with obstructions	Prevent collision with obstruction	Rock scree and avalanche protection structures	P-3
		Rock scree and avalanche detectors	P-4
		Level crossing obstacle detectors	P-5
		Clear track flange from obstructions	P-19
Points movement under train	Prevent points movement under train	Interlocking to prevent points movement whilst track occupied	P-9
Wheel structural or profile failure	Monitor wheel / brake temperature	Hot wheel / hot brake detectors	P-12
		Machine vision device	F-4
	Detect wheel defects	Wheel load / wheel load impact detector	P-13
		Wheel profile measurement systems	P-16
		Machine vision device	F-4
	Prevent wheel failure	Replace composite wheels with monoblock wheels	P-27
		Replace tread brakes for disc brakes (reduce heat activation)	P-32
		Wheel set integrity inspection programme	P-36
		Saw tooth braking to limit heat exposure on wheels	P-44
		Anti-lock device	F-6
		Use of trackside sliding wheel detector	F-7
		Install handbrake interlock to prevent train movement with handbrake applied	F-8
Overloading / skew loading / improper loading	Detect improper loading conditions	Wheel load / wheel load impact detector	P-13
		Machine vision device	F-4
	Prevent improper loading conditions	Use of registered and certified loading personnel	P-40
		Use of wagon balance to detect overload conditions	P-47
Loose equipment	Detect / prevent dragging loose equipment	Dragging object detector	P-14
		Install under-frame cages to retain brake components	P-34
		Regular greasing / check of buffers to prevent them falling off	P-35
		Machine vision device	F-4
Wagon/ rolling stock failures	Detect bogie hunting (steering)	Bogie performance monitoring equipment	P-15
	Better riding quality	Increased use of bogie wagons	P-31
	Prevent safety failures of rolling stock	Safety critical maintenance activities to be checked by two persons	P-39
Train composition failures / buffer locking	Reduce compression forces and buffer locking	Use of central couplers	P-30
		Locomotive and first wagon to be in brake position G	P-41
		Operational limit on brake application in certain track geometry	P-42
		End of train device	F-1
Train braking failure	Detect onset of train brake defects	Perform dynamic brake testing during operation to detect defects	P-43
Overspeeding	Prevent overspeeding	Initiate braking prior to passing signal to reduce overspeeding risk	P-45
Failure to take correct action when alarm raised	Alarm management	Implement / improve alarm management instructions	P-46

Finally, to supplement this analysis, the work reported in Section 7.0 regarding costs and other factors will enable a cost-benefit assessment to be completed in Part B.

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Appendix I Terms and Definitions

Term	Description
(the) Agency	European Railway Agency
CSI	Common Safety Indicator
CSM	Common Safety Method
CST	Common Safety Target
DDD	Derailment Detection Device
DNV	Det Norske Veritas
EVIC	European Visual Inspection Catalogue)
IM	Infrastructure Manager
JSSG	Joint Sector Support Group
Long Term	Measures that are unlikely to able to be introduced before 10 years
Medium Term	Measures that could be introduced within 5 to 10 years
NDT	Non Destructive Testing
NSA	National Safety Authority
RAM	Reliability, Availability and Maintainability
RID	Regulations Concerning the International Carriage of Dangerous Goods by Rail
RIV	Regolamento Internazionale Veicoli)
RU	Railway Undertaking
Short Term	Measures that could be introduced before 1st of January 2013
SMS	Safety Management System
Target countries	EU-27 countries plus the 3 candidate countries, Norway and Switzerland
TDG	Transport of Dangerous Good Regulations
TSI	Technical Specification for Interoperability
UIC	International Union of Railways

Appendix II Rolling Stock and Rolling Stock Operations - Questionnaire

Questionnaire Format

Thank you for participating in this study, the subject of which is summarised in the attached Invitation Letter from the European Railway Agency ("ERA").

Det Norske Veritas Ltd ("DNV") has developed a questionnaire to provide us essential study information. Our questions are set out to capture information on the controls applied by the freight operators / owners to protect against freight train derailments. A similar questionnaire has been prepared and issued to infrastructure owners. This questionnaire consists of the following parts:

1. Respondent details and background information.
2. A section addressing controls in place to prevent or mitigate freight train derailments.
3. A section seeking your experience / ideas on possible additional controls that could be implemented in the short term.
4. A section asking for your knowledge and thoughts on longer term freight train derailment that could be implemented information in the longer term.
5. A final section for you to add any additional information you feel may be useful to this study.

We would be obliged if you could return and complete this questionnaire before ***22nd October 2010***.

There is also an on-line version available. If you would prefer to respond on-line please contact Gavin Astin (gavin.astin@dnv.com) by e-mail.

Your Confidentiality

This information is being collected by DNV for the purposes of a study to assess the existing technical and operational measures against freight train derailments in the Community's railways. This study is being carried out on behalf of the ERA. The information may be shared with ERA but will not be disclosed to any other organization. DNV's analysis of the information provided by respondents may be published by ERA, but individual responses will not be published. Respondent's names will be kept confidential and will not be published or disclosed to any other organisation. Respondents have the right at a later date to change the answers they provide. The information will be stored and processed securely by DNV in compliance with the Data Protection Act laws of the United Kingdom and the European Union.

Part 1: Respondent Details / Background Information

Name: ………………………………………………………………………………

Company: ………………………………………………………………………………

Job Title: ………………………………………………………………………………

E-mail: ………………………………………………………………………………

Phone: ………………………………………………………………………………

Mobile: ………………………………………………………………………………

Please provide a ***brief*** description of the freight services operated by your company and your area of responsibility. Please can you indicate in your response the proportion of your freight traffic which is:

- National (starts and stops within your national boundaries).
- International (starts or stops outside your national boundaries).

Please tell us which units (train km or wagon km) have been used to calculate the percentage.

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

The information supplied will be treated in accordance with the confidentiality statement above. Please can you indicate any further restrictions that may apply.

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Part 2: Derailment Risk Controls Currently In Use

Question 2.1: Freight Train Derailment Prevention - Risk Controls Used Today

Do your present operations include any freight train ***derailment prevention*** measures which address the following derailment causes / precursor conditions (please answer this question only for controls that are applied to your rolling stock – do not include infrastructure devices such as trackside detectors):

- Hot axle boxes and axle journal failures.
- Wheel flats and wheel failures.
- Suspension failures.
- Bogie structural failures / under frame items falling off.
- Freight wagon loading errors.
- Brake failures (including setting and testing).
- Inappropriate train operation (over speed, excessive or inappropriate application of braking effort etc).
- Freight train composition (relative positioning of loaded and empty wagons etc).
- Any other causes.

If so, please can you describe these risk control measures below (please use extra space / attachments if required).

Technical measures (e.g. systems or devices; for example on-board condition monitoring etc):

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Operational measures (e.g. standards, work instructions; for example stricter controls regarding train composition or wagon / suspension type etc):

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Procedural measures (e.g. to reduce the possibility of human errors; for example independent checking of loading conditions etc):

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

For ***each measure*** you have specified above, please can you clarify if you have:

a. Implemented this as part of a response to a National, European or International regulatory requirement.
b. Implemented this as part of a company, local or other requirement.

Please state which requirement the control measure addresses:

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

If you have implemented any measures what is your experience of their effectiveness in terms of preventing derailments?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Do you know the approximate unit costs associated with the introduction of these measures (purchase / developments costs, implementation and upkeep costs, disposal costs etc)?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Question 2.2: Freight Train Derailment Mitigation - Risk Controls Used Today

Do your present operations include any freight train ***derailment mitigation*** measures (to reduce the consequences of a freight train derailment)? Such systems may include:

- Special protective features on tank wagons to reduce the risk of tank penetration in case of collision or derailment.
- The use of on-board derailment detection devices to automatically apply train brakes as soon as a derailment is detected.
- Any other measure reducing the impacts immediately after a derailment has been initiated.

If so please can you describe these risk control measures below (please use extra space / attachments if required).

Technical measures (e.g. systems or devices):

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Operational measures (e.g. standards, work instructions etc):

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Procedural measures (e.g. to reduce the possibility of human errors etc):

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

If you have implemented any measures what is your experience of their effectiveness in terms of reducing the consequences of a derailment?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

For ***each measure*** you have specified above, please can you clarify if you have:

a. Implemented this as part of a response to a National, European or International regulatory requirement.
b. Implemented this as part of a company, local or other requirement.

Please state which requirement the control measure addresses:

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Do you know the approximate unit costs associated with the introduction of these measures (purchase / developments costs, implementation and upkeep costs, disposal costs etc)?:

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Question 2.3: Freight Train Derailment - Maintenance

Please can you describe whether you own and maintain your own rolling stock and the responsibilities for maintenance?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Please can you describe the controls in place to ensure that maintenance is performed to an acceptable standard on your freight wagons and locomotives. Please consider in your response how appropriate maintenance standards are selected, how competency standards for maintenance personnel are developed and how compliance is demonstrated. (If your maintenance is sub-contracted, what controls do you apply to ensure acceptable maintenance standards in your supply chain.)

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Part 3: Your Experience / Improvement Actions

Question 3.1: Freight Train Derailment – Your Views?

Based on your own experience, can you please describe your viewpoint on freight train derailments? Are you satisfied with the present situation and what do you consider is the main problem that has to be improved with respect to track, rolling stock and operations?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

What additional risk control measures do you think could be quickly implemented (before 1st January 2013) to reduce either the frequency or consequences of freight train derailments?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

What are your views on the costs and benefits associated with the possible implementation of these additional measures?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Part 4: Technological and Longer Term Developments

Are you aware of any new technology (e.g. systems / devices) currently under development that may be available at some time in the future to reduce the frequency or minimise the consequences of freight train derailments? Examples may include telematic systems, on-board condition monitoring and supervision systems etc. Please provide details:

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

If you have answered yes above, what are your thoughts about this and are you planning to implement / test this new technology. Also, what are your views on the supply of electrical power to such systems?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Do you have any views on the types of changes that could be made to current instructions (TSIs, if applicable, and other international or national standards) that would improve freight train derailment performance? If so please can you describe these?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Part 5: Other Comments

Do you have any other comments and thoughts you believe are important when considering the subject of freight train derailment performance?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

There are no more questions. Thank you for you time.

Appendix III Infrastructure Design and Operation, Train Defect Detection and Condition Monitoring

Questionnaire Format

Thank you for participating in this study, the subject of which is summarised in the attached Invitation Letter from the European Railway Agency ("ERA").

Det Norske Veritas Ltd ("DNV") has developed a questionnaire to provide us essential study information. Our questions are set out to capture information on the controls applied by the infrastructure owner / manager to protect against freight train derailments. A similar questionnaire has been prepared and issued to freight operating companies and wagon owners. This questionnaire consists of the following parts:

1. Respondent details and background information.
2. A section requesting details of the respondent's network.
3. A section seeking your experience / ideas on the present situation regarding freight train derailments on your infrastructure and in general.
4. A section addressing risk control measures used today for the supervision of train and rolling stock in order to prevent freight train derailments.
5. A section addressing standards and actions regarding infrastructure design and maintenance that are in place to prevent freight train derailments.
6. A section asking for the infrastructure holder's ideas and thoughts on the future strategy for measures to improve freight train safety.
7. A final section for you to add any additional information you feel may be useful to this study.

We would be obliged if you could complete and return this questionnaire before ***22nd October 2010***.

There is also an on-line version available. If you would prefer to respond on-line please contact Gavin Astin (gavin.astin@dnv.com) by e-mail.

Your Confidentiality

This information is being collected by DNV for the purposes of a study to assess the existing technical and operational measures against freight train derailments in the Community's railways. This study is being carried out on behalf of the ERA. The information may be shared with ERA but will not be disclosed to any other organization. DNV's analysis of the information provided by respondents may be published by ERA, but individual responses will not be published. Respondent's names will be kept confidential and will not be published or disclosed to any other organisation. Respondents have the right at a later date to change the answers they provide. The information will be stored and processed securely by DNV in compliance with the Data Protection Act laws of the United Kingdom and the European Union.

Part 1: Respondent Details / Background Information

Name: ………………………………………………………………………………

Organisation: ………………………………………………………………………………

Job Title: ………………………………………………………………………………

E-mail: ………………………………………………………………………………

Phone: ………………………………………………………………………………

Mobile: ………………………………………………………………………..

Please provide a ***brief*** description of your responsibility in your organisation:

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

The information supplied will be treated in accordance with the confidentiality statement above. Please can you indicate any further restrictions that may apply.

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Part 2: Information about your network

Question 2.1: Size, Character and Classification of Network

What is the approximate size of your network in terms of:

- Line km.
- Track km.
- What percentage share of your network is classified as Trans-European Networks (TEN) and would have to satisfy TSI-regulations in case of new or upgraded line? (Please mark this not applicable if this does not apply to your operations.)

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Please can you tell us if your network is designed and open for mixed traffic or dedicated for passenger or freight traffic? Please specify approximate percentage share of network length for. Please tell us which units (train km or wagon km) have been used to calculate the percentage:

- Mixed freight and passenger traffic.
- Dedicated or predominantly for freight traffic only.
- Dedicated or predominantly for passenger traffic only.

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Approximately how many freight operating companies do you have on your network?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Question 2.2: Design and Maintenance Characteristics

For some design parameters there might be a conflict between optimised track and infrastructure for freight transport and optimised track and infrastructure for passenger transport. For those parts of your network open and utilised for mixed traffic to what extent are the design parameters of the network optimized for freight or passenger traffic with respect to design speed, cant etc. Please provide a description:

- Freight traffic.
- Passenger traffic.

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Part 3: Freight Train Derailment – Your Views?

Based on your own experience, can you please describe your viewpoint on freight train derailments? Are you satisfied with the present situation in your country and what do you consider is the main problem that has to be improved with respect to infrastructure, rolling stock and operations?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Can you make a judgement with respect to what percentages of derailments in your country are caused by the following factors:

- Infrastructure failures.
- Rolling stock failures.
- Operational failures.
- Others (please specify).

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

What additional risk controls do you think could be quickly implemented (before 1st January 2013) to reduce either the frequency or consequences of freight train derailments?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

What are your views on the costs and benefits associated with the possible implementation of these additional controls?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Part 4: Supervision of Freight Train Technical and Operational Conditions – Risk Controls Used Today

Question 4.1. Technical Condition and Supervision of Trains

Various forms of train supervision installations are available for trackside monitoring of safety critical conditions of the train and track/infrastructure. Do your present operations include any trackside train and track/infrastructure ***condition monitoring installations*** installed in order to prevent freight train derailments? We are interested in measures which among others address the following causes of freight train derailments / accidents:

- Hot axle boxes and axle journal failures.
- Overheating of braking installations.
- Wheel flats and wheel failures.
- Overweight/skew loading of rolling stock.
- Dragging objects/derailments.
- Loading gauge infringements.
- Avalanches, rock falls and earth-slide.
- Any other causes.

To what extent have you installed the above mentioned trackside monitoring installations in your network and how densely along the track they are installed on various types of lines? (Please specify for each type of detector you apply.)

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Can you describe how the information these condition monitoring devices provide is used by the infrastructure owner and or train operator / rolling stock owner?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

If you use these devices please can you clarify if you have done so in response to a national regulatory requirement, company standard etc:

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Do you have any experience with regard to the efficiency of the above train supervision and condition monitoring installations, and to what extent are safety critical conditions detected in sufficient time to avoid accidents?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Do you know the approximate unit costs associated with the introduction of these installations (purchase / developments costs, implementation and upkeep costs, traffic costs etc)?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Do you use any other ***technical*** measures (i.e. systems or devices) to prevent or militate against freight train derailments?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Question 4.2. Supervision of Train Operations and Speed

To what extent are the lines used by freight trains equipped with automatic train protection equipment to prevent over speeding and violation of stop signals along track and in the approach to stations and signals at stations? Please describe the type of installation used.

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

How large a part of your infrastructure that is open for freight traffic is equipped for control against over speeding?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

What is the functional basis or limitations of the system with respect to continuous or discrete point-wise updating of information along track?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Does the system provide complete and continuous speed supervision and activate brakes in case of significant over speeding, or does it give alarms only?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

In case of a discretely updated system how does it handle train acceleration against a control and information update point?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Part 5: Infrastructure Design and Maintenance to Avoid Freight Train Derailments

A review of freight train derailment accident reports has shown that a very significant part of the freight train derailments results from failures and sub-standard conditions of the infrastructure.

Typical failure conditions are:

Substructure failures:

- Embankment subsidence.
- Earth slides, avalanches.
- Substructure wash-out.
- Bridge failure.
- Tunnel failure.

Structural failure of track superstructure:

- Rail fractures.
- Joint fractures.
- Switch component failure.
- Water accumulation in superstructure ballast.

Track geometry failure:

- Excessive track twist.
- Excessive track width.
- Sun curves.
- Track height failures and track wave patterns.

Other causes.

Question 5.1: Infrastructure Design Parameters

What are the maximum load (axle load and metre load) as well as train speed allowed for freight trains operating on existing conventional railway lines in your network?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

For some design parameters there might be a conflict between an optimised track for freight transport and an optimised track for passenger transport. To what extent do you consider these conflicts of interests are balanced in the design and lay-out of old and new railway lines in your network?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Question 5.2: Infrastructure Condition Supervision and Maintenance Priorities

Please can you describe your preventative maintenance regime and explain how you inspect and maintain your infrastructure to ensure that it remains within design parameters with respect to safety performance? Please consider in your response how appropriate maintenance standards and maintenance frequencies are selected for your infrastructure.

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

To what extent are funds allocated to provide the necessary maintenance to ensure a safe infrastructure in order to avoid derailment and other accidents:

- By track access funds?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

- By general state funding?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Are the requirements of freight trains and freight only lines given equal priority to the passenger train requirements when allocating maintenance resources to infrastructure?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Please can you explain your philosophy in relation to the problem of conflicts of interest. [A typical conflict of interest can be: Speed standard of mainline verses track standard of sidetracks at locations used for freight train to be overtaken by freight trains. A number of freight train derailments occur in sidetracks at stations which have not been well maintained].

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Please can you describe how competency standards for maintenance personnel are developed and how compliance is demonstrated? (If you use external resources please can you describe the controls in place within your supply chain?)

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Part 6: Available Technology and Longer Term Developments

Are you aware of any new technology (e.g. systems / devices) currently under development that may be available at some time in the future to reduce the frequency or minimise the consequences of freight train derailments? Please provide details:

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

If you have answered yes above, what are your thoughts about this and are you planning to implement / test this new technology?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Do you have any views on the types of changes that could be made to current instructions (TSIs – if applicable - and other international or national standards) that would improve freight train derailment performance? If so please can you describe these?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

Part 7: Other Comments

Do you have any other comments and thoughts you believe are important when considering the subject of avoiding and/or reducing the consequences of freight train derailments?

Please enter your responses here. Use extra attachments or expand this text box if more space is required.

There are no more questions. Thank you for you time.

Appendix IV Supplier Questionnaire

Introduction and Common Questions

The purpose of the project

Det Norske Veritas is carrying out a study on behalf of the European Railway Agency to identify, describe, analyse and assess the most efficient options for existing or new safety measures (technical, operational or organisational) contributing to preventing or mitigating freight derailments in the Community's railways. A semi-quantitative assessment of the measures' efficiency (cost/benefit) shall be carried out and the impact of the measure on the fault/event tree shall be identified. The study was started in mid 2010 and will complete by June 2011.

The purpose of the questionnaire

The purpose of this questionnaire is to collect information on technical measures from the industry, primarily suppliers/manufacturers of such devices and systems. By technical measures we mean: "Technical devices to prevent or mitigate derailment or system monitoring the state of the railway system (rolling stock / infrastructure) to allow detection of derailment or early detection of hazardous conditions that may lead to derailment, and which upon detection takes appropriate action (recording, alarm, emergency brake)." This includes, but is not limited to, measures such as:

- Hot axle box/bearing detector (HABD)
- Acoustic bearing defect detectors
- Hot wheel and hot brake detectors
- Wheel load detectors & Wheel impact load detectors
- Derailment or dragging object detectors
- Truck lateral instability detection (truck hunting) / Truck performance detectors
- Wheel profile measurement system / Wheel profile monitoring unit
- Loading gauge infringement detectors (High car detector / Wide-load detector)

Confidentiality

The information provided will be used solely for the purposes of this study. The information may be shared with ERA but will not be disclosed to any other organization. DNV's analysis of the information provided by respondents may be published by ERA, but individual responses will not be published. Respondent's names will be kept confidential and will not be published or disclosed to any other organisation. Respondents have the right at a later date to change the answers they provide. The information will be stored and processed securely by DNV in compliance with the Data Protection Act laws of the United Kingdom and the European Union

Interviewee

No	Question	Response
1-1	Name of organisation/company	
1-2	Name of interviewee	
1-3	What is your role in the organisation?	
1-4	Contact details of interviewee	

Identification of organisation and products

No	Question	Response	Guidance/notes
2-1	What kind of products does your company produce which can contribute to reducing the probability or consequence of derailment?		Some examples are provided above (hot axle box detector etc). For ***each product*** we are asking that you complete a separate product specific form which has also been sent to you
2-2	Has your company marketed similar products in the past which are no longer produced or marketed?		Please identify specific product names/identifiers if possible
2-3	Do you manufacture all of these products yourself or are you a reseller for some of them?		

Please see separate questionnaire for product specific questions.

Future developments

No	Question	Response	Guidance/notes
6-1	What other types of technical measures are you currently developing?		
6-2	When will these be available in the market place?		
6-3	Are you aware of other future developments with respect to technical measures for preventing/mitigating derailment?		Ongoing research in companies/research institutions/universities?

Product Specific Questions

The purpose of the project

Det Norske Veritas is carrying out a study on behalf of the European Railway Agency to identify, describe, analyse and assess the most efficient options for existing or new safety measures (technical, operational or organisational) contributing to preventing or mitigating freight derailments in the Community's railways. A semi-quantitative assessment of the measures' efficiency (cost/benefit) shall be carried out and the impact of the measure on the fault/event tree shall be identified. The study was started in mid 2010 and will complete by June 2011.

The purpose of the questionnaire

The purpose of this questionnaire is to collect information on technical measures from the industry, primarily suppliers/manufacturers of such devices and systems. By technical measures we mean: "Technical devices to prevent or mitigate derailment or system monitoring the state of the railway system (rolling stock / infrastructure) to allow detection of derailment or early detection of hazardous conditions that may lead to derailment, and which upon detection takes appropriate action (recording, alarm, emergency brake)." This includes, but is not limited to, measures such as:

- Hot axle box/bearing detector (HABD)
- Acoustic bearing defect detectors
- Hot wheel and hot brake detectors
- Wheel load detectors & Wheel impact load detectors
- Derailment or dragging object detectors
- Truck lateral instability detection (truck hunting) / Truck performance detectors
- Wheel profile measurement system / Wheel profile monitoring unit
- Loading gauge infringement detectors (High car detector / Wide-load detector)

Confidentiality

The information provided will be used solely for the purposes of this study. The information may be shared with ERA but will not be disclosed to any other organization. DNV's analysis of the information provided by respondents may be published by ERA, but individual responses will not be published. Respondent's names will be kept confidential and will not be published or disclosed to any other organisation. Respondents have the right at a later date to change the answers they provide. The information will be stored and processed securely by DNV in compliance with the Data Protection Act laws of the United Kingdom and the European Union.

Product: <Please state the name/identification of the product here and fill in one of these questionnaires per product (preferably with one file per product, renaming the file to the product name)>

Market

No	Question	Response	Guidance/notes
3-1	What is the primary function of the product?		
3-2	How does the product work? Where is it installed? What technology is employed?		
3-3	Is the product employed primarily for passenger traffic, primarily for freight traffic or both?		
3-4	When was this product introduced to the market for the first time?		
3-5	Has the product since been updated? If yes, what are the major changes introduced and when were these introduced?		

No	Question	Response	Guidance/notes
3-6	Are you working on further developing this product? If yes, when is the new generation/version likely to be available in the market? What will the major improvements/changes be? If no, when is it likely to be withdrawn from the market?		
3-7	How **many items** of this product have you sold world wide/in the EU throughout its lifetime? What has the total volume of sales been **in monetary terms** (world wide/EU)?		Please provide specific information on what the numbers cover (years, countries). Number of items may also be specified in categories: • Below 50 • 50-500 • Above 500 Volume of sales may also be specified in categories: • Below 1.000.000 € • 1.000.000 – 10.000.000 € • Above 10.000.000 € Please state currency units.
3-8	Which countries constitute the most important markets for this product?		

No	Question	Response	Guidance/notes
3-9	What do you think is the potential market size for this product (world wide/EU) **in number of units** if the product were to be adopted on a more wide spread basis? What do you think is the potential market size for this product (world wide/EU) **in monetary terms** if the product were to be adopted on a more wide spread basis?		Number of items may also be specified in categories (NOTE THAT THESE ARE DIFFERENT FROM ABOVE): • Below 500 • 500-5000 • Above 5000 Volume of sales may also be specified in categories (NOTE THAT THESE ARE DIFFERENT FROM ABOVE): • Below 10.000.000 € • 10.000.000 - 100.000.000 € • Above 100.000.000 €
3-10	What do you think will be the most important market geographies in the future?		
3-11	What are the main competing products to this product?		Competing products may also include substitutes, i.e. products based on other technologies or with other functions, but serving the same purpose.
3-12	What is your market share (in %) for this type of product world wide / in EU?		
3-13	How do you assess your market position compared to the competition?		Market leader, one of a few major suppliers, one of many suppliers.

Costs and benefits

No	Question	Question/response guidance	Guidance/notes
4-1	What is the indicative price of a single product? What is the effort required to install a product (hours of work)?		Prices should be exclusive of VAT. If indicative price is not available, the following categories may be used instead: • Below 5.000 € • 5.000 - 10.000 € • 10.000 – 50.000 € • More than 50.000 €
4-2	Does the product require any regular maintenance activities? What is the effort associated with these activities (hours of work/year)? When it fails, is the whole unit replaced, or can a lower level repair be made? What is the effort on average associated with such repairs (hours of work/year)? Are there any specific disposal requirements with cost implications?		
4-3	What are the assumptions of the costs given above?		

No	Question	Question/response guidance	Guidance/notes
4-4	How should the product be deployed to maximise its benefits? Where should it be installed? How densely should it be installed?		
4-5	What operational aspects need to be considered in order to reap the benefits of the product?		

RAMS aspects

No	Question	Response
5-1	What is the estimated lifetime of the product?	
5-2	What is the estimated Mean Time Between Failure or other reliability measure of the product?	
5-3	What is the estimated Mean Time To Repair or other maintenance measure of the product?	
5-4	How will failures of the product be detected? Will all failures of the product be detected? If not, are these failure modes dangerous?	
5-5	What is the estimated rate of False Alarms of the product?	
5-6	Do you have a system for collecting reliability/availability statistics from actual installations? What is the in-service reliability performance of this equipment?	
5-7	What is the actual measured Mean Time Between Failure or other reliability measure of the product?	
5-8	What is the actual measured Mean Time To Repair or other maintenance measure of the product?	
5-9	What is the actual measured rate of false alarms?	
5-10	Has the product been approved by relevant safety authorities? Which safety authorities? What is the geographical scope of the approval?	

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a different approach for a new reality:

MANAGING RISK

Det Norske Veritas

Assessment of freight train derailment risk reduction measures:

A1 – Existing measures

Report for European Railway Agency
Report No: BA000777/02
Rev: 02

18 April 2011

MANAGING RISK

Assessment of derailment risk reduction measures:
A1 – Existing Measures
for

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Summary: This document provides a summary of existing measures in use to prevent or mitigate the consequences of freight train derailments

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0.0 Executive Summary

0.1 Study Scope and Objectives

Det Norske Veritas (DNV) is completing a study on behalf of the European Railway Agency (the Agency), the objective of which is twofold:

1. Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation within 5 to 10 years). For these measures, Part A work is also required to assess the market status for technical measures (defined as devices or systems) and establish objective performance data for the identified measures. The work in Part A also extends to identifying, as far as is possible, potential long term measures (not expected to be ready to implement within 10 years) as an input to other research projects currently underway.
2. Part B has the objective of analysing the measures identified in Part A with a view to establishing those that show the most promise from a risk reduction viewpoint. Part B addresses such measures which are available at the short and medium terms.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland. In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

This report concerns the Part A remit associated with ***identifying all prevention and mitigation measures that exist today.*** Other work in Part A deals with the other scope requirements, and is separately reported. It should be noted that this report is factual in nature and does not seek to make any assessment regarding performance or effectiveness of the identified measures - all measures reported here are to be taken forward for consideration on Part B.

0.2 Methodology and Study Results

The measures reported here have been identified from a number of sources:

1. Direct consultation with Infrastructure Managers (IMs), Railway Undertakings (RUs) and other stakeholders within the rail freight community.
2. Research of accident reports and other publications (Network Statements etc).
3. Literature surveys and internet research.

The work has identified:

- 47 measures that are in place to reduce the likelihood of a freight train derailment.
- 13 measures that are in place to mitigate the consequences of a freight train derailment.

Considering preventative measures, these are categorised as follows:

- Technical infrastructure (7 measures), for example the use of “check rails” at certain locations.
- Control, Command and Signalling (2 measures), for example interlocking of points operation whilst track is occupied.
- Trackside rolling stock supervision (8 measures), for example hot axle box detection systems.

- Infrastructure organisational / operational (8 measures), for example measures to ensure that the flange groove is free from obstructions.
- Rolling stock technical (10 measures), for example replacement of composite wheels for monoblock wheels.
- Rolling stock organisational / operational (4 measures), for example wheel set integrity inspection.
- Train loading / pre-departure checks (2 measures), for example the qualification and registering of people tasked with ensuring train loading conditions are in accordance with requirements.
- Train operations (6 measures), for example the development and implementation of rules for dealing with alarms (that may be raised from hot axle box detection systems, and other such devices).

Considering mitigation measures, these are categorised as follows:

- Rolling stock technical (4 measures), for example the use of devices to detect a derailed axle and then automatically apply train brakes.
- Infrastructure (5 measures), for example the use of dragging obstacle detectors.
- Operational (4 measures), for example the separation of passenger and freight traffic onto dedicated lines.

0.3 Conclusions and Next Steps

This work reported here has established what we believe to be a comprehensive list and description of existing measures that are in place to reduce the likelihood or consequence of a freight train derailment. However future work (Part B) will supplement, if required, the list of measures discussed in this document and add any new measures that are advised to the project team.

The next project step will take these existing measures forward into Part B and assess their effectiveness in terms of freight train derailment risk reduction, in accordance with the Part B study objectives.

Contents

1.0 Introduction

In order to have an effective rail network the occurrence of derailments must be minimised. Historically, this has been achieved through technological, operational and organisational improvements and the voluntary adoption of common practices and design standards. More recently the introduction of the Railway Safety Directive, Interoperability Directive and Technical Specifications for Interoperability has led to a more harmonised and open approach, especially with respect to cross border traffic. Other directives, such as the International Regulations for Transport of Dangerous Goods by Rail (RID), also have an important role to play in the minimisation of risk for certain types of rail transport.

During this time, national and more recently EU wide measures have been introduced to prevent and mitigate the consequence of freight train derailments.

The purpose of this document is to identify these existing measures and report them so that they can be further considered with regards to their effectiveness. A specification for this task, [1] is provided below:

A specification for this task, [1] is provided below:

> *Existing measures shall cover both prevention and mitigation measures of freight train derailments. Task A.1 will identify the existing measures (either regulatory at national and at EU level, or voluntary, for example at Company level) and, where applicable, the related specific device/system in use. The identification shall cover human, operational, organisational and 'technical' measures (i.e. based on the use of a device or a specific technical system). The identification should contain a reference to existing regulatory requirement (in RSD, TSIs, National Safety or Technical rules) in which each given measure contributes.*
>
> *For EU Member States, an exhaustive list of 'technical' measures shall be provided. For at least the USA and Japan, the most commonly applied technical measures will be listed as well as the most innovative ones.*
>
> *Existing safety measures means currently applied for implementing a given regulation requirement, or applied on a voluntary basis.*

The objective of this report is to identify a comprehensive listing and description of existing measures currently in place for the reduction of freight train derailment safety risk. This report does not however seek to make any assessment regarding performance or effectiveness.

The work reported here will be taken forward to a further project stage (Part B) that will seek to identify the most promising measures from those identified here. The future work (Part B) referred to will supplement, if required, the list of measures discussed in this document and add any new measures that are advised to the project team.

All identified measures will be considered in Part B.

2.0 Description of the Train Derailment Problem

2.1 Introduction

The railway transport system consists of:

- A fixed infrastructure comprising train formation yards, track, power catenaries, signalling and telematics system for communication.
- A number of transport units consisting of traction equipment and load carrying units (rolling stock) normally coupled into trains of a certain length.
- Operational personnel in an organizational structure that ensures qualified personnel as well as appropriate operational procedures and information management for handling the trains on the relevant infrastructure in a safe manner.

The essence of a safe railway operation is to manage and ensure the following:

1. Structural and functional integrity of the infrastructure and its subsystems.
2. Structural and functional integrity of the rolling stock.
3. Control of the infrastructure – train interface in terms of wheel – rail guidance.
4. Train operation and management necessary for a safe and effective operation.

The management of all four tasks is important and we will address each of them briefly below in relation to the derailment problem.

2.2 Definition of Derailment and Relation to Other Accidents

Annex I of the Railway Safety Directive /50/ gives a listing of the main accidents types to be applied in specification of indicators related to accidents. This categorization is also used by the ERADIS database and is as follows:

- Collisions of trains, including collisions with obstacles within the clearance gauge.
- Derailment of trains.
- Level-crossing accidents including accidents involving pedestrians at level-crossings.
- Accidents to persons caused by rolling stock in motion, with the exception of suicides.
- Fires in rolling stock.
- Others.

Derailment is specified as one of the primary accident groups, but a derailment may also occur as a consequence of other primary accidents specified above, for instance collision with obstacles and level-crossing accidents. For many of these accidents it is the derailment that causes severe consequences. In the search for preventive measures we have included preventive measures to reduce the frequency of accidents likely to cause a derailment when the derailment is considered to be the part of the accident producing the most severe consequence. This particularly applies to collisions with obstacles within the clearance gauge in terms of stones, earth slides ice accumulations etc.

Note that to distinguish between measures that are primarily in place to prevent collisions, but which have secondary benefits in also preventing subsequent derailments, we have classified all our measures with either “D” or “I”, see tables later in this document. D (direct) has the meaning that the measure is applied with the principal objective of reducing the risks associated with derailments, where I (indirect) signifies that reducing derailment risk is a secondary benefit.

Derailment is defined as an enduring loss of the contact with the running surface of the railhead of at least one wheel.

2.3 Structural and Functional Integrity of the Infrastructure

Important elements to minimize derailments are the integrity and functionality of the track and the provision of an unobstructed train gauge as well as the functionality and safety of the signaling system. This includes:

- Integrity of the substructure, e.g. integrity of bridges, tunnels avoidance of subsidence and foreign objects on track and in the free train profile. Safety critical failures can be collapse of tunnels and bridges, track subsidence, foreign objects on tracks and in the free profile of trains, rock screes and avalanches on track. (A number of these causes may initially lead to collision with obstruction, with derailment as a secondary consequence, as discussed above.)
- Integrity of the superstructure including track, rails, points (turnouts), sleepers, rail fastening equipment etc. Safety critical failures can be track buckles, rail ruptures, worn rails, broken sleepers, lost or damaged rail fastenings.
- Functionality and safety of the signaling system with regard to clear and correct train driving information with respect to movement allowances and operational speed along the line.

Each of the above groups is briefly described below:

2.3.1 Substructure Failures

The substructure consists of the structural earthworks for the railway, bridges and tunnels in order to provide a basis for the rail superstructure. It also includes the side terrain as far as is necessary to ensure the safety of the rail infrastructure. Substructure failures which can cause derailments are:

- Structural earthworks eroded and washed away due to flooding of rivers and streams crossing or running parallel to the railway.
- Subsidence of earthwork and superstructure ballast due to water accumulation and high water level in the earthwork due to insufficient or failed drainage.
- Foreign objects from side terrain in form of earth and rock screes and trees blocking the required free train profile, including vehicles from crossing or parallel roads. Structural collapse of bridges and tunnels. (A number of these causes may initially lead to collision with obstruction, with derailment as a secondary consequence, as discussed above.)
- Frost heave in cold countries.

Protection against external hazards as well as inspection and maintenance of track drainage and side terrain are important activities to minimize derailments.

2.3.2 Superstructure Failures

The superstructure consists of the top ballast layer, the sleepers, rail fastenings and the running rails. Points and rail crossings also belong to the superstructure. Superstructure failures that can cause derailments are among others:

- Ruptures and excessive wear of main rails, switch rails and joint bars.
- Broken or missing rail fastenings.
- Point geometry failures.

Derailments due to track geometry failures which often are an interface problem between track and rolling stock are discussed in Section 2.5.1.

2.3.3 Signaling and Train Control Equipment

Failure and insufficient functionality of the signaling and train control equipment can also be a cause of derailment with ambiguous signaling information or points being allowed to operate while a train is passing or located on top of the point.

2.4 Structural and Functional Integrity of the Rolling Stock

Important elements to minimize derailments are the integrity and functionality of the rolling stock. This includes:

- Integrity of the rolling stock running gear including wheelsets (wheels, axles and bearings), suspension and bogie structure. Typical safety critical failures are ruptures of axles and wheels, suspension failures in terms of broken or locked springs or sheared bearings.
- Integrity of the wagon or load carrying units, frame and load bearing capability. Typical safety critical failures are wagon frame twist, failure of load bearing elements, buffer failure.
- Integrity of train braking equipment. Typical safety critical failures in relation to derailment are brakes that are non operational or partly operational only, brakes that do not release and lead to overheating wheels, or if braking equipment falls off the wagon.

2.4.1 Wheelset and Bearing Failures

Critical components in relation to train derailment are wheelsets and bearings, and the following types of failures may occur:

- Sheared bearings or increased friction in bearings causing overheating of the axle box and rupture or shearing of the axle journal (i.e. the parts of the axle that are outside of the wheel). This type of failure can be discovered by trackside detectors (hot axle box detectors or acoustic bearing failure detectors). If a bearing is damaged a hot axle box can develop very quickly and the situation can only be detected by traffic staff or by trackside detectors.
- Rupture of axle shaft or axle journal due to fatigue. This type of failure is often initiated by a mechanical scratch or defect in the axle material or a corrosion attack due to a fault or mechanical damage to the corrosion protection layer of the axle. The crack initiation is slow and maybe difficult to detect unless it has a visible cause. Once the crack has grown to a size that can easily be detected by testing equipment, the further growth can be fairly rapid. Detection and correction of possible crack initiation points are therefore essential. Increased use of high strength materials can reduce the fatigue lifetime of the axle.

  This type of failure will normally not be detected by hot axle box detectors or any other type of detectors, at least not if the crack is located in the axle shaft (i.e. between the wheels).
- Wheel failure. The most common type of wheel failure is “out of roundness” failures such as wheel flats, wheel tread wear and shelling, oval wheels etc. By themselves they seldom cause derailments, but wheel tread failures and out of roundness lead to increasing load on the bearing and wheel flats may rupture rails, in particular under cold weather conditions.
- Wheels can be of two types: either monoblock wheels where the entire wheel is forged in one piece, or as a composite wheel with a separate rim and an outer tyre which is shrink fitted on the wheel.
  - For composite wheels the tyre can come loose and move sideways on the rim affecting the wheel width of the axle and cause derailment, or it can break and fall off or come

loose entirely with the same result. Wheel tyre heating due to strong braking action can cause the tire to move on the wheel rim. Composite wheels have therefore been removed from operation in some countries with mountainous lines where prolonged braking action is required. Rim and tyre wheels should normally be marked so that any relative movement between the wheel and rim can easily be discovered.

- For monoblock wheels a rupture of the entire wheel may occur either due to a material failure or a mechanical defect initiating a crack. Heating of the wheel tread by strong braking action by tread brakes can contribute to wheel rupture.

2.4.2 Wagon Frame and Wheel Suspension Failures

The twisting flexibility of a wagon frame and the suspension is important in order to avoid unloading of a wheel in a twisted track in transition curves. There are requirements relating to the flexibility of railway wagons and suspension to ensure that the wheels are not unloaded under normal track conditions. Further the suspension dampens forces to the track from wagon movements.

Failures that can cause derailments are ruptured suspension springs or wagon frame twist. In particular wagon frame twist can be difficult to discover during visual inspection.

2.4.3 Brake Failures

Failures of train brakes and inappropriate braking actions can cause derailments of freight trains. The most obvious is if the train can not be braked to adhere to signals or speed reduction signs along the line, and if the train is in a steep descent a runaway train may be the result. In order to avoid such situations there are requirements for brake testing prior to departure in all railway operations.

Failures of brake action of a single wagon are not considered critical and hence it is not uncommon that brakes of a single wagon are closed off if there are failures with the brake equipment e.g. brake blocks missing or brake blocks not meeting minimum thickness (and they cannot be replaced prior to departure). Further, if the brakes of a wagon do not release properly it is a cause for closing the brakes of the wagon as braked wheels cause wheelflats that can damage the rails.

The braking force of the individual wagons is adjusted according to the loaded condition of the wagon, either by automatic weighing valves or by a manual handle. The speed of brake application and the braking profile according to train speed can also be adjusted by manual handles on the side of the wagon with 3 possible positions G, P & R. Normally the brakes of wagons in freight trains are operated in position P apart from the locomotive and first wagons in long trains that have to be operated in brake position G.

Application of the brakes of a freight train is controlled by manipulating the drivers brake valve in the front of the trains and reducing the pressure in the brake pressure line. The speed of brake signal transmission is governed by the speed of sound in the pressure main and the minimum transmission speed according to UIC 540 is 250 m/s. Freight train length of approximately 800 metres are allowed in some countries e.g. Denmark. Hence, the brake application in the front may occur more than 3 seconds prior to the brake application in the rear of the train. This will cause strong compression forces in the train that can cause derailment in sharp curves or if brakes are applied in deviated train routes across stations. The requirement of putting the brakes of the locomotive and the forward wagons in brake position G is to limit the compression forces as G is a slow brake action position.

2.5 Control of the Interface between Train and Infrastructure

Track geometry failures are a frequent group of infrastructure caused derailments.

A rail vehicle consists of a body supported by secondary suspension on bogies in which the wheelsets are mounted and dampened by means of primary suspension. Track guidance of the wheel is achieved in principle by the following two provisions:

- The wheel surface contacting the rail is conical which means that in straight track a centering force is exerted on the wheelset if there is a slight lateral displacement. The centering effect promotes a better radial adjustment of the wheelset tyres of the wheel. This leads to more rolling, less slipping and hence less wear.
- The running surface of the rail wheel has flanges on the inside of the track to prevent derailment. In case of more considerable lateral displacement both in curves and on switches, the lateral clearance between wheelset and track is not sufficient to restrict lateral displacement adequately by means of the restoring mechanism previously discussed. Should the wheel flange touch the rail head face high lateral forces and wheel and rail wear will occur.

2.5.1 Derailment due to Track Twist

A derailment due to track twist occurs when there is a high horizontal guiding force between wheel and rail and a reduced vertical load that is insufficient to prevent the wheel flange from climbing the rail. A horizontal guiding force always occurs in curves and a reduced vertical load can occur due to track twist or insufficient torsional flexibility of the wagon frame and suspension (springs).

Track twist occurs as a designed and constructed feature of the railway track in transition curves leading into and out of a circular canted curve or due to uncorrected faults in the trackbed. Factors that contribute to unloading of wheels in twisted tracks are:

- Increased horizontal guiding force due to tight curve.
- Low wheel loads due to empty or partly loaded vehicles.
- Torsionally stiff vehicles in particular if they have a long wheel basis.
- Skew loaded vehicles, and:
    - Low train speed.
    - Unfavorable friction conditions associated with dry rails.
    - Another unfavorable factor can be compression forces in the train due to uneven braking along the train with too strong braking in the front of the train.

Derailment due to track twist is therefore a complex phenomenon not always easy to control under all operational conditions, but generally it is most likely to occur at low speed. Speed reduction may therefore not be an appropriate risk reducing measure for excessive track twist failures.

2.5.2 Derailment due to Height Failure (cyclic tops)

Height failures in the track can cause derailments, in particular if there are regular undulations in the track causing unfavourable excitations of the wagon suspension at the travelling speed of the train. Such failures are normally not discovered by local static measurements. A derailment due to height failure (cyclic top) can also be caused by single dip followed by a top. Such conditions may develop in track passing one or more points if the substructure is weak.

Derailments due to height failures or cyclic tops normally occur at high speed. Speed reduction is a relevant risk reducing measure.

2.5.3 Derailment due to Excessive Track Width

If the dynamic track width becomes excessive one of the wheels can fall below the rails. This occurs most often where the track superstructure and rail fastening is weak, either with lost fastenings or old wooden sleepers not giving good support for the fastening. This is most likely to occur on track that has not been given sufficient priority in maintenance, either on sidelines or in sidetrack at the stations. Speed reduction may decrease the derailment risk.

2.5.4 Derailment due to Track Buckles

Heating of the track may cause sudden track buckles (sun curves). They occur abruptly, often while train is passing, and can cause very serious derailments. They occur most often in curves and close to a fixed point in the track. It is controlled by addressing the track temperature or track stresses during construction and the position of the track. Rail creep due to braking and/or traction can contribute to developing heat buckles.

2.6 Train and Infrastructure Operation

Operational actions and omissions by transporters, train operating staff, rolling stock operators as well as infrastructure traffic controllers can influence the risk of derailment in many ways as indicated below:

- By inappropriate loading of wagons, i.e. skew loading or insufficient fastening of transported loads.
- By inappropriate train composition with uneven train load and train brake distribution.
- By insufficient train inspection and brake testing.
- Switching of the point whilst the point is occupied by a train.
- By mishandling of the train en-route by train driver.

Derailments classified as operational failures include a very wide variety of causes involving different actors. Inappropriate loading is one of the more significant of these causes and is discussed in more detail below.

2.6.1 Loading Failure

Restrictions apply in every country with regard to maximum allowed load of a wagon as well as lateral and longitudinal load distribution.

Among the applicable restrictions are:

- Maximum axle load, both in relation to rolling stock and infrastructure limitations.
- Longitudinal and lateral load distribution in the wagon.
- Requirements for securing of loads against movement along the route.

An increased use of containers and swap bodies however makes it difficult to control the load distribution. An increased use of large front wheel loaders for loading of hopper wagons also represents a new challenge with regard to controlling against skew loading, as loading of hopper wagons by front wheel loaders can cause significant skew loading. Due to a high centre of gravity this can be particular critical under certain track conditions. An example of a skew loaded hopper car is shown in Figure 1.

Figure 1: Skew loaded hopper car

2.7 Coarse Derailment Cause Distribution

To put the freight train problem into context, DNV has completed a review 103 accidents occurring across the EU-27 and candidate countries, plus Norway and Switzerland. Whilst this is not comprehensive enough to provide a thorough analysis of the problem, it does give some useful insights which we report below. In this context, derailment analysis is used to identify the main causes and indirectly existing measures. Identification of measures was complemented by surveys of stakeholders. The (103) derailments analysed is not used for statistical purpose, for that objective it will be completed with other samples and conservative assumptions during Part B work.

We have noted that the accident investigation reports are generally focussed on finding the direct derailment causes and do not often go behind the direct cause to find the deeper roots of the accident. For example, if a derailment is caused by excessive track twist the investigation rarely investigates the question of why the track twist was too high, or why a known track twist had not been corrected within specified time limits. Bearing in mind this limitation, the following is a coarse indication of accident causal distribution.

Infrastructure causes (including combinational causes where infrastructure is a contributing cause) accounting for 35% - 45% of derailments within the 103 accidents studied:

- By far the most significant cause in this category is track geometry failure. It is interesting to note that in many of the cases where faulty track geometry has been a derailment cause the track geometry has been significantly outside allowable limits, and this condition has been known by the infrastructure owner.
- Superstructure failures are the next most common cause, although at a significantly lower incidence level.

Rolling stock failures (including combinational causes where rolling stock is a contributing cause) account for approximately 35 % of derailments within the 103 accidents studied:

- The most significant cause of accidents in this category is axle failures, resulting from hot axle boxes. It is interesting to note when considering derailments caused by this cause that Hot Axle Box Detectors (HABD) are by no means an absolute mitigation. From our accident analysis we have identified a number of derailments where the freight train passed a HABD shortly before a derailment occurred. These events occurred in Sweden, Germany and Austria where HABD are relatively densely populated. Wheel failures and bogie suspension and structure failures are the next most common cause.

Operational causes (including combinational causes where operational is a contributing cause) accounting for about 25% of derailments within the 103 accidents studied:

- The most significant cause of accidents in this category are those caused by poor train loading.
- 40 – 50 % of operational causes are related to improper loading in terms of skew loading or insufficient load fastening.

Finally we note that derailment is very often a result of a combination of several causes. Typical examples are

- Track twist, narrow curve with high cant and low train speed or train braking.
- Track twist and twisted or skew loaded wagons.
- Track geometry fault and strong compression forces in train due to poorly managed train composition or less than optimal train handling by the driver.

Finally, we note from further consultation, reported in Section 4.2 that this analysis (and indeed any analysis based on the process of averaging causes across many countries) smoothes out national differences. For example, one respondent to our consultation indicated 65% of freight train derailments are caused by rolling stock failures, whilst a separate response indicated only 30% of freight train derailments were attributed to rolling stock failures. Such differences will be considered and addressed further in the following study stages.

3.0 Framework for Existing Measures

3.1 Background

The various countries having an operational rail network all have a set of rules, regulations and operational procedures for design, construction and maintenance of the infrastructure and rolling stock, as well as for traffic operation[1]. The totality of each set of national regulations is quite extensive; as an example the Swiss traffic operation regulations (Fahrdienstvorschriften) issued by Bundesamt für Verkehr and applicable to all Swiss railways comprises around 630 pages.

Despite their being physical, technical, operational and regulatory differences between countries, cross border rail freight has been possible for more than 150 years and the railway has been an important medium for international freight transport in Europe during this period. This has been achieved through standardization of the basic design of freight wagons through the works of UIC (Union Internationale des Chemins de Fer), International Union of Railways and the RIV (Regolamento Internazionale Veicoli), International Wagon Union, to suit interoperation with wagons from different countries on most normal gauge tracks.

Notwithstanding these standardization initiatives, it has been the case that traction units (for example) often have to be changed at borders due to differences in traction power and/or different train control systems. Traditionally, there has also been a requirement that wagons in international traffic have to be inspected and checked for conformance with national operational standards at the borders. Increasingly, international trains are now operated in trust, “Vertrauensfahrt” in German (although EU legislation requires that the railway undertaking must ensure that the train is safe when operating it). This reduces the ability of the individual countries to enforce specific national requirements, in particular with regard to train operation.

3.2 Towards a more Standardized Approach

More recently there has been a move towards a more competitive standardized and open approach to international rail traffic (freight and passenger). This has been achieved in the form of various Directives and Technical Specifications which we briefly summarize below.

3.2.1 The European Railway Safety Directive

The European Railway Safety Directive (2004/49/EC) supports the development of open and transparent access to the European rail market. The Directive, which was introduced in 2004, establishes a common regulatory framework designed to ensure that safety does not present a barrier to the establishment of a single market for railways. At the end of 2008 the Railway Safety Directive was amended, and the revised Railway Safety Directive (2008/110/EC) must have been transposed into national law by 24 December 2010. The key requirements of the Directive are under implementation in Member States guided by the National Safety Authorities for the railways.

The key measures introduced by the Railway Safety Directive 2004 are listed below:

- The requirement for each Member States to notify the European Commission of all of their relevant National Safety Rules.
- The establishment of Common Safety Indicators (CSIs) which are high level indicators of significant risks to the mainline rail network (e.g. signals passed at danger and broken rails).

[1] Rules, standards and instructions as discussed in this section provide some degree of control against derailments, but cannot cover all eventualities, failures and sub-standard conditions that may lead to derailment.

- The establishment of Common Safety Methods (CSMs) which are harmonized approaches to risk management, the exchange of safety relevant information and the evidence resulting from the application of a risk management process.
- The establishment of Common Safety Targets (CSTs) which define the minimum safety levels and safety performance that must at least be reached by the system as a whole in each Member State, expressed in risk acceptance criteria for individual risks to passengers, employees, level crossing users, 'others' and unauthorized persons on the railway.
- The requirement for Safety Authorizations and Certificates which requires the Member States' National Safety Authority to grant safety authorizations to Infrastructure Managers and safety certificates to Railway Undertakings (e.g. train operating companies). The purpose of safety authorizations/certificates is to provide evidence that railway operators have established suitable Safety Management Systems (SMS) and are operating in accordance with them.
- The Investigation of Accidents.

3.3 Interoperability Directives

The European Commission has prepared a range of regulations to improve the interoperability of the European railways, not only with regard to hauling of freight and passenger cars, but regarding the overall operation of the railways.

In order to achieve this, a number of Interoperability Directives for the railway system have been developed and enforced by the European Community.

- The first Interoperability of the Trans-European High-speed Rail System (and subsequent amendments), 96/48/EC of 23 July 1996 covered the development of the high speed rail system, mainly for passenger transport. The first directive of 23 July 1996 was later amended as specified below:
- The Interoperability Directive (2008/57/EC) for the Community Rail System sets out a number of essential requirements to be met for interoperability, which include safety, reliability and availability, health, environmental protection and technical compatibility along with others specific to certain sub-systems. The Directive also requires the production of mandatory Technical Specifications for Interoperability (TSIs) which define the specifications required to satisfy those essential requirements.

3.4 Technical Specifications for a Harmonised European Rail System

The TSIs are specifications drafted by specialist groups to ensure the interoperability of the trans-European rail system. The TSI outlines the essential requirements' and basis for design of an interoperable railway system in Europe. Table 1 below specifies the TSIs applicable for conventional rail infrastructure and freight trains that can have influence the risk of derailments.

Table 1: Overview of TSIs with Relevance to Derailment

Reference:	Document Title	Status:
ERA IU-INF-090902-TSI 4.0	Trans-European Conventional Rail System – Subsystem Infrastructure	Final Draft TSI; dated 18/09/2009. /2/
EUR-Lex – Official Journal – Vol 49 – 2006 - L 344. Vol 52 – 2009 – L 45	Technical specification of interoperability relating to the subsystem rolling stock — freight wagons of the trans-European conventional rail system	Commission decision of 28th July 2006; amended by commission decision of 23rd January 2009

Reference:	Document Title	Status:
08/57-ST05 10.06.2010	Draft Commission Decision concerning Technical Specification for Interoperability relating to the rolling stock sub-system – "Locomotives and Passenger rolling stock" of the trans-European conventional rail system	Final draft issued for approval of European Commission
ERA IU-RST-19112009-TSI Report	Trans-European conventional Rail System – Locomotives and Passenger Rolling Stock[1]	Comment report to Final Draft TSI; dated 19/11/2009
EUR-Lex – Official Journal – Vol 49 – 2006 L 359. Eur-Lex – Official Journal – Vol 53 - 2010 L-280, page 29 – 58.	Technical specification of interoperability relating to the subsystem Traffic Operation and Management of the trans-European conventional rail system.	Commission Decision 2010/640/EU amending Decisions 2006/920/EC and 2008/231/EC (26 Octobre 2010) Annex P5: Decision 2009/107/EC of amendment Decision 2006/861/EC and 2006/920/EC (23 January 2009) Decision 2006/920/EC (11 August 2006)
EUR-Lex – Official Journal – 2006 – L 284	Technical specification for interoperability relating to the control-command and signalling subsystem of the trans-European conventional rail system	Decision 2009/561/EC - Amendment of Decision 2006/679/EC; Decision 2008/386/EC - Command Subsystem ERTMS modifying Annex A to 2006/679/EC and Annex A to 2006/860; Decision 2006/860/EC - Control and command subsystem ERTMS modifying Annex A to 2006/679/EC; Decision 2006/679/EC
EUR-Lex – Official Journal – Vol 51 – 2008 – L 64	Technical specification of interoperability relating to safety in railway tunnels in the trans-European conventional and high-speed rail system.	Decision 2008/163/EC
EUR-Lex – Official Journal – Vol 49 – 2006 – L 13	Technical specification for interoperability relating to the telematic applications for freight subsystem of the trans-European conventional rail system	Regulation 62/2006/EC

The TSIs are not fully implemented and there is a long transition period for many of the items. Often the TSIs leave it to the infrastructure manager and railway undertakings to develop the detailed operational procedures, maintenance regimes and intervention limits for safety critical parameters. Due to the above there is still some way to go to have a harmonized European railway.

3.5 European Standards

The documents listed in Table 2 include a list of standards and other documents relevant to the design and conformity assessment of subsystems and interoperability constituents. For each TSI, two groups of documents are listed:

- The standards or other documents (or parts thereof) which are specifically referred to in the TSIs and which are therefore mandatory
- The standards or other documents (or parts thereof) that are not refereed to in TSIs are not mandatory.

Table 2: Standards lists for TSIs

Standard lists of relevance to HS TSIs	
Publication date	Title
08-12-2008	Standards in HS Control command signaling TSI (2006/860/EC)
08-12-2008	Standards in HS Energy subsystem TSI (2008/284/EC)
08-12-2008	Standards in HS Infrastructure subsystem TSI (2008/217/EC)
08-12-2008	Standards in HS Operation TSI (2008/231/EC)
08-12-2008	Standards in HS Rolling stock subsystem TSI (2006/232/EC)
Standards lists of relevant to CR TSIs	
Publication date	Title
08-12-2008	Standards in CR Control command and signaling TSI (2006/679/EC)
08-12-2008	Standards in TSI for noise in aspects of conventional rolling stock (2006/66/EC)
08-12-2008	Standards in CR Operation TSI (2006/920/EC)
08-12-2008	Standards in CR Rolling stock – Freight wagons TSI (2006/861/EC)
Standards lists of relevance to transversal TSIs	
Publication date	Title
08-12-2008	Standards in TSI relating to persons with reduced mobility in the trans-European conventional and high speed rail systems (2008/164/EC)
08-12-2008	Standards in TSI trelating to safety in railway tunnels in the trans-European conventional and high-speed rail systems (2008/163/EC)

3.6 National Rules and Regulations and Voluntary Rules

3.6.1 National Rules and Regulations

As discussed in the opening of this Section, national rules have always existed and will still exist – at least for the foreseeable future - despite the introduction of a more harmonized framework for international rail traffic.

These notified national rules are used in addition to the TSIs and describe nationally binding conditions that must be met. However, these national rules must ensure that the railway system is interoperable and must ensure that current safety levels are not eroded.

According to Article 8(1) of the Railway Safety Directive (2004/49/EC), Member States shall establish binding national safety rules. Article 8(2) required the Member States to notify these safety rules to the Commission before April 30 2005. After this date, Article 8(4) requires the notification of any amendment (including repeal) to these notified rules and also of any new national safety rules.

Annex II of Directive 2004/49/EC, as amended by Directive 2008/110/EC, describes the national safety rules that shall be notified. These are:

1. Rules concerning existing national safety targets and safety methods;
2. Rules concerning requirements on safety management systems and safety certification of railway undertakings;

3. Common operating rules of the railway network that are not yet covered by TSIs, including rules relating to the signalling and traffic management system;
4. Rules laying down requirements on additional internal operating rules (company rules) that must be established by infrastructure managers and railway undertakings;
5. Rules concerning requirements on staff executing safety critical tasks, including selection criteria, medical fitness and vocational training and certification as far as they are not yet covered by a TSI;
6. Rules concerning the investigation of accidents and incidents.

It should be noted that rules, which wholly concern requirements set out in TSIs in force, do not need to be notified.

The Agency has published the "Guideline for Member States on the Notification of National Safety Rules"; this document is available on the Agency's WEB.

ERA is responsible for registering the national safety rules included in the notifications that have been validated. ERA manages a database of notified national rules and update the status of the registered rules when amendments to these rules are registered.

The principal content of the national safety rules is provided in the official national languages and sometimes in English to facilitate the use of this information. However, there is no legal obligation to provide an official English translation. Please, therefore, note that in all cases the information in the respective national language takes precedence.

3.6.2 Company and Voluntary Rules

Company / voluntary rules are those controls that are put in place by an organization, usually in addition to national rules. Their purpose is normally to improve business or safety performance, or to otherwise secure some benefit from their adoption.

3.7 Regulations for Transport of Hazardous Materials

3.7.1 RID Regulations

RID refers to the international regulations for transport of dangerous goods by rail (Règlement concernant le transport international ferroviaire des merchandises dangereuses) /15/. The RID regulation specifies under what conditions various materials are allowed for international transport by rail. The conditions comprise:

- Classification of goods.
- Packaging requirements.
- Tank usage including filling of tanks.
- Information and marking requirements.
- Requirements regarding testing and approval of packaging materials and tanks.
- Use of transportation modes (including loading, co-transportation and unloading).

The RID regulations are not concerned with railway technology and railway operation apart from tank design, and information and marking requirements.

3.7.2 National and Company Regulations

In addition there can be stricter regulations and requirements to transport of Dangerous Goods on national and company level for instance with regard to shunting restrictions to wagons with dangerous goods including tank wagons with hazardous materials.

Chemical companies or train operators might have stricter regulations with regard to various form of shield protection of tank wagons. Infrastructure managers and train operators might have restrictions on shunting operations Railway. In Scandinavia and Central Europe therefore very dangerous goods are therefore excluded from shunting humps, for instance chlorine. This is admitted in some Baltic countries.

4.0 Methodology for Identification of Existing Measures

4.1 Introduction

- Our study has used several methods to identify those measures that are used today to prevent of mitigate the consequences of freight train derailments: Direct consultation with infrastructure managers and railway undertakings.
- Research of accident reports and other publications.
- Literature surveys and internet research.

4.2 Consultation

DNV has identified organisations representing freight operators, wagon owners, infrastructure managers and trade associations, inviting them to participate through responding to questionnaires. We summarise the question categories below.

Table 3 Question Categories

Freight Operators and Wagon Owners	Infrastructure Managers
• What is currently done to prevent or mitigate freight train derailments: – What measures are currently applied and why do you apply them? – Are the measures you apply effective?	• What is currently done to prevent or mitigate freight train derailments: – What devices are used to supervise trains (hot axle box detectors etc) and what is their density? Are these installed to meet a requirement (international, national or company)? – How is the information provided by these devices used? – Are the condition monitoring measures you apply effective? – Do you use some form of speed supervision on your freight lines? – What type of speed supervision is used?
• Maintenance: – Who performs maintenance on your wagons and locomotives? – What controls and competency standards are in place to ensure that maintenance is performed correctly?	• Design and Maintenance: – For mixed traffic, are the track parameters optimised for passenger or freight? – What is the maximum axle load/speed? – What is your preventative maintenance philosophy? – How is maintenance funded and are freight lines given equal priority? – How are conflicts of interest dealt with? – What controls and competency standards are in place to ensure that maintenance is performed correctly?
• Current performance / short term measures: – What is your experience and what are your views on your own performance with regard to freight train derailments? – Where do you consider improvements are most needed? – Are you aware of any new measures that could be applied in the short term to improve the situation and what are your views on the costs that might be associated with these measures? – Are there any changes that could be made to instructions such as TSIs that you consider would be beneficial?	• Current performance / short term measures: – What is your experience and what are your views on your own performance with regard to freight train derailments? – What is the approximate division between derailment causes by rolling stock, infrastructure and operational failures? – Are you aware of any new measures that could be applied in the short term to improve the situation and what are your views on the costs that might be associated with these measures? – Are there any changes that could be made to instructions such as TSIs that you consider would be beneficial?
• Future advances: – Are you aware of/have plans to test new technology that could form the basis of a longer term solution to the problem of freight train derailments – What are your views of the provision of electrical power to wagons/	• Future advances: – Are you aware of/have plans to test new technology that could form the basis of a longer term solution to the problem of freight train derailments

Freight Operators and Wagon Owners	Infrastructure Managers
• Other comments	• Other comments
	• What is the size and nature of your network: – Proportion TEN classified? – Proportion mixed traffic/freight only/passenger only?

The consultation exercise has been conducted on a confidential basis, and we are not able to identify the specific individuals or organisations responding to the questions, however at the time of reporting we can provide the following details relating to respondents.

Table 4 Consultation Respondents

Country	Freight Op / Wagon Owner	Infra Manager	Country	Freight Op / Wagon Owner	Infra Manager
Austria	Yes	Yes	Luxembourg	Yes	
Belgium		Yes	Macedonia		
Bulgaria	Yes		Netherlands		Yes
CER	Yes	Yes	Norway	Yes	Yes
Croatia		Yes	Poland		Yes
Czech Republic			Portugal		Yes
Denmark	Yes	Yes	Romania		
Estonia			Slovakia	Yes	Yes
Finland	Yes	Yes	Slovenia	Yes	
France		Yes	Spain	Yes	
Germany	Yes		Sweden	Yes	
Greece			Switzerland	Yes	Yes
Hungary		Yes	Turkey		
Ireland			UIP	Yes	
Italy			UNIFE	Yes	Yes
Japan			Great Britain	Yes	Yes
Latvia	Yes	Yes	United States	Yes	Yes
Lithuania	Yes	Yes			

It is to be noted that in some cases the responses from trade associations provide the views of a number of their members, some of whom have chosen not to respond individually. The combined coverage (based only on individual country responses, not trade associations) covers approximately 80% of the total freight traffic volume in EU27/EEA countries.

4.3 Accident Analysis and Other Sources

In addition to measures that are established through direct consultation we have, as previously discussed, sought to review a number of accident reports, network statements, industry journals and other information sources. Our accident analysis for example has covered Germany, Sweden, Italy, Romania, Czech Republic, Estonia as well as other countries. We have also reviewed some national technical rules.

Finally, having established what we believe to be a comprehensive set of existing measure, we are currently in the process of sharing our findings with National Safety Authorities asking them to confirm the degree to which each measure is embedded in that country.

5.0 Identified Existing measures

5.1 What is an Existing Measure?

The definition in Section 1.0 states that: *Existing safety measures means currently applied for implementing a given regulation requirement, or applied on a voluntary basis*

In some cases this definition is problematic. For example several technologies exist in the USA and Canada that are not, to the best of our knowledge, applied within Europe (mainly those that require electrical power to freight wagons). In the context of this study we consider such measures "new" in Europe. For measures which are so classified, we apply the following additional requirements for this work, [1], which state:

- *Short term means that the safety measure is ready to be applied or to be introduced in EU regulation by 1st January 2013.*
- *Medium term means that the safety measure will be ready to be applied or to be introduced in EU regulation within 5 to 10 years.*
- *Long term means that the safety measure will be ready to be applied or to be introduced into EU regulation after complementary development and tests, not achievable before ten years*

Therefore measures which exist outside of Europe are classified as either short, medium or ling term. Such measures are not addressed in this report, but are considered in our A2 and A3 work.

5.2 Classification of Measures

There are at least 3 dimensions of classification of existing measures that can be introduced. **One dimension** is whether the measure is aimed at the prevention of derailments or at mitigating the consequences of derailments.

The **second dimension** is whether the measure is directed towards one or more of the following stakeholders:

- The infrastructure manager responsible for maintenance and operation of the infrastructure.
- The user, keeper or lessor of the rolling stock.
- The train operator responsible for the train composition, including traction unit and the movement of the train.
- Entities in charge of maintenance.

The owner and operator may be one and the same company, but there is an increasing business in Europe of privately owned rolling stock which is hired out to the various rail operating companies or transporters. Hence, the wagon owner in today's railway system is often different from the train operator. Other entities may be responsible for performance of the long term maintenance of the rolling stock on behalf of the owner or the train operating company, although the train operator is always responsible for the pre-departure inspections of trains.

The **third dimension** is whether the measure is of a human, organisational, operational or technical in nature. The distinction between these types of characters is not always clear cut. Below is an explanation that the project has tried to adhere to:

- Human measure: Measures to improve the individual's capability to perform his duties in a correct and safe manner. This includes competence, knowledge, decision support information systems for the persons that have the responsibility to carry out a certain task.
- Organisational measure: Measures pertaining to the management of the organisation, including staff training, safety management system, operational planning, human resource management, handling of requirements related to independence, roles and responsibilities etc.
- Operational measures: Measures in this category include operating instructions or operational rules that are in place in part to reduce the risk of freight train derailments. Examples might include speed restrictions, rule book actions etc.
- Technical measure: Technical devices to prevent or mitigate derailment or system installed in the infrastructure for monitoring the state of the railway system (rolling stock / infrastructure) to allow detection of derailment or early detection of hazardous conditions that may lead to derailment, and which upon detection takes appropriate action (recording, alarm, emergency brake).

The typical characteristics of the various measures are indicated in the following tables.

Table 5: Preventive Measures

	Human	Organisational	Operational	Technical
Infrastructure	Competence, decision support, checklists	Resources/training Inspection & maintenance programs	Intervention & safety limits	Equipment/protective measures
Rolling stock		Resources/training Inspection & maintenance programs	Intervention & safety limits	Equipment/protective measures
Train operation		Resources/training	Procedures	Decision support software

Table 6: Mitigation Measures

	Human	Organisational	Operational	Technical
Infrastructure	Competence, decision support, checklists	Resources/training	Procedures	Equipment/protective measures
Rolling stock		Resources/training	Procedures	Equipment/protective measures
Accident management		Resources/training	Procedures	

5.3 Limitations and Exclusions

5.3.1 Design Requirements

In Section 3.0 we discussed the existence of national safety and technical rules, and other requirements, that cover (but are not limited to) design requirements and design standards. These may translate to 100's or possibly 1000's of individual requirements, the majority of which may have at least an indirect bearing on the frequency or consequences of freight train derailments.

A feature of these requirements is that they operate within a framework of measures that maintain railway safety to an appropriate level for that country. For example, track design requirements and parameters may differ between countries, and a more relaxed design requirement may be compensated for by other measures, such as improved maintenance, stricter intervention limits and operational rules or possibly the introduction of external measures such as flange lubrication systems etc.

We consider that it is not possible to extract such individual requirements from the totality of measures applied to manage freight train derailment performance, and then attempt to estimate the potential benefit that requirement may have in a completely different operating context. Further, whilst we cannot say that there would be no benefit to applying alternative (more robust) design standards throughout Europe, we can be sure that the costs of such measures are potentially enormous.

The study, at its current stage, has therefore not considered detailed design requirements. However, with the benefit of a risk model in later study stages, this hypothesis will be further tested to confirm this conclusion.

5.3.2 Technical and Other Measures

We have been advised or were already aware of some technical and other measures that have a role to play in the fight against derailment. Some of these have a direct purpose as a derailment preventative or consequence reduction measure, whilst some have an indirect role to play. Examples of the former would be check rails, and the latter flange lubrication of locomotives.

In the tables that follow, these are identified as either (D) direct, or (I) indirect.

5.4 Preventive Measures

5.4.1 Overview of Preventive Measures

In the following tables various existing measures to prevent derailments, and other primary accidents with a high probability of derailment as a follow on consequence, are listed. When some individual countries are mentioned as employing the measure it does not mean that they are the only countries (or companies) to apply the measure. Mentioning of countries or companies applying the measure is to justify the measure as an existing measure. It is worth noting at this point that, as discussed in Section 4.3 further work is in hand to further refine the application of existing measures.

We use the term “general railway knowledge” to describe measures that we believe are well known and accepted in the industry, and would be acknowledged by rolling stock or infrastructure engineers as having a positive effect on reducing the probability of derailment.

Some general measures, like hot axle box detectors and various type of wheel load detectors have several suppliers and use different technologies. In such cases only the generic type is mentioned. In some cases different measures can be used for almost the same purpose. In Section 5.5 a further description of the various measures is presented.

Table 7: Infrastructure Preventive Measures

Type of measure	P#	Measures and motivation:	Where applied:	Source for Information:
Technical infrastructure	P-1 (D)	Installation of check rails to prevent derailments, in particular in sharp curves, as it will hinder flange climbing on outer rail in sharp curves. Check rails are also used in other conditions. For further info see 5.5.1.1	In points in most countries. In line track with sharp curves GB and republic of South Africa.	Network Rail Track construction standard, NR/SP/TRK/102
	P-2 (I)	Installation of track and flange lubrication in front of track sections with narrow curves to reduce rail flange friction and limit the risk of flange climbing on rail with subsequent derailment consequences. For further info see 5.5.1.2. See also flange lubrication measure on rolling stock (locomotives) 5.5.4.1.	Several countries including Austria. Great Britain	Ref. 21
	P-3 (I)	Installation of rock scree and avalanche protection structures along the line to stop or deflect rock screes and avalanches. For further info see 5.5.1.3. (Note derailment is a secondary consequence and collision the primary consequence.)	Countries with avalanche and rock fall risk including European Alp countries, Norway, USA, Canada as well as others.	Norwegian track regulation
	P-4 (I)	Installation of rock scree and avalanche detectors on sections with high risk of rock screes and avalanches along track where protection structures are not possible to install or are not deemed sufficient. For further info see 5.5.1.4. (Note derailment is a secondary consequence and collision the primary consequence.)		Norwegian track regulations
	P-5 (I)	Installation of obstacle detectors at level crossings in order to reduce collision risk at level crossing - will also reduce risk of follow-on derailment. For further info see 5.5.1.5. (Note derailment is a secondary consequence and collision the primary consequence.)	Denmark & Sweden	Ref. 17
	P-6 (D)	Use of ground penetration radars (Geo radars). Ground penetration radars are used to survey conditions of track bed superstructure with regard to quality and water content. This is mainly used through ad hoc baseline runs to provide information for planning of maintenance and renewal, but permanent installations can also be considered. For further info see 5.5.1.6.	Several countries including US and Norway.	Ref. 16
	P-7 (D)	Rolling stock mounted equipment for monitoring of rail profile conditions. For further info see 5.5.1.9.	Mermec supplied equipment	Mermec brochure /42/
Infrastructure; Control Command and Signalling	P-8 (I)	Track circuit as part of signalling system may detect rail ruptures. For further info see 5.5.1.7	Most countries	General railway knowledge
	P-9 (D)	Interlocking of points operation while track is occupied. This is not fully implemented at shunting yards. Hence a number of derailments occur due to points being operated while it is occupied by a train. This action very often causes derailment. Extend use of interlocking of remote controlled points to include tracks at shunting yards used for train movements. Interlocking of switch movement if the switched is occupied by rolling stock. For further info see 5.5.1.8	The protection measure is utilised and applied in most countries. The degree of application of point interlocking at shunting yards varies.	Several derailments reported due to shifting of point while occupied by train.

Type of measure	P#	Measures and motivation:	Where applied:	Source for Information:
Trackside rolling stock supervision	P-10 (D)	Installation of hot axle box (hot bearing) detectors for detection of faulty and hot bearings and axle journals in order to remove them from train prior to derailment. For further info see 5.5.2.1.	Several European countries. See 5.5.2.1 for more info.	Questionnaire response & Ref /12/
Trackside installations to supervise rolling stock	P-11 (D)	Installation of acoustic bearing monitoring equipment (This is partly an alternative to hot axle box detectors). The purpose of the installation is to detect faulty bearings by sound analysis and implement bearing maintenance prior to bearing seizure and hot temperature development. For further info see 5.5.2.2.	US, GB, Norway (installation plans)	Questionnaire response & Ref /12
	P-12 (D)	Installation of hot wheel and hot brake detectors. For further info see 5.5.2.3.	Several countries.	Network statement, Questionnaire response & Ref /12
	P-13 (D)	Installation of wheel load and wheel impact load detectors. For further info see 5.5.2.4.	Several countries.	Network statement, Questionnaire response & Ref /12
	P-14 (D)	Installation of dragging object and derailment detectors. For further info see 5.5.2.5.	US and other countries	Ref /12/
	P-15 (D)	Bogie performance monitoring/Bogie lateral in-stability detection (bogie hunting). For further info see 5.5.2.6.	US and other countries, including Turkey.	Ref /12/
	P-16 (D)	Wheel profile measurement system / Wheel profile monitoring unit. For further info see 5.5.2.7.	US and other countries	Ref /12/
	P-17 (I)	Installation of loading gauge infringement detectors/ profile- and antenna protruding detection. For further info see 5.5.2.8. (Note derailment is a secondary consequence and collision the primary consequence.)	US /12/ and Switzerland /49/ and other countries	Ref /12/
Infrastructure Operational/ organisational	P-18 (I)	Make sure available maintenance resources are sufficient in relation to network extent and traffic levels. If not possible to ensure sufficient resources a measure could be to close low traffic lines or take little used tracks out of operation. Lines and tracks where the minimum infrastructure safety requirements can not be maintained should be closed down. For further info see 5.5.3.1	Low traffic line closure has been common in several countries.	General railway knowledge
	P-19 (D)	Ensure that the track/train clearance gauge including the flange groove is free of obstructions that can cause collisions or derailments. Special focus to flange groove in level crossings. For further info see 5.5.3.2.	Normal inspection and maintenance in most countries.	A1 final draft report reviewer
	P-20 (D)	Perform ultrasonic rail inspection of track at sufficient frequency in order to detect rail cracks before dangerous ruptures occur. This is an activity carried out by most infrastructure managers with frequencies dependent upon rail age and traffic loads. For further info see 5.5.3.3.	The activity is performed by most infrastructure managers. Frequency varies according to track loading.	General railway knowledge
	P-21 (D)	Perform track geometry measurement **of all tracks** in order to detect track sections requiring maintenance actions. Regular track geometry measurements are carried out by	Most infrastructure managers but frequency may vary.	Accident investigation reports

Type of measure	P#	Measures and motivation:	Where applied:	Source for Information:
		most infrastructure managers. The completeness of the measurements with respect to track coverage at stations as well as intervals may vary. Frequency normally dependent upon traffic load and allowable speed level of track. For further info see 5.5.3.4.	Mixed coverage of sidetracks.	
	P-22 (D)	Establish EU-wide intervention and/or immediate action limits for track twist. The final draft TSI for CR Infrastructure specifies safety limits for track twist but intervention limits are left to the NSA or infrastructure managers of the various countries and they vary to a certain extent. Since the rolling stock are to be interoperable across all infrastructures the track intervention limits should also be corresponding. For further info see 5.5.3.5	Lack of consistency between countries, e.g. GB & Norway with regard to track twist intervention limits.	Final draft TSI CR Inf. Ref.2 & RGS GC/RT5021 /20/
	P-23 (D)	Establish EU-wide intervention and/or immediate action limits for variation of track gauge. Present limits varies among infrastructure managers and the intervention limit specified in the final draft TSI for CR Infrastructure is less stringent than what is presently applied in many countries. For further info see 5.5.3.6.	Variation in maximum gauge width between countries and towards TSI CR INF. Ref. 2.	Final draft TSI CR Inf. Ref.2 & RGS GC/RT5021 /20/
Infrastructure Operational/ organisational	P-24 (D)	Establish EU-wide intervention and/or immediate action limit for cant variations. In addition it should be considered to introduce a limit for excessive cant in track positions where trains are likely to stop or operate at low speed. Many derailments occur in track sections with narrow curves and high cant at low speed. For further info see 5.5.3.7.	Swiss & Norwegian track regulations	Swiss /32/ & /33/ & Norwegian track regulation /34/
	P-25 (D)	Establish EU-wide intervention and/or immediate action limit for height variations and cyclic tops which does not exist in Final draft TSI for Conventional rail infrastructure. For further info see 5.5.3.8.	GB and Norway at least.	GB /20/ and Norwegian track regulation /35/

Table 8: Rolling Stock Preventive Measures

Type of measure	P#	Measures and motivation:	Where applied:	Source for information:
Rolling stock technical or structural	P-26 (I)	Flange lubrication of locomotives. Requirement for installation of onboard lubrication of locomotive flanges to be able to provide necessary track/flange contact lubrication. The measure must be seen in relation to the application of trackside installed lubrication in curves. Reduces friction available for wheel flange climbing. For further info see 5.5.4.1.	US, Austria, Switzerland, Norway and others	Requirement specified in Network Statement of SBB & BLS. /29/ & /30/
	P-27 (D)	Replace composite wheels with monoblock wheels. Composite wheels have a more complex inspection and maintenance requirements and seems to have a higher failure rate causing derailments. For further info see 5.5.4.2.	Several countries or companies are prohibiting use of composite wheels for new and existing rolling stock.	General knowledge
	P-28 (D)	Replace metal roller cages in axle bearings by polyamide roller cages. For further info see 5.5.4.4.	CargoNet & DB Schenker freight wagons.	SHT Investigation report /24/. EUB

Type of measure	P#	Measures and motivation:	Where applied:	Source for information:
				Jahresbericht 2009 /47/.
	P-29 (D)	Replace existing axles for stronger axles or axles with improved material properties with regard to crack initiation and crack propagation. For further info see 5.5.4.3.	VTG exchanges axles for tank wagons	Railway Gazette International /10/.
	P-30 (D)	Increase the use of central coupler between wagons in fixed whole train operation. With an integrated draw gear and buffer function in a central coupling the rolling stock side buffers becomes superfluous. This will reduce side buffer loads and reduce risk of derailment due to buffer locking and couples that are too loose or too tight between wagons. For further info see 5.5.4.5.	Australia, US, former USSR including Baltic states in EU. 1520/24 mm gauge lines in Eastern Europe. Train for iron ore transport from Kiruna towards Narvik and Luleå	General railway knowledge
	P-31 (D)	Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis. For further info see 5.5.4.6.	US & Europe	General railway knowledge
	P-32 (I)	For new rolling stock install disc brakes instead of wheel tread brakes. Major motivation may be less noise in relation to Noise TSI, but also less heat activation of wheels, which may reduce derailment risk. For existing rolling stock, exchange wheel tread brakes with disc brakes for existing rolling stock. For further info see 5.5.4.7.	Employed for many new wagons and is the dominating brake type for new passenger rolling stock	General railway knowledge
	P-33 (D)	Rolling stock should be designed to operate safely over a track twist of up to 17 per mille over a 2.7 m base, and up to 4 per mille over an 11.2 m base. This will reduce derailment frequency due to track twist. Further info in 5.5.4.8.	Republic of Ireland and Northern Ireland	TSI for freight wagons Specific case item 7.2.2.4.5. Ref. 3
	P-34 (D)	Secure brake gear located in the underframe of the wagon to ensure that braking components tat become loose does not fall to the ground and can not provoke a derailment. For further info see 5.5.4.9.	Sweden, Norway and Germany and possibly other countries	Questionnaire response
	P-35 (D)	Regular greasing and check of fastening of rolling stock buffers to reduce risk of a buffer falling off and causing derailment. Alternatively, strengthen fastening elements. For further info see 5.5.4.10	Routinely greased and inspected in most countries	A1 final draft report reviewer
Rolling stock Operational / organisational	P-36 (D)	Wheel set integrity inspection (ultrasonic) programs. For further info see 5.5.5.4.	Most wagon owner and train operating companies.	Company inspection and maintenance standards.
	P-37 (D)	Derating of allowable axle loads for type A-I and A-II axle designs. For further info see 5.5.5.3.	Applicable countries, ref recommendation from ERA JSSG.	Ref /6/
	P-38 (D)	Inspect axles of freight train rolling stock according to EVIC (European Visual Inspection Catalogue). For further info see 5.5.5.2.	Most European countries Program implemented by ERA JSSG	Ref /5/
	P-39 (D)	Requirement for double check and signing of safety-classified (S.-marked) maintenance operations. For further info see 5.5.5.5.	Norway	Questionnaire response

Table 9: Preventive Measures applied to Train Loading and Operation

Type of measure	P#	Measures and motivation:	Where applied:	Source for information:
Train loading / human	P-40 (D)	Qualified and registered person responsible for loading. The person must show sufficient competence and be registered by the train operator. For further info see 5.5.6.1	Spain & Bulgaria	Questionnaire response
Pre-departure inspection and brake settings/ human	P-41 (D)	Locomotive and first wagons of long freight train in brake position G (Lange locomotive). For further info see 5.5.6.2 Various countries have operational requirements that the locomotive and the first wagons of a train shall be put in brake position G to limit the compression forces of the train when braking with the pneumatic activated train brakes.	Germany, Austria and Switzerland, as well as Norway and Sweden to a lesser degree.	DB Netz AG; Richtlinie Züge fahren und Rangieren /37/ Accident reports
Train operations/ human:	P-42 (D)	Limitations on use of brake action in difficult track geometry, particularly at low speed, to avoid high compression forces of train that could cause buffer locking and derailment. For further info see 5.5.6.4	Switzerland, Austria & possibly other countries	Austrian Accident report into derailment at 8th of April 2009 /31/. Swiss FDV. /27/.
	P-43 (I)	The ATP-system of some countries including Norway, Sweden and Finland, called ATC, has a function to perform a dynamic brake test on the route to get actual test information with regard to the train braking performance. For further info see 5.5.6.3.	Sweden	Trafikstyrelsen JvSFS 2008:7 bilaga 11 /38/.
	P-44 (D)	Saw tooth braking should be applied when using pneumatic brakes to limit speed in long and steep descents in order to limit heat exposure to wheels. For further info see 5.5.6.5	Switzerland	Schweizerische Fahrdienstvorschriften /26/
	P-45 (D)	When passing a signal showing a reduced speed, the driver should initiate the braking or speed reduction action prior to passing the signal. This could reduce the risk of over-speeding in track deviations. For further info see 5.5.6.6	Switzerland	SBB Regulation; Infrastruktur R 301.11 Bremsen 300.14 - Punkt 14.2.
	P-46 (D)	Trafikverket in Sweden (former Banverket) has recently issued a new regulation for how various alarms should be handled. Traffic controllers and drivers should not be allowed to override detector alarms. For further info see 5.5.6.7.	Sweden	BV regulation BVF 592.11 /36/.
	P-47 (D)	Wagons equipped with a balance to detect overload in visual inspection. ***Note, this measure is currently being investigated to determine the details.***	Switzerland	Questionnaire response

5.5 Description of Preventive Measures

This section describes the technical measures in more detail, summarizing:

- The function of the measure.
- The types of defects / problems it can prevent or mitigate.
- The technology employed.

5.5.1 Infrastructure installed technical measures to limit derailment risk

5.5.1.1 Application of Check Rails in Narrow Curves

Check rails are installed to guide the wheels in rigid crossings and point crossings. Check rails may also be installed in sharp curves to prevent derailments as it will hinder flange climbing on outer rail in sharp curves, In some countries (e.g. Germany) check rails may also be used to give an additional safety against derailment when the track is passing safety critical installations as supports of overhead bridges.

A picture from the Republic of South Africa taken from Voest Alpine net page shows how check rails can be applied in curved line sections /19/.

Figure 2: Example from RSA showing check rail installation in curved track

RSSB's Railway Group Standard GC/RT5021 /20/ Track system Requirements specifies that track in passenger lines with a radius of 200 metres or less should be fitted with a check rail to reduce the risk of derailment.

Other infrastructure managers also install check rails in difficult track geometries, but the degree of application varies. Check rails can also be a cause of derailment in some circumstances, in particular with an excessive track width, so check rails require tight control of the track width.

Check rails should not be confused with guard rails (M-5) that are installed to limit the consequences of a derailment, see 5.6.2.1.

5.5.1.2 Application of Track or Flange Lubrication at Selected Track Positions

Lubrication of the flange and track contact point is an important measure to reduce the friction between rail and wheel flange and hence reduce the risk of derailment in difficult track geometries, i.e. in narrow curves or track sections with high cant and/or high twist. Normally the lubrication is obtained by lubrication of the wheel flange of traction units.

For track sections where this is not deemed sufficient, for instance in deviated routes at turnouts, trackside flange or track lubrication points can be installed to provide the necessary lubrication. Lubrication can also be provided by special track lubrication train runs at regular intervals or under dry weather or hot temperature conditions.

Below is shown the picture of a track installed lubrication installation /22/, and test results /23/ showing the effect of lubrication of the track flange contact point.

The reduced lateral track force in narrow curves should cause less wear, less noise and less risk of derailment.

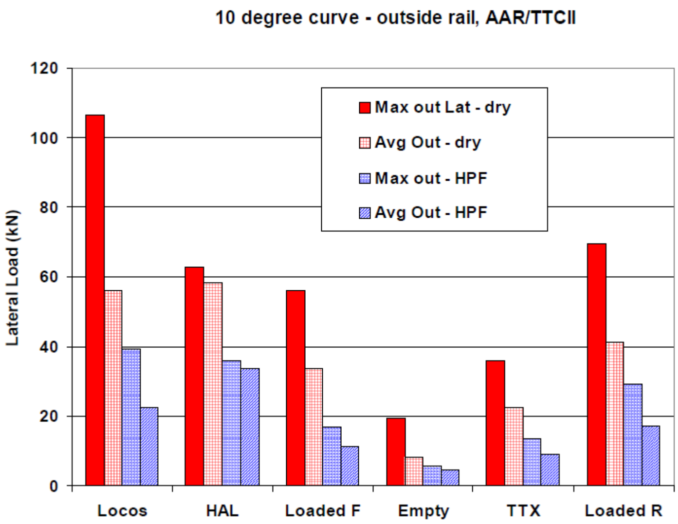


Figure 3: Track mounted lubrication installation and test results from narrow curve

5.5.1.3 Rock Scree and Avalanche Protection

On track sections with high risk of rock screes and avalanches structural track protection measures are often installed to stop or deflect rock screes and avalanches. Structural protection measures can be applied in combination with detection installations and operational measures and restrictions. Various measures are used in exposed countries including protection, detection, artificial release at convenient times, speed reductions. The selected measures are tailor made for the local topography and hazards and this is not a generic measure that might have a universal application.

Note that this measure is primarily used to prevent collision with obstruction, with derailment a secondary consequence.

5.5.1.4 Rock Scree and Avalanche Detection Systems

At line sections with a high risk of rock screes and avalanches and where structural protection is deemed too costly or not considered sufficient rock scree and avalanche detectors are installed. They can be in the form of detecting fences which will detect loads falling down on them from higher levels or as acoustic detectors detecting the noise associated with such phenomena. The last type can cover larger areas but are not as selective as a fence along the line. Systems to detect rock screes and avalanches are used in Norway and Switzerland and possibly other places.

The measure is often combined with structural protection measures or operational restriction measures.

Note that this measure is primarily used to prevent collision with obstruction, with derailment a secondary consequence.

5.5.1.5 Obstacle Detectors at Level Crossings

High speed collisions with heavy road vehicles are likely to cause derailment, but in such situations the derailment is a follow on consequence of another accident that may have severe consequences by itself.

The purpose of obstacle detectors is to discover obstacles on the track that could be a safety critical hindrance to the train. Obstacle detectors are installed at level crossings to detect if cars are standing blocking the tracks at the crossing or at other locations where the track can be blocked by foreign objects. Typical application of obstacle detectors are at barrier protected level crossings. In Sweden they are used or have been used at approximately 100 level crossings of the following type according to ref /17/:

- Where cars are likely to queue across a level crossing due to short distance from level crossing to road junction.
- In frequently used level crossings where maximum train speed is above 160 km/h. A train speed up to 200 km/h is allowed in Sweden over existing level crossings and obstacle detectors are applied.

We know such detectors are in use, or have been used, also in other countries.

Various detection methods can be applied to detect the obstacle e.g. metal detection loops in the roadbed, infrared light or laser technology. How laser technology can be applied as obstacle detector in a level crossing is shown in Figure 4. Ref /18/.

If an object is detected between the gates during gate lowering, the lowering is not continued and a restrictive signal protected by an ATC order is given to the train. The car can leave the crossing and the train will start braking such that it may stop in front of the level crossing if it is not clear. According to Trafikverket in 15 years there has only been one serious collision between a car and a train on such a level crossing, when a car ran through the gates just in front of the train /17/.

Note that this measure is primarily used to prevent collision with obstruction, with derailment a secondary consequence.

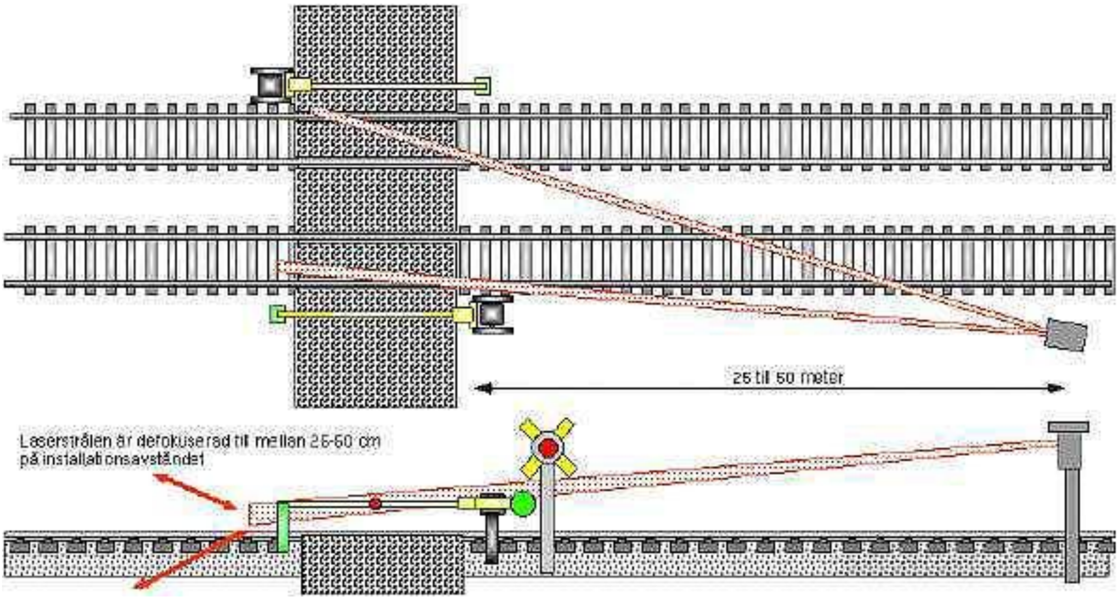


Figure 4: Laser technology used for obstacle detection at level crossings

5.5.1.6 Subsidence and Ground Instability Detection

Ground penetration radars are used to survey conditions of trackbed superstructure with regard to quality and water content /16/ & /43/. This is mainly used through ad hoc baseline runs to provide information for planning of maintenance and renewal, but permanent installations can also be considered in places where the railway is located on unstable ground that is considered exposed to high water level in substructure, subsidence or landslides. Certain types of ground instability detectors can be installed which will detect high water levels subsidence and landslides outside of acceptable limits.

5.5.1.7 Track Circuits to Detect Rail Ruptures

Track circuits are applied in the signalling system of most infrastructure managers. Track circuits will detect some type of rail ruptures and prevent signals to be set for a track section with a ruptured rail and hence prevent derailments. However, supervision for rail ruptures is not the main purpose of the track circuit and there are several types of rail ruptures the track circuits cannot detect. Track circuit systems for detection of track occupation are to an increasing degree being replaced by axle counters of many infrastructure managers. Axle counters are not able to detect track ruptures.

5.5.1.8 Interlocking of Points Operation while Track Occupied

Points at main lines and at main tracks at stations are normally interlocked to prevent operation of the point while the point section of track is occupied by rolling stock. This is not fully implemented at shunting yards even at tracks being used for train movements. Hence a number of derailments occur due to points being operated while occupied by a train. This action very often causes derailment. An existing measure is interlocking of remote controlled points to include track at shunting yards used for train movements in such a way that the switch can not be moved while the switched is occupied by rolling stock.

5.5.1.9 Rolling Stock Mounted Equipment for Rail Profile Measurement

Suppliers are marketing rail profile measurement systems that can be mounted on commercial rolling stock and used for continuous supervision of track geometry and measurement of rail wear. According to the supplier the monitoring results are equally good as those that can be obtained by special measurement cars and trains with the advantage of more frequent measurements.

This technology incorporates the latest laser and video camera technology to provide accurate and immediate report on the profile and wear condition of the rail whilst travelling at track speeds. The video cameras capture full cross-sectional rail profiles from the base/web fillet area up to the top-of-rail surface to allow comprehensive and accurate rail measurements. /42/.

The equipment installed on commercial rolling stock is an alternative to separate measurement runs by inspection wagons.

5.5.2 Trackside Installations to Supervise Rolling Stock

5.5.2.1 Hot Axle Box/Bearing Detector (HABD)

High temperature in the axle box or the bearing of an axle may be a sign of a mechanical structural defect under development. This can be in the form of high friction in the bearing or a developing rupture in the axle journal. By monitoring the temperature of axle boxes, a failure state of the bearing may be detected and an alarm raised either to the train driver or to the train control centre. Hot axle box detectors for freight trains are normally located along the track monitoring the temperature of axle box of all passing trains. Axle box monitoring devices can also be located on the vehicle, continuously monitoring the temperature of the axle boxes, but this is normally not applied on freight trains as the individual freight wagon does not have any electricity to power such monitoring equipment. Wayside detectors usually consist of one or more thermal sensors continuously measuring infrared radiation, and should be capable of detecting both normal temperature and high temperature axle boxes.

Combined with an axle counting feature it can identify which train axle has an excessive temperature and once the train has passed the detector it transmits this information to the train control centre or the train driver directly. If the hot axle box detector is combined with a vehicle identification system the information about axle temperature can also be transmitted to the wagon operator or owner. This is mainly useful if the detectors are networked and a temperature trend can be identified. Some systems will calibrate measurements with the ambient temperature.

Normal requirements to the site localisation for a hot axle box detection installation are:

- Track to be level, avoiding inclines.
- Track to be straight, avoiding curved area.
- Away from tunnel and cuttings.
- Ease of access for construction and maintenance.
- Suitably located to permit train regulation on alarm activation, i.e. to allow trains to be stopped at a siding were possible so it does not affect mainline traffic.

Hot axle box detectors are commonly used in the European railways. The number of axle box detectors installed can be quite high. Here are some approximate figures taken from questionnaire response, network statements and other sources. The below figures are mainly indicative and does not cover all countries that have installed hot axle box detectors:

- US: around 6000 detectors, /12/
- Germany: around 460 detectors, /48
- GB: around 200 detectors. /Network statement/
- Switzerland: around 80 detectors. /Questionnaire response/

Hot axle box detectors are also frequently installed in Austria, Sweden and Finland.

Not all countries use them with similar frequency. They are not installed in Slovakia nor are they particularly frequently installed in the Netherlands or Denmark. In Denmark they are only installed in front of the Great Belt tunnel and in the Netherlands they are installed on the new high speed line from Amsterdam towards Antwerpen and in the new Betuwe freight route from Rotterdam to the German border.

In the TSIs developed for harmonisation of the European railways it is only the TSI for Safety in Railway Tunnels that makes hot axle box detectors mandatory. They require "line-side hot axle box detection or predictive equipment shall be installed at strategic positions on networks with tunnels so that there is a high probability of detecting a hot axle box before the train enters a tunnel and that a defective train can be stopped ahead of the tunnel(s)". Other TSIs specifies the geometrical features of a hot axle box detector, i.e. where the detectors should look for increased temperature.

Hot axle box detectors are not a foolproof measure. Firstly, the damage and the associated temperature development can be so fast that a derailment occurs prior to the development being detected by a hot axle box detector. Secondly, when an alarm is raised, the train has to slow down and stop at a convenient location to let the driver inspect the situation and a derailment may occur before the train has stopped. Thirdly, when the train is stopped it may take some time until the driver is able to move to inspect the axle box in question and the temperature might have dropped in the meantime and nothing is detected and the journey is continued. Once the train is moving again the situation reappears and a derailment occurs.

5.5.2.2 Acoustic Bearing Detectors

Acoustic bearing detectors are, like hot axle box/bearing detectors, used to detect developing mechanical structural defects associated with wheel bearings. It is, however, not based on temperature measurement, but on the analysis of the sound as wheel sets pass by. The major advantage over hot axle box detectors is that acoustic bearing detectors are able to detect developing defects much earlier as such defects will result in increased noise. Acoustic bearing detectors are placed wayside and consists of a microphone array and a system unit which analyses the sound and raises an alarm if dangerous defects are detected. Used in combination with vehicle identification systems, the system may also be used to store information on individual vehicles and wheel sets in a central database, allowing for trend analysis and preventive maintenance.

The amount of noise produced by the bearing during deterioration may depend on the design of the bearing and acoustic bearing detectors may not work equally good for all type of bearings.

5.5.2.3 Hot Wheel and Hot Brake Detectors

Braking can increase the temperature of the wheels and brake pads. In particular this can be a problem with brakes that have not released and continuously apply braking action. The rise of temperature may itself be a problem if it leads to structural changes in the wheel material. If the wheel comes completely stuck it may skid along the rail resulting in wheel flats etc. Hot wheel detectors are positioned wayside and use the same technology as hot axle box/bearing detectors, i.e. thermal sensors measuring the temperature of passing wheels. Used in combination with axle counting devices or vehicle identification systems, the system is able to identify the vehicle and wheel of any higher than normal temperatures and raise an alarm.

Cold wheels may in some situations (e.g. if positioned at the bottom of a downward slope) indicate that brakes have not been applied where they should have been, i.e. that brakes are defective or working poorly. However, non-operating brakes on a single wagon are normally not a problem and often wagons may have the brakes locked out if a fault with the brakes of the wagon has been detected in the train brake test.

Railways that have installed hot axle box detectors often combine them with hot wheel and hot brake detectors. They are not mandatory by any TSI.

5.5.2.4 Wheel Load Detectors & Wheel Impact Load Detectors

Several different types of wheel load detectors exist. They are installed at various locations in many countries. In The Netherlands they are used as input for calculation of load dependent track access charges for rail operators in their “quo Vadis system”.

Wheel load and wheel impact load detectors can be used to detect a range of different faults with a wagon or its loading:

- By measuring the wheel loads of an axle it can detect overloading of the wheels and axles or skew loading of the wagon either due to a wrongly applied load in longitudinal or transversal direction, a shifted load or due to a wagon or bogie frame twist, suspension or spring failure.
- Wheel load detectors can also detect wheel failures in of terms general out of roundness or more specifically wheel flats and wheel tread damages due to shelling and spalling. As the wheel moves around this causes wheel impact load on the rail, which again cause damage to rails (including rail breaks) or increase the temperature of bearings and lead to hot a hot axle box.

Wheel load detectors are wayside detectors measuring the size and variations of the load of wheels as they pass by. Several different technologies are employed depending on the various faults to be detected. Some use strain gauges, others analyse sound or measure the deflection of rails between sleepers as trains pass using optical sensors. Accelerometers can also be used.

If the situation is severe an alarm is raised and the train has to be stopped to check the wagon(s) that have triggered the wheel load detector alarm, or the train speed may be adjusted. Used in combination with vehicle identification systems, the train operator and/or wagon owner may receive a message about the out-of-limit characteristics in order for rectifying actions to be implemented prior to further operation of the wagon.

Wheel load detectors can be combined with hot axle box detectors, but are often installed in departure tracks from train formation yards. Alternatively, they are installed in main tracks immediately after train formation yards in order to detect the situation as soon as possible. Faults can also occur along the route. In general there are fewer trackside wheel load detectors than hot axle box detectors.

5.5.2.5 Derailment and Dragging Object Detectors

Derailment and dragging object detectors can be installed to identify if a train has a derailed axle, or equipment that has come loose from a wagon and being dragged along the track between the rails. Such detectors may be installed in front of large stations or structures where the situation may cause major damage. They are extensively used in the US.

Early dragging equipment detectors were of the "brittle bar" type. Fixed elements between and beside the rails would break when struck by foreign objects. Their breakage would interrupt an electric circuit that formed part of the reporting system, and the train would be stopped and inspected. The introduction of "self-restoring" dragging equipment detectors, which are hinged and sprung so they return to position after impact, have reduced maintenance requirements for such installations. Figure 5 shows a typical derailment and dragging object used in the US. If employed in Europe one has to modify the design to avoid being hit by hanging screw couplers.

The derailment and dragging object detectors will also detect derailments and are also included as a mitigating measure.

Figure 5: Typical US derailment and dragging object detector

5.5.2.6 Bogie Steering Performance Detectors/Lateral Instability Detection (bogie hunting)

This wayside defect detection system is capable of detecting and identifying train bogies that exhibit poor performance. This system monitors safety performance in several regimes such as: potential of flange climb derailment, gauge spreading, and rail over. This state-of the-art system has the capability to benchmark bogie performance on a fleet-wide basis. They are used in the US and at least in Turkey.

5.5.2.7 Wheel Profile Measurement System / Wheel Profile Monitoring unit

Damage to the wheel profile may be a contributing cause to derailments. Whereas wheel impact load detectors can detect some wheel profile problems, wheel profile measurement systems provide a more complete picture. They are also based on other technology: analysis of wayside digital camera images highlighting the profile using lasers or strobe light. A number of wheel profile parameters are captured, e.g. flange height, flange width, flange slope, tread hollow and rim thickness. Some measurement systems can operate with trains passing at high speeds (e.g. up to 140 km/h).

5.5.2.8 Loading Gauge Infringement Detectors (Profil- und Antennenortungsanlage)

These are detector installations that can detect wagon structures or loads and objects protruding from the wagon that are too high or wide for the allowable loading profile of the line in question Derailments or other accidents can be caused by loads protruding outside of the allowed loading gauge, and detectors can be applied to detect such situations. The situation can occur due to shifting loads or by loading the car with an object that exceeds the allowable loading gauge for the line in question. Shifting load situations can normally also be detected by wheel load detectors. Increasing volume of transport of autocars and HGVs by rail has caused interest in controlling the antenna height of cars, but more due to fire risk in tunnels than due to derailment risk.

Loading gauge infringement detectors are most likely to be installed in front of track sections with reduced loading profile (e.g. tunnels) or in front of bridges with overhead bearing structure.

Note that this measure is primarily used to prevent collision with obstruction, with derailment a secondary consequence.

5.5.3 Infrastructure Applied Operational and Organisational Measures

5.5.3.1 Closure of Lines and Tracks

If the available resources are not sufficient to maintain lines and tracks at stations according to minimum safety requirements it is from a derailment and safety viewpoint better to close the lines or tracks for operation than trying to keep lines operational in a state where all safety margins are removed.

Accident investigation reports from various countries have shown that many accidents occur due to known infrastructure failures that there might not be resources to repair, or such repair has not been prioritized within available resources. Such conditions increase the risk of freight derailment and if hazardous materials are transported on such lines it might be a public risk.

5.5.3.2 Inspection and maintenance to ensure free clearance gauge

The clearance gauge should be kept free of obstructions when trains are due to arrive. This is a general inspection and maintenance task carried out by all infrastructure managers. Special focus should be given to the flange groove in level crossings. If the flange groove is obstructed by hard solid objects it can cause derailments. Level crossings with rubber elements (Strail) can reduce the risk.

In countries with severe winters snow ice can pack in the flange groove and around the rail during periods of frost during night and thaw during daytime. In particular this can be a risk if free water seeps over the track, for instance in level crossings. The risk is most severe for passenger trains.

5.5.3.3 Ultrasonic Rail Inspection Wagon

The infrastructure managers provide for ultrasonic inspection of the rails by various forms of wagons in order to detect cracks and fractures that can cause rail ruptures. Either the infrastructure manager owns the inspection equipment or the inspection is done by contractors. The ultrasound inspection provides the infrastructure manager with information with regard to the quality of the rails and the need for rail replacements.

The frequency of ultrasonic rail inspections is determined by the infrastructure manager based on the rail age and traffic loads on the actual line accounting for available resources and equipment performance.

5.5.3.4 Track Geometry Measurements

Regular track geometry measurements are carried out by most infrastructure managers. In order to be reliable they should be carried out under dynamic loaded conditions. The track geometry of railway lines is regularly measured by track inspection wagons or trains which provide dynamic loading to the track while doing the measurement. Among the geometric parameters measured are:

- Track gauge variations.
- Track cant.
- Track twist.
- Track height variations.
- Track lateral position faults.

In addition modern measurement wagons can inspect rail surface conditions in terms of rail wear and various rail surface defects. The completeness of the measurements with respect to track coverage at stations as well as intervals may vary. Frequency is normally dependent upon traffic load and allowable speed limit of track.

The frequency of inspection is based on local conditions and environmental factors, ground stability, line speed and traffic loads accounting for available resources and equipment performance. Normal frequencies can be 2 to 6 times a year with increased frequency for lines with more traffic and higher allowable speed.

5.5.3.5 Track Twist Intervention Limits

Excessive track twist is among the most frequent derailment causes often in combination with other causes such as skew loading, wagon frame twist and low speed in narrow curve with high cant etc. In many cases where track twist is a major factor leading to derailment the actual track twist exceeds allowable twist limits, and in some cases the situation has also been known to those responsible for track maintenance.

Track twist requirements must be looked at in combination with requirements and limitations for rolling stock flexural stiffness. The ORE B55 RP8 document has analysed the conditions for derailment. Ref./8/.

The final draft TSI for Conventional Rail Infrastructure specifies safety limits (or immediate action limits) for track twist as follows:

> "All TSI Categories of Line
>
> (1) The immediate action limit for track twist as an isolated defect is given as a zero to peak value. Track twist is defined as the algebraic difference between two cross levels taken at a defined distance apart, usually expressed as a gradient between the two points at which the cross level is measured. The cross level is measured at the nominal centres of the rail heads.
>
> (2) The track twist limit is a function of the measurement base applied (l) according to the formula:
>
> Limit twist = (20/l + 3)
>
> (a) where l is the measurement base (in m), with 1.3 m l 20 m,
>
> (b) with a maximum value of 7 mm/m.

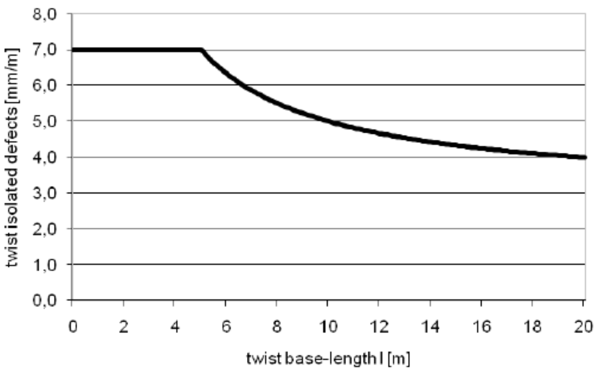


Figure 3: Limit for track twist for all TSI Categories of Line

> (3) The Infrastructure Manager shall set out in the maintenance plan the basis on which it will measure the track in order to check compliance with this requirement. The basis of measurement shall include at least one measurement base between 2 and 5 m.
>
> TSI Categories of Line IV-F, IV-M, V-F, V-M, VI-F, VI-M, VII-F and VII-M
>
> (4) If the radius of horizontal curve is less than 420 m and cant D > (R – 100)/2, track twist shall be limited according to the formula: Limit twist = (20/l + 1.5), with a maximum value between 6 mm/m and 3 mm/m depending on the twist base length as shown in Figure 4.

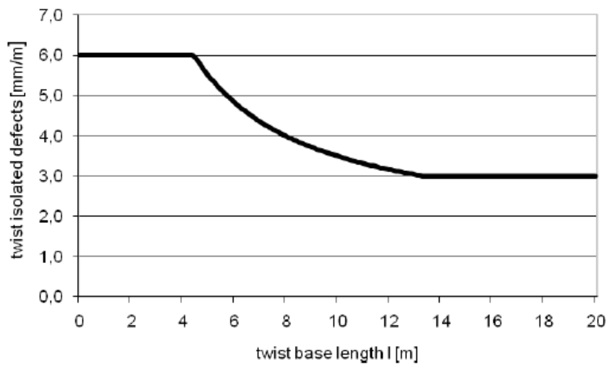


Figure 4: Limit for track twist for freight and mixed lines on small curves

”

The above limits specified in the TSI are safety limits that require immediate traffic shut down. According to recent accident investigation reports several derailments have occurred due to track twist in tracks within the safety limit specified above.

The TSI specifies that intervention limits shall be developed by infrastructure managers or national safety authorities (NSA). Today’s intervention and safety limits for track twist varies somewhat between different countries within EU.

An existing measure adopted by some infrastructure managers has been to impose more stringent limits for these parameters which suggest a more widespread adoption of harmonised limits may be beneficial. The reason for this is that rolling stock meeting the TSI for freight wagons is interoperable through the European Union and hence criteria for track maintenance activities should be harmonized in order to be able to maintain a high level of safety against derailment due to track twist. The intervention and safety limits should be viewed in relation to the lubrication status of the track.

Further, one should make sure that the developed criteria can handle allowable skew loading conditions of wagons with a certain margin.

5.5.3.6 Immediate Action Limit for Variation of Track Gauge

The immediate action limits for variation of track gauge are set out in the final draft TSI for Conventional rail.

Speed [km/h]	Dimensions [mm] - Nominal track gauge to peak value	
	Minimum track gauge	Maximum track gauge
V 80	-9	+35
80 < V 120	-9	+35
120 < V 160	-8	+35
160 < V 200	-7	+28

The above immediate action limit is significantly less rigorous than today’s action limit for many countries as for instance GB /20/ and Norway /35/. A review of the limits may be warranted if there is a strategy to reduce derailment frequencies. The argument for harmonised limits is as for 5.5.3.5.

5.5.3.7 Immediate Action Limit for Variation in Cant and Excessive Cant

Action limits for variation in cant relative to design cant is specified in the final draft TSI for Conventional Rail Infrastructure.

TSI Categories of Line IV-F, IV-M, V-F, V-M, VI-F, VI-M, VII-F and VII-M (Requirements for passenger lines (P-lines) are excluded as they are not open for freight traffic.)

(1) The in service cant shall be maintained within +/- 20 mm of the design cant, but the maximum cant permitted in service is 170 mm.

Additional to the above some countries, such as Norway and Switzerland, have general limitations of allowable excessive cant, specifically at locations where trains are expected to stop at a signal or drive slowly /33/ & /34/. This requirement is of special importance at locations with narrow curves where trains may have to stop in front of signals and where there also is high track twist when leaving out of transition curves.

5.5.3.8 Immediate Action Limitation for Track Height Variation

Among others, the railways of Norway and Britain have intervention limits for variation in track height. The intervention limits specified in Britain and Norway is relatively consistent, but with some minor variations. Variations in track height and cyclic tops may cause derailment, in particular if there are cyclic variations. A report issued in January 2006 as a result of a research work financed by Rail Safety & Standards Boards identified height variations and cyclic tops to be one of the most frequent high speed derailment causes /21/.

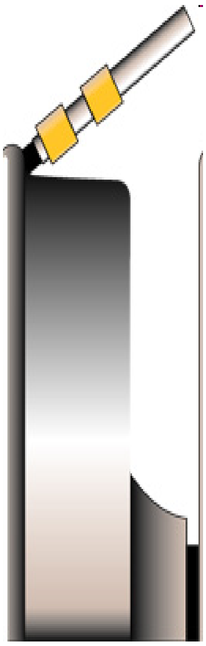
A measure could be that the Final draft TSI for Conventional Rail infrastructure is modified to include quantitative limitations on height faults. An interoperable rolling stock fleet will benefit from harmonised track intervention and safety limits.

5.5.4 Rolling Stock Applied Technical Measures

5.5.4.1 Flange Lubrication at Locomotives

In some countries, in particular countries with a high proportion of curved tracks, there is a requirement to fit main traction units with flange lubrication to reduce the friction of the contact between wheel flange and rail. Specification for flange lubrication requirement for traction units and type of lubrication is found in the Network statements of SBB & BLS /29/ & /30/.

Reduced friction between wheel flange and track also reduces the necessary traction force and energy use on curvy track sections /23/. Other countries with less narrow curves and a more level network do not apply flange lubrication to the same degree.



The Austrian railways ÖBB has the following specification for flange and track lubrication as introduced in the software of locomotive type “Taurus” /7/:

- “< 20 km/h: no flange lubrication.
- v > 20 km/h normal flange lubrication.
- v in range 73 – 90 km/h for more than 2 minutes: increased flange lubrication (Mode Berg 2).
- v in range 30 – 72 km/h for more than 3 minutes: strongly increased flange lubrication (Mode Berg 1)”.

Recent accident investigations in Austria /7/ have found that the above lubrication programme may not give sufficient lubrication at localised difficult track geometries at low speed e.g. at track with reduced speed or in sparsely used tracks at stations. Added lubrication might therefore be required at curvy track in the above mentioned speed classes.

According to the TSI for locomotives and traction units there are no requirements for flange lubrication.

In order for track lubrication to be effective across Europe it should be considered whether it should be required that freight train traction units employed in international traffic should be equipped with flange lubrication.

5.5.4.2 Replace Composite Wheels of Freight Wagons with Monoblock Wheels

A composite wheel consists of a wheel rim with an outer shrink fitted ring comprising the wheel tread and the flange. A tyre retaining ring helps to keep the assembly in place. Composite wheels have the advantage that the ring can be replaced once it is worn down. A disadvantage with composite wheels is that the wheel ring can come loose and be displaced, in particular due to heating in prolonged braking actions. A wheel with a displaced or lost wheel ring is likely to derail.

Monoblock wheels are forged or rolled from one block and have fewer failure modes, however, also for these wheels prolonged and excessive heating due to braking can cause material failure and wheel rupture with consequential derailment. Some railway undertakings, in particular those with very mountainous lines, favour monoblock wheels and have completely exchanged all their composite wheels with monoblock wheels.

An existing measure with extended application is therefore to replace composite wheels with monoblock wheels.

5.5.4.3 Replace Existing Axles with Higher Strength Axles

The private wagon owner VTG with a large fleet of tank wagons recently made a decision to replace axles in most of their rolling stock to axles with higher strength according to a notice in Railway Gazette International of December 2009 /10/. According to the notice all their rolling stock axles are to be replaced by 2015.

The allowable axle load of the rolling stock is not expected to be increased and the main reason for the replacement is an increased safety against axle ruptures and derailments.

5.5.4.4 Replace Metal Roller Cages in Axle Bearings by Polyamide Roller Cages

The Norwegian rail freight operator CargoNet decided approximately 10 years ago to exchange their axle bearings from using brass roller cages to polyamide roller cages /24/. The implementation of the decision has been by replacement when the wagon and axle boxes are in for overhaul. The rationale for the replacement was a number of derailments due to hot axle boxes and shearing of axle journals prior to the decision being made. The cause of many of the failures was wheel damages. The polyamide cages were considered less prone to failures due to vibration impact.

The same measure has recently been recommended by the German National investigation body, Eisenbahn-Unfallsuntersuchungsstelle des Bundes (EUB) towards Eisenbahnbundesamt (EBA), the German National Safety Authority and the relevant railway undertaking, and has been accepted /47/.

5.5.4.5 Increase Use of Central Couplers for Wagons in Block Trains

Central couplers are commonly used across the world in North America including USA and Canada, Australia as well as the Commonwealth of Independent States (former Soviet republics) including the Baltic Countries. Central couplers are also commonly used in Finland as Russian rolling stock often used. In the rest of Europe central couplers are mainly used for fixed train units for passenger transport, or for freight transport in heavy haul operations, e.g. the iron ore transport from the Swedish iron ore mines to the ports of Narvik and Luleå. In rail freight transport operations by fixed block trains with bogie wagons with uniform loading, central couplers will reduce curve forces and ensures that compression forces occur centrally in the train. This will reduce the derailment risk.

An existing measure that could be given wider usage is therefore the introduction of central couplers of 4 axle rolling stock with bogies in block train operation.

5.5.4.6 Increase Use of Bogie Wagons instead of Single Axle Wagons

The rolling stock of the European railways consist of a mixture of single or coupled 2 axle units with single axles or bogie wagons with 2 or 3 2-axle bogies. Normally, bogie wagons have better riding quality and a lower derailment rate.

An exchange of single axle wagons for bogie wagons could therefore be a measure to reduce the number of derailments. This is already applied for most heavy bulk transport applications. For the transport of light weight goods and lightly loaded containers and swap bodies this is not the case. For such transport operations, wagons based on single axle wheel allows for a long loading basis to be obtained with a minimum of weight and cost; whilst this is advantageous commercially it is not beneficial with respect to minimising derailment risk.

A review of accident reports indicates that these types of cars have an increased derailment frequency, often in combination with high track twist.

5.5.4.7 Exchange wheel Tread Brakes with Disc Brakes

Existing fleets of freight wagons are to a large degree equipped with wheel tread brakes utilising cast iron brake blocks (shoes). Some modern wagons are equipped with composite brake blocks or disc brakes mainly due to new noise criteria.

To move the brake action away from the wheel tread, as is the case with disc brakes, also has a safety advantage as the wheel tread material is less heat affected and increased braking force can be applied without the risk of overheating the wheels. This may reduce the failure rate for both composite and monoblock wheels. Application of disc brakes will increase the torsion loads on axles and the strength of existing axles must be checked before implementing it on existing wagons.

Disc brakes also have some disadvantages as they does not clean the wheel tread for rub that may form in the wheel-rail contact if the wheel is blocked for a short period.

The measure is applied for some new freight wagons, mainly to limit noise from train braking.

5.5.4.8 Increase Requirement to Twist Flexibility of Rolling Stock

The WAG TSI (TSI for rolling stock freight wagons) as a specific case for the Irish railways (Republic of Ireland and Northern Ireland) in § 7.7.2.2.4.5 allows a stricter requirement to twist flexibility for freight rolling stock on that network than for the rest of Europe. The relevant paragraph of TSI Wag reads:

> "Rolling stock should be designed to operate safely over a track twist of up to 17 per mille over a 2.7 m base, and up to 4 per mille over an 11.2 m base".

This will make the rolling stock much less likely to derail due to track twist and should be considered also for the rest of Europe. However, it is unlikely that all existing RIV marked freight wagons will satisfy such a requirement.

5.5.4.9 Apply safety slings of steel wire on underframe brake gear

In order to prevent brake falling from a wagon and possibly causing a derailment, parts of the brake rigging that could come loose should be secured by safety springs of steel wire. This is a requirement in some countries or done by some freight operating railway undertakings.

5.5.4.10 Regular check and greasing of buffer fastening

Rolling stock buffers can be lost and be a cause for train derailment, but it is not a frequent derailment cause. Various preventive measures are normally in place to control this possible derailment cause as: inspection of buffer fastenings and regular greasing of buffer plates as well as buffer cylinder contact parts. If considered necessary fastening elements should be strengthened.

5.5.5 Rolling Stock Applied Operational and Organisational Measures

5.5.5.1 Task Force (TF) made up of Experts in the field of Freight Wagon Maintenance and Railway Axles

A task force under administration by ERA has been set down by European railways after the Viareggio accident to investigate what action can be taken to reduce the risk of such accidents.

The objective of the first phase of the work was to address and develop urgent measures as a follow-up to information on problems with broken axles (cases in AT, DE, IT). For this purpose the sector set up a Joint Sector Support Group (JSSG) and focused on the following tasks:

- Investigate further and with urgency the width and character of the problem with broken axles, based on information from NSAs and the operators and study the need to reduce the maximum permitted axle load for wagons with certain types of axles that may have been overloaded without adequate maintenance supervision.
- Review the relevant actions in the sector action plan and develop the necessary accompanying measures (European Visual Inspection Catalogue – EVIC, etc.).
- Review ongoing standardization activities and identify further areas for standardization and/or the need for review of standards.

5.5.5.2 Implementing the European Visual Inspection Catalogue for Axle Inspections

Since 01.04.2010 a European-wide voluntary program of wagon owners for visual examination of axles and wheels has started. The purpose of the inspection is partly to identify surface marks and scratches in wheels and axles that can act as crack initiators.

The EVIC can be considered as a reference manual for RUs and keepers providing the criteria to freight wagon maintenance staff to visually identify, during light maintenance in workshops (i.e. without disassembling from the wheel-sets), axles with a potentially increased risk for safe operation. A wheel-set/axle which doesn’t meet the EVIC-criteria will be discarded from service and undergo non-destructive tests (NDTs). Additionally, a sample of axles fulfilling the EVIC-criteria will also be subject to NDT.

This program runs over the next 4 years for rail tank cars and 6 years for other railway wagons. The examination according to EVIC-catalogue will be done from April 2010 on each wagon, which enters a workshop for repair (operational maintenance) outside from revision. The inserted wheel-sets are examined and the workshop will inform the wagon owner about the result. Results with regard to inspection progress are to be reported to the ERA. All private owners announce the collected inspection results over the federation VPI (or VDV) monthly to for European-wide evaluation of the results.

A catalogue document describing the defects to be looked for has been developed.

5.5.5.3 Derating of Allowable Axle Load for Certain Axles

Investigations by the ERA JSSG set down after the Viareggio accident indicates that an increase of the axle load of types A-I and A-II axles has been allowed nationally for some countries even though this exceeds the intended design load. The JSSG has recommended that maximum operational axle load limitations for A-I and A-II axles are limited to 20 tonnes. A-III axles are allowed a continued operation with 22.5 tonnes axle load provided strengthened inspection and maintenance routines are introduced /6/.

Type A axles comprises more than 75 % of existing wheel axles in European rolling stock.

5.5.5.4 Wheel Integrity Inspection (ultrasonic)

Wheel ruptures and damage to the wheel profile may be a contributing cause to derailments. Whereas wheel impact load detectors can detect some wheel profile problems, wheel profile measurement systems and wheel ultrasonic integrity inspection with respect to cracks can provide a more complete picture. They are also based on other technology: analysis of lasers and digital camera images highlighting the profile using lasers or strobe light. In addition wheels have to be inspected for material cracks that can cause ruptures.

Various NDT methods can be used for crack detection including ultrasonic. Technology exists for supervision stations in depots that can do the necessary inspections while the train passes the supervision station in low speed. Measurements can be stored in a central database for monitoring of trends and planning of maintenance.

5.5.5.5 Requirement for Double Check and Signing of S-marked Maintenance Operations

CargoNet, the largest freight rail operator in Norway, has classified their maintenance activities according to whether the maintenance operation is safety critical or not. The safety critical maintenance operations, called S-marked activities, have to be double checked and signed out by 2 persons. This is considered to reduce the likelihood of faults and omissions in the maintenance work of safety critical items of the rolling stock.

5.5.6 Train Operational Measures

5.5.6.1 Qualified Persons Responsible for Loading Safety

In Spain it is required by law to have a qualified and certified person responsible for supervising the loading of trains. In the recent national legislation in Spain companies performing loading and unloading tasks are required to designate a responsible person. The person designated must demonstrate sufficient knowledge in order to be deemed qualified, and the designated person is registered with the train operator. Also in Bulgaria a qualified person is to be responsible for correct train loading. This information is received from questionnaire response.

5.5.6.2 Locomotive and First Wagons of Long Freight Train in Brake Position G (“Lange locomotive”)

When operating long freight trains in brake position P the delayed application of pneumatic train brakes in the rear of the train compared to the front of the train causes significant compression forces. In order to limit train compression forces when operating pneumatic brakes of a freight train in position P the locomotive(s) and the first wagon(s) of a long freight train shall be put in brake position G to limit the compression forces of the train when braking with the pneumatic activated train brakes.

In Germany the requirements are specified in /37/ and for freight trains weighing 800 – 1200 tonnes the locomotive should be placed in brake position G. For freight trains weighing 1200 tonnes or more, the locomotive and the 5 first wagons are to be placed in brake position G. The above train weight values are exclusive of locomotives.

5.5.6.3 ATP-system for Testing of Braking Performance of Train Mechanical Brakes

The ATP-systems of some countries including Norway, Sweden and Finland called ATC, has a function to perform a dynamic brake test on the route to get actual test information with regard to the train braking performance.

In Sweden it is mandatory to test the train brake performance by this system as soon as possible after departure from a train formation station. Specifications in JvSFS 2008:7 bilaga 11 /38/.

5.5.6.4 Limitations on use of Brake Action in Long Freight Trains

Regardless of type of brake activation it is important to restrict brake actions in difficult track geometries at low speed. In particular this applies when freight trains are routed through deviated point settings with narrow curves across stations. The traffic operation regulations of Austria /31/, Switzerland /27/, and other countries, specify limitations.

Electro-dynamic braking

Operational braking in freight train is mainly carried out by using electro-dynamic brakes at the locomotive. This produces compression forces in the train and the brake force at the locomotive has to be limited in difficult track geometries in order not to jeopardize safety against derailment. Train operators therefore have specified limitations with regard to allowable use of electro-dynamic brakes, in particular at low speed. Here are some examples:

- CargoNet (Norway): 150 kN.
- ÖBB (Austria): 100 kN for speeds < 40 km/h and 150 kN for 50 km/h=/< speed > 150 km/h, /31/.
- SBB (Switzerland): 150 kN.

For older locomotives such limitations has to be adhered to by the driver. For modern locomotives the limitations are programmed into the brake and traction control computers.

Use of pneumatic brake

The Swiss traffic operation regulations /27/ specifies that when passing deviated point settings with speed limitations to 40 km/h the application of pneumatic brakes should be limited to 0,5 bar pressure reduction unless during emergency.

Further, the regulations specifies that after an emergency braking at above specified track conditions the train should be inspected before continued operation.

5.5.6.5 Saw Tooth Braking Applied when Pneumatic Brakes used in Long Descents

When pneumatic brakes have to be applied to restrict the speed in long descents the Swiss traffic regulations (Fahrdienstvorschriften) /26/ specifies that saw-tooth braking should be applied. This means that during a brake application of approximately 60 seconds the speed should be restricted so much that there can be an interval of minimum 90 seconds without brake application until the next pneumatic brake application. By such actions the heat exposure to the wheels is limited and the risk of wheel damage is reduced and hence reducing the risk of derailment.

If necessary, the speed should initially be reduced so the above specified brake actions are sufficient to maintain allowable speed during the descent.

5.5.6.6 Initiate Braking Prior to Passing Signal or Sign Requiring Braking Action

When passing a signal showing a reduced speed, the driver should initiate the braking or speed reduction activities prior to passing the signal. This is a requirement of the Swiss operating rules /13/. For a number of reasons this may reduce the risk of over-speeding and derailment in track deviations:

- The braking action is initiated earlier and a gentler braking will ensure sufficient speed reduction according to signals and signs.
- There is less chance of the driver forgetting the speed reduction signal if the braking action is initiated immediately.

5.5.6.7 Improved Handling of Trackside Detector Alarms

It is not uncommon that hot axle box alarms are acted upon too late so the derailment has already occurred when the train stops or reduces the speed. Further, there are several examples of accidents that seem to have occurred due to overriding of a hot axle box alarm, either because the time taken for the driver to inspect the axle box has taken too long (thus cooling has occurred), or possibly because there is not a convenient location to stop and inspect the train without delaying other traffic, etc..

Trafikverket in Sweden (former Banverket) has recently issued a new regulation for how various alarms should be handled (BVF 592.11) /36/. The document specifies the actions to be carried out after a detector alarm registration is received and restricts the traffic controller's and train driver's possibility to override detector alarms.

5.6 Consequence mitigating measures

5.6.1 Overview table of existing consequence mitigating measures

In the following table the various existing measures to mitigate the consequences of derailments are briefly presented. In Section 5.6.2 a further description of the various measures are included.

Table 10: Consequence Mitigation Measures

Category:	M#	Measures and motivation:	Where applied:	Source
Rolling stock	M-1 (D)	Derailment detection detectors (valves) to avoid derailed wagons from being dragged along for long distances. For further info see 5.6.2.3.	By train operators in Switzerland & Slovenia. Similar system in use in RWE Rheinbraun	Knorr Bremse & Questionnaire info A2 final draft report reviewer
	M-2 (D)	Equip tank wagons with impact shield to protect tank against penetration (US-requirement also used in Sweden). For further info see 5.6.2.4.	RID requirement for some materials, e.g. chlorine. Country requirements: US, Sweden	RID /15/ & RSSB /11/
	M-3 (I)	Install emergency warning lights on locomotive to warn train on neighbouring track going in opposite direction. For further info see 5.6.2.5.	Switzerland	BAV Fahrdienstvorschriften /28/ Accident report Mühlehorn
	M-4 (D)	Attach mechanical guides at the bogie structure or on wagon support at appropriate position to ensure that a derailed wagon most likely is kept along the track and does not overturn or become hit by other wagons. For further info see 5.6.2.6.	High speed trains in France, Sweden and Japan. Similar system in use in RWE Rheinbraun	Document received from Mr Emmanuel Ruffin of ERA. /39/ A2 final draft report reviewer
Infrastructure	M-5 (D)	Existing requirement for safety rails (guard rails) at bridges and in tunnels. For further info see 5.6.2.1.	Several countries for bridges. Denmark for to tunnels	General railway knowledge
	M-6 (D)	Battering rams in front of safety critical pillar supports of roof structures and overbridges in order to prevent derailed rolling stock damaging such safety critical structures. For further info see 5.6.2.8.	Germany	A1 final draft report reviewer
	M-7 (D)	Installation of dragging object and derailment detectors. The detector will detect both dragging objects and derailments. For further info see 5.5.2.5.	US and other countries	Ref /12/
	M-8 (D)	Installation of deviation points leading to a safe derailment place in strongly descending tracks from marshalling yards and train formation stations. For further info see 5.6.2.2.	Norway, Sweden,United Kingdom etc.	Preliminary Accident investigation report /44/ & Press news from JBV /45/
	M-9 (I)	Radio or cell phone communication installations like GSM-R in order to transfer emergency stop orders to trains. For further info see 5.6.2.7.	To be implemented as part of Interoperability directive and TSIs command, control and signalling.	Part of ERTMS specification in TSI command, control and signalling /
Operational	M-10 (I)	Separate passenger and freight traffic to separate lines to a larger degree (which is also EU-policy). For further info see 5.6.3.1.	High speed lines for passenger traffic. Betuwe route (NL) for dedicated freight	EU-programme
	M-11 (D)	Restrictions on freight traffic in general or hazardous materials transport in special through certain busy passenger terminals and/or underground stations to restrict traffic and limit the consequences of a derailment. For further info see 5.6.3.2.	Examples are banning of general freight traffic through airport train stations (e.g. Oslo and Schippol)	NL - Prorail Network Statement 2010 /25/
	M-12 (D)	Develop and apply a checklist for dangerous goods transport as the Swiss checklist for dangerous goods transport by freight trains. For further info see 5.6.3.3	Switzerland	BAV Checklisten – Checkliste Gefahrgut.
	M-13 (D)	Requirement for activating of warning lights in driving end of train. For further info see 5.6.3.3.	Switzerland	BAV Fahrdienstvorschriften /28/

5.6.2 Description of Technical Consequence Mitigating Measures

5.6.2.1 Installation of Guard Rails between Running Rails

The European railways in general install guard rails between the running rails at bridges to limit the movement of a derailed wagon. In some countries and railway lines (e.g. Øresund tunnel in Denmark) guard rails are also fitted in tunnels. The measure could be given a wider application in order to limit the free movement of a derailed wagon and hence may limit the consequences of a derailment.

Guard rails should not ne confused with check rails (P-1) that are installed to limit the consequences of a derailment, see 5.5.1.1.

5.6.2.2 Installation of Deviation Points leading to a “Safe” Derailment Places

In order to handle runaway rolling stock in strongly descending tracks from marshalling yards controlled derailment points may be provided to avoid runaway rolling stock accelerating in the descending tracks and causing large consequence collisions or derailments or other accidents further down the line. Such trap points are frequently used in many networks and are derailment devices to limit consequences if other safety measures have failed or are are not sufficient.

Severe accidents due to a lack of safety trap points have recently occurred March 24th 2010 at Alnabru/Sjursøya in Oslo Norway /44/ causing 3 fatalities and 4 serious injuries, and December 3rd 2005 at Salerno in Italy /46/ causing one fatality and 3 injuries. Pursuant to the Alnabru/Sjursøya accident Jernbaneverket in Norway has installed deviated points leading to a safe derailment location /45/.

In addition, a derail or derailer is a device used to prevent fouling of a track by unauthorized movements of trains or unattended rolling stock. It works (as the name suggests) by derailing the equipment as it rolls over or through the derail.

5.6.2.3 Installation of Derailment Detector Valves

The purpose of a derailment detector is to detect that a derailment has occurred and to either automatically employ brakes to bring the train to a halt or to warn the driver and allow the driver to take appropriate action. The technology employed is typically a spring mass valve measuring vertical acceleration. Acceleration above a certain threshold activates the emergency brake valve. The derailment detector valve is installed on rolling stock in Slovenia and Switzerland (tank wagons), and is provided by tank car hire wagon companies.

It is also reported that similar systems are used by RWE Rheinbraun trains operating in Germany.

5.6.2.4 Crash Protection of Tank Cars

Tank wagon hire companies have available for hire rail tank wagons with a large number of elements for improving the safety of hazardous goods transport services.

The rail tank wagons are fitted with special buffers with additional deformation elements and structural protection to prevent damage for impact speeds up to approx. 35 km/h depending upon the size of the train. It is a requirement for transport of many types of hazardous materials that the wagon is equipped with protection against buffer locking (Überpufferung) to prevent structural damage to the tank and wagon frame in an accident. RID specifies the minimum requirement for wagons used for various type of materials /15/.

The unit also features protective shields on both ends of the tank serving as a crumple zone and protecting the tank bottom from perforation in the event of buffer locking and overriding. Design improvements on the fittings dome provide added protection against leakage if the vehicle overturns or rolls over. The additional optional safety elements increase the tare weight by only approx. 1.2t.

The CPR tank car (Crash Protected Rail Tank Car) meets the valid rail standards (e.g., UIC, RIV) and European standards for rail tank cars EN12561. In terms of design and technology, the wagon is optimal for cross-border transport services.

5.6.2.5 Install Warning Lights in Driving End of Train

In Switzerland it is a requirement that locomotives are quipped with warning lights in the front that can be lit to warn trains on the neighbouring track in the opposite direction about possible dangers in terms derailed wagons etc. Installation of such warning lights can be extended to other countries.

These warning lights (red flashing lights) should be activated if the train driver suspects that the neighbouring track could be blocked or interfered by a derailment or other obstruction. See also 5.6.3.3.

5.6.2.6 Derailment Guides on Bogies and Wagon Supports

A number of high speed passenger trains are equipped with structures or equipment in the bogie which ensures that the wagon is kept along the track if a derailment of one axle occurs. Examples of such trains are TGV in France, X-2000 in Sweden and Shinkansen in Japan. In many cases the guiding devices has been installed for other purposes and for other functions, but their guiding effect has been proven in accidents. /39/

It is also reported that similar systems are used by RWE Rheinbraun trains operating in Germany.

5.6.2.7 Emergency communication equipment

Emergency communication connection from between trains and tratffic central and trains can reduce the time from derailment to train stop and hence reduce consequences. GSM-R is a cell phone based communication system that is specified as pert of ERTMS and will be standard system in the EU-countries.

5.6.2.8 Battering rams/structural protection

Safety critical structural supports of platform roofs, large overbridges located between tracks or close to tracks may be given additional protection in the form of battering rams or other forms of structural protection to limit the risk of damage from derailed rolling stock. The measure are used to protect special safety critical structures and is not very commonly used.

5.6.3 Description of Organisational and Operational Consequence Mitigating Measures

5.6.3.1 Separation of Freight and Passenger Traffic by Route or Time

In order to minimise the risk of hazardous materials rail transport, hazardous materials trains should as far as possible be separated from heavy passenger rail traffic by route or time of operation in order to minimize the consequence. Hazardous material trains should if possible also be routed around high population density residential areas.

5.6.3.2 Restrictions on Freight Traffic through busy City Terminals and/or Underground Stations

Restrictions on freight traffic in general or hazardous materials transport in particular through certain busy passenger terminals, city centres and/or underground stations to restrict traffic and limit the consequences of a derailment.

Examples are banning of general freight traffic at busy lines around Rotterdam and Amsterdam or through airport train stations as Oslo Airport and Schipol in Amsterdam /25/.

5.6.3.3 Develop and Use a Checklist for Dangerous Goods Transport

The Swiss “Bundesamt für Verkehr” has developed a checklist for use by freight train transport of dangerous goods /41/. The checklist is meant as an operational aid in controlling freight train transports of dangerous goods. The checklist could be adopted for use in the EU and other countries.

5.6.3.4 Requirements for Activation of Warning Lights in Driving End of Train

In Switzerland it is a requirement that safety warning lights (red flashing lights) in the front of the train are activated if there is a suspicion that a derailment has occurred and there is a chance that the neighbouring track is blocked by the derailment or other obstruction. /28/

Improved communication systems by GSM-R required by ERTMS can be an alternative to the above measure.

6.0 Detector status in the USA

The Association of American Railroads is the main interest organisation of the American railways and has provided information about the situation in the United States of America and Canada.

6.1 US Detector Deployment Status

According to information by AAR the following deployment status in the US with regard to number of various types of detectors at 2009 for the various wayside detectors is as follows: /12/

Deployment Status of detector installations in the US installed and maintained by railroads:

- Wheel Impact Load Detectors (about 130).
- Truck Steering Performance (about 30).
- Acoustic Bearing (about 25).
- Hot Bearing Box (about 6000).
- Wheel Profile (about 10).
- Brake Shoe Thickness (about 3).
- Cracked Wheel (1).
- Safety Appliance (2).
- High Speed Stability (about 70…added to WILD).
- Hot/Cold Wheel (about 700).
- Dragging Equipment (about 6000).

Most detectors' types are coupled with Automatic Equipment Identification (AEI) information.

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a different approach for a new reality:

Det Norske Veritas

Assessment of freight train derailment risk reduction measures:

A2 – Markets for Technical Measures

Report for European Railway Agency
Report No: BA000777/03
Rev: 02

12 April 2011

MANAGING RISK

Assessment of freight train derailment risk reduction measures: Markets for Technical Measures
for

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Summary: This document presents a review of the types of technical measures available for the purpose of reducing the likelihood or consequence of freight train derailments. For these measures, this document reviews the state of the market.

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0.0 Executive Summary

0.1 Study Scope and Objectives

Det Norske Veritas (DNV) is completing a study on behalf of the European Railway Agency (the Agency), the objective of which is twofold:

1. Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation within 5 to 10 years). For these measures, Part A work is also required to assess the market status for technical measures (defined as devices or systems) and establish objective performance data for the identified measures. The work in Part A also extends to identifying, as far as is possible, potential long term measures (not expected to be ready to implement within 10 years) as an input to other research projects currently underway.
2. Part B has the objective of analysing the measures identified in Part A with a view to establishing those that show the most promise from a risk reduction viewpoint. Part B addresses such measures which are available at the short and medium terms.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland. In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

This report concerns the Part A remit associated with the identification of ***market status for technical measures (defined as devices or systems)***. Other work in Part A deals with the other scope requirements, and is separately reported. It should be noted that this report is factual in nature and does not seek to make any assessment regarding performance or effectiveness of the identified measures - all measures reported here are to be taken forward for consideration on Part B.

0.2 Methodology and Study Results

The establishment of market share status proceeded using the following methodology:

1. Establish from other work in Part A the list of existing and future technical measures that are, or could be, applied to reduce rail freight train derailment risk.
2. For the technical measures identified from 1 above, complete research to establish total market size for technical measures, market share and other pertinent information through:
    a. Interrogation of railway suppliers published material and product catalogues.
    b. Re-use of existing research on market suppliers
    c. Direct consultation with the railway supplier market to establish relevant information on the products they offer.
3. Consolidate the results from this task, and other tasks in Part A, to arrive at this market status report.

The work reported here has studied the following ***existing*** technical measures:

- Hot Axle Box Detection (HABD) systems (devices to detect hot axles and raise an alarm so that the defective wagon can be inspected). We concluded this to be a mature market, with many existing suppliers. Pricing levels are likely to be stable, and unlikely to be influenced by further regulation.

- Acoustic Bearing Monitoring (ABD) systems (devices to detect early onset of bearing failure). We concluded this to be an existing technology, although with few installed applications within the European rail community (it is predominantly used in countries such as China, the USA and Australia). It is dominated by a few suppliers. These suppliers seem to have different geographical foci. Extension into the European market would present a new market opportunity for these existing suppliers.
- Wheel Load / Wheel Load Impact Detectors (devices to detect wheel defects, Y/Q forces etc). We concluded this to be an existing market with many suppliers of systems offering different solutions to the same problem. Pricing levels are likely to be stable, and unlikely to be influenced by future regulation.
- Bogie Performance Monitoring systems (devices to detect tracking problems and other bogie defects). We concluded this to be a new and emerging market, dominated by a few suppliers. The potential market (in terms of potential device population) is considered to be small because only a small number of these systems are required.
- Wheel Profile Measurement systems (devices to check wheel profile, wheel diameter etc). The market is relatively small, but represented by at least 8 suppliers offering different systems with systems of this type being in use for at least 2 decades. Pricing levels are likely to be stable.
- Loading Gauge Infringement Detectors (to detect out of gauge loads, dragging equipment etc). Our analysis of measures in this category has revealed a small number of suppliers of such systems. We are aware however that other approaches exist to detecting out of gauge loads using measurement devices and bespoke engineered systems.
- Derailment Detection Systems (devices to detect axles that have derailed). The size of the existing market is growing, and currently about 2,000 wagons are equipped world-wide. The potential future market size is significant, and could extend in theory to every freight wagon. The technology is not new, although the application to this purpose is novel. Prices of products are relatively cheap and it is considered there is little room for further price reductions.

The work reported here has studied the following ***potential future*** technical measures:

- Image Analysis Systems (devices to detect loose items, such as braking equipment, coupler separation etc). We are aware of no installations of these systems within the European rail community. These systems are provided by a small number of suppliers. Potential market share/size for these systems cannot accurately be predicted. However, the functions performed by such systems are provided by other devices presently installed or by other risk controls applied.
- Anti-lock Devices (devices to reduce wheel locking for freight wagons). Our analysis of measures in this category has revealed one supplier of such systems. The potential market size is similar to the derailment detector devices, reported above.
- Sliding Wheel Detectors (devices to detect wheel locking – fitted trackside). Our analysis of measures in this category has revealed one supplier of such systems. It is likely that deployment of such devices would be limited to exits from freight loading bays / routes such that defective braking could be identified prior to entering service which will define the potential market share.

0.3 Conclusions and Next Steps

This work reported here has established market information for those technical measures that have been identified by the study team to date. However future work (Part B) will supplement, if required, the information provided in this document and add any new information that is advised to the project team.

The next project step will take this information forward into Part B where it will be used to provide input to task of assessing the effectiveness of these measures (and other non technical measures) in terms of freight train derailment risk reduction, in accordance with the Part B study objectives.

Contents

1.0 Introduction

1.1 Background

This document is prepared against the requirements of the European Railway Agency's (ERA) study "Assessment of existing technical and operational measures against freight train derailments in the Community's railways", [1]. The task description for the work reported in this document is as follows:

> *The task A.2 will provide data on markets related to 'technical measures'. The volume of existing market and sales, in and outside EU, shall be described as well as the respective shares of key designers, manufacturers, suppliers.*

In addition to this task report, the following additional reports are relevant and are referred to as appropriate:

- Task A1, [2]. This document provides information about existing safety measures that are applied in the railway system to reduce the likelihood or mitigate the consequences of derailments, and more specifically freight train derailments.
- Task A3, [3]. This document provides an assessment of the function and performance of the existing, short and medium term measures that are in place, or could be applied in the future, to reduce the likelihood or mitigate the consequences of derailments, and more specifically freight train derailment.

1.2 Definitions

The following definitions are used within this document:

- Existing safety measures means currently applied for implementing a given regulation requirement, or applied on a voluntary basis, [1].
- Short term (safety) measure means that the safety measure is ready to be applied or to be introduced in EU regulation by 1st of January 2013, [1].
- Medium term (safety) measure means that the safety measure will be ready to be applied or to be introduced in EU regulation within 5 to 10 years, [1].
- A technical (safety) measure is defined as being a device or a specific technical system, [1].

Safety measures discussed within this document include:

- Human measures, defined as: Measures to improve the individual's capability to perform his/her duties in a correct and safe manner. This includes competence, knowledge, decision support information systems for the persons that have the responsibility to carry out a certain task.
- Organisational measures, defined as: Measures pertaining to the management of the organisation, including staff training, safety management system, operational planning, human resource management, handling of requirements related to independence, roles and responsibilities etc.
- Operational measures, defined as: Measures in this category include operating instructions or operational rules that are in place in part to reduce the risk of freight train derailments. Examples might include speed restrictions, rule book actions etc.
- Technical measures, defined as: Measures that are based on a device or particular technical system.

Finally, the main work for this task is listed in Section 3.0. The following terms and definitions apply:

- Device: This is the specific name or identifier of that device.
- Producer: This is the name of the organisation that produces / manufacturers that device.
- Technical Summary: This is a summary of the technology used.
- Development Status: This is a description of the history, major device updates.
- Currently Installed Base: Installed base is the estimate of the number of devices that are currently installed and in-service.
- Estimated Market Share and Main Competitors: Wherever possible, market share represents the estimated percentage (or other measure) that describes the share that device has when compared to the total market size for that device. In some cases this has not been possible however and so other monetary measures are sometimes used. Main competitor represents the supplier's view of which products are the main alternatives to that device.

This report does not seek to make any assessment regarding cost effectiveness of these measures. In this regard, the work reported here will be taken forward to a further project stage (Part B) that will seek to identify the most promising measures from those identified here. The future work (Part B) referred to will supplement, if required, the list of measures discussed in this document and add any new measures that are made advised to the project team.

All identified measures will be considered in Part B.

2.0 Methodology

2.1 Purpose

The purpose of the market research is to:

- Collect information on suppliers and current / future products in the market;
- Understand the market structure for various technical measures, i.e. in terms of whether there is only a single supplier (monopoly), a few major suppliers (oligopoly) or many suppliers (competitive market). Some suppliers may also be dominant;
- Understand the current size of the market compared to the potential size. A small difference indicates a mature market; a large difference indicates an emerging market and may also imply that there will be periods where demand outstrips supply. The difference may also be a rough indicator of the cost of introducing a measure.

2.2 Data Collection

2.2.1 Establishing Existing and Future Measures

The work to establish the portfolio of all ***existing measures*** (Table 1 below) was informed by our A1 work [2]. Our A1 [2] report summarises the measures that are currently used by Infrastructure Managers (IMs), Railway Undertakings (RUs) and other railway stakeholders in the area of rail freight risk reduction. As reported in A1 [2] these measures were identified through a review of available literature, network statements, accident reports and the like.

In addition, DNV embarked on a process of direct consultation with IMs, RUs and other railway stakeholders and received responses from 38 such organisations identifying 47 preventive measures and 13 mitigation reduction measures.

Concerning ***future measures*** (Table 2 below), part of our direct consultation included questions that requested respondents' views on future innovations and measures related to freight train derailment risk reduction measures. Further, this direct consultation also included railway trade and research organisations thus enabling their views (and those of their members) regarding existing and future measures to be established.

2.2.2 Measure Classification

In our report A1 [2], all measures were classified into operational, organisation, technical or human as required by the Terms of Reference (TOR) [1]. Those classified as ***technical measures*** (defined by the Agency as being based on a device or particular technical system), were considered in this report, as also required by the TOR [1].

2.3 Market Share and Market Details for Technical Measures

Following on from the work reported above, DNV sought to establish potential market suppliers for the identified technical measures. A number of methods were used to achieve this goal:

- In some cases the IM, RU or railway stakeholder responding to the direct consultation provided details of suppliers.
- Internet research was completed to identify additional suppliers to the market.
- Previous research work on this subject was interrogated and two reports have been particularly helpful in this respect:
  - Rail Safety and Standards Board (2008), Identification of existing and new technologies for wheelset condition monitoring, RSSB Report for Task T607, July [4].

- TTCI (2010), 15th annual AAR Research Review, Presentation from March 2-3, 2010 [5].

Once suppliers were identified, DNV invited these organisations to contribute to the project through a second round of direct consultation. This consultation took the form of a supplier questionnaire and / or interview format. The interview guide / questionnaire is included in Appendix I. The questionnaire consists of two parts:

- Part 1 is an Introduction to the study and Common Questions, i.e. not pertaining to a specific product;
- Part 2 are product specific questions. We requested that one questionnaire per product be filled in.

Initial contact with each supplier was, in most cases made using telephone, and, when receiving a positive response to participation, either an interview arranged, or a questionnaire issued. In total, we have received product information on over 30 technical measures following this work.

As will be seen from the information provided in Appendix I, suppliers were asked for their assessment of existing and potential market size, their share of the market, costing information etc. Collectively, the information gathered from all the sources described above was used to estimate market share information.

2.4 Discussion of Challenges Related to the Data Collection Process

Securing active involvement from suppliers has been a challenge, requiring perseverance and time. In general, we have found that larger suppliers with an existing market with the European Union (EU) have been reluctant to respond. In contrast, suppliers with newer products and/or lower penetration into existing EU markets have been more responsive.

Some suppliers who have responded have considered that certain data relating to market share, product pricing and technology cannot be released, despite the confidentiality clauses surrounding this work. Finally, in many cases, data on market size and share was not known by the suppliers.

This of course means that the results of our market assessment may not be as robust as we would like it to be, based solely on supplier responses. We have addressed this issue where possible by:

- Reviewing IM and RU responses to our consultation on safety measures (as reported in [2, 3]). In some cases this consultation and subsequent further communication has identified the types of technical measures used.
- Establishing the quantity of suppliers in the market for a given technical measure, thus enabling a judgement of whether the market is a monopoly, oligopoly or competitive.
- Establishing the maturity of the market and its current regulatory status.

Through these method enhancements, DNV considers that the data obtained is fit for its intended purpose.

2.5 Existing Measures for Market Research

Below we tabulate the conclusions of this work in terms of existing measures. In these tables those that have been classified as technical measures are shown as being subject to market assessment.

Table 1 List of Existing Measures

Measure Number	Description	Market Assessment	Comment / Discussion
P-1	Check rail	No	Check rails are a well established mechanical measure with many suppliers.
P-2	Track and flange lubrication installed on track	No	Track and flange lubrication systems are installed primarily as measures to reduce track wear, although they are thought to contribute to reducing derailments in certain cases. However, as derailment mitigation is not their primary purpose we have not considered them here.
P-3	Rock scree and avalanche protection structures	No	This is construction work at specific sites thought to be vulnerable to natural hazards – not a product bought off the shelf.
P-4	Rock scree and avalanche detectors	No	These systems are primarily engineered systems – purpose built to specific sites, not products bought off the shelf.
P-5	Obstacle detectors at level crossings	No	The primary objective of obstacle detectors is to avoid collisions usually at level crossings, although they may contribute to minimising the risk of a follow-on derailment. They are not considered here.
P-6	Geo radars	No	Geo radars. IMs currently employ techniques for the identification of track superstructure faults. Further, track superstructure faults appear, based on our accident review, to make only a minor contribution to freight train derailments.
P-7	Rolling stock mounted equipment for monitoring of rail profile conditions.	No	Rolling stock equipment for rail profile monitoring. This technology allows for quicker and more efficient inspection of rail profile conditions (compared with the use of specialist vehicles) The main benefits of such systems are cost and efficiency, rather than safety. These are not considered further.
P-8	Track circuit	No	Track circuits are part of a normal signalling system and although they may also help detect rail ruptures, are generally not for this on its own. They are not considered here.
P-9	Interlocking of points operation while track is occupied	No	This is part of a normal interlocking system. Interlocking of points operation is a question of the design of the interlocking system and is not a product bought off the shelf.
P-10	Hot axle box (hot bearing) detectors	Yes	
P-11	Acoustic bearing monitoring equipment	Yes	
P-12	Hot wheel and hot brake detectors	No	These are often provided as a function of hot axle box detectors, and for the purposes of this assessment are jointly considered with P-10.
P-13	Wheel load and wheel impact load detectors	Yes	
P-14	Dragging object and derailment detectors	No	See M-6
P-15	Bogie performance monitoring/Bogie lateral instability detection (bogie hunting)	Yes	
P-16	Wheel profile measurement system / Wheel profile monitoring unit	Yes	
P-17	Loading gauge infringement detectors / profile and antenna protruding detection	Yes	
P-18	Sufficient availability of maintenance resources	No	Operational/organisational measure.
P-19	Clearance of obstructions from flange groove (particularly at level crossings)	No	Normal inspection and maintenance in most countries.
P-20	Ultrasonic rail inspection	No	This measure relates to the frequency of rail inspections.
P-21	Track geometry measurement	No	This measure relates to the frequency and coverage of track geometry inspections.

Measure Number	Description	Market Assessment	Comment / Discussion
P-22	EU-wide intervention/action limits for track twist	No	Operational/organisational measure.
P-23	EU-wide intervention/action limits for track gauge variations	No	Operational/organisational measure.
P-24	EU-wide intervention/action limits for cant variations	No	Operational/organisational measure.
P-25	EU-wide intervention/action limits for height variations and cyclic tops	No	Operational/organisational measure.
P-26	Flange lubrication of locomotives	No	This is equipment mounted on the locomotive which would perform a normal function. The equipment will not have the capability of detecting a possibly dangerous situation.
P-27	Replace composite wheels with monoblock wheels	No	Wheels are a part of any locomotive or wagon. It is a simple mechanical measure. Both types of wheels have existed for a long time and constitute alternative technologies. Most suppliers of wheels will provide both types of wheels.
P-28	Replace metal roller cages in axle bearings by polyamide roller cages.	No	Roller cages in axle bearings are a part of any rolling stock. Different types of cages have existed for a long time and constitute alternative technologies.
P-29	Replace existing axles for stronger axles or axles with improved material properties with regard to crack initiation and crack propagation	No	Axles are a part of any locomotive or wagon. It is a simple mechanical measure. Different types of axles have existed for a long time and constitute alternative technologies. Most suppliers of axles will provide different types.
P-30	Increase the use of central coupler between wagons in fixed whole train operation.	No	Couplers are a part of any locomotive or wagon. Different types of couplers have existed for a long time and constitute alternative technologies. Mandating a new type of couplers will raise a number of problems in the transitory period – except for isolated transportation routes.
P-31	Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis.	No	This means buying new types of wagons – it is not a measure that can be applied to old rolling stock.
P-32	Install disc brakes instead of wheel tread brakes.	No	Brakes are a part of any locomotive or wagon. Different types of brakes have existed for a long time and constitute alternative technologies. Most suppliers of brakes will provide different types.
P-33	Rolling stock design for track twists	No	This means buying new types of wagons – it is not a measure that can be applied to old rolling stock.
P-34	Secure brake gear underframe	No	This requires a special design for new wagons or retrofitting existing wagons; retrofitting requires some form of rebuilding, i.e. it is not a product bought off the shelf.
P-35	Regular greasing and checks of rolling stock buffers.	No	Operational measures
P-36	Wheel set integrity inspection (ultrasonic) programs	No	This is the normal wheelset inspection program carried out to by all RUs to ascertain that the wheels and axles are free of safety critical wear damages and cracks. This is normally carried out by visual inspection as well as ultrasonic or other NDT-methods while the train is in a depot.
P-37	Derating of allowable axle loads	No	Operational/organisational measure.
P-38	EVIC (European Visual Inspection Catalogue)-based inspection of freight train rolling stock axles	No	Operational/organisational measure.
P-39	Double check and signing of safety-classified maintenance operations	No	Operational/organisational measure.
P-40	Qualified and registered person responsible for loading	No	Human measure.
P-41	Locomotive and first wagons of long freight trains in brake position G	No	Human measure.
P-42	Limitations on use of brake action in difficult track geometry	No	Human measure.
P-43	Dynamic brake test on the route	No	Human measure.

Measure Number	Description	Market Assessment	Comment / Discussion
P-44	Saw tooth braking to limit heat exposure to wheels	No	Human measure.
P-45	Initiation of braking or speed reduction prior to passing signal showing reduced speed	No	Human measure.
P-46	Not allowing traffic controllers and drivers to override detector alarms	No	Human measure.
P-47	Wagons equipped with a balance to detect overload in visual inspection.	No	Human measure.
M-1	Derailment detection devices	Yes	
M-7	Dragging object / derailment detectors	No	In the context of derailment detection these devices offer an alternative to M-1. To be comparable however these devices would have to be fitted at a very high frequency along the track, with high installation costs and maintenance costs. On the basis that the cost would be prohibitive (compared to M-1 we have not considered these further.
M-2 to M-6 and M-7 to M-13	These measures are excluded from the scope of future assessment during Part B [1] and hence are not required to have an effectiveness assessment allocated to them.		

2.6 Future Measures

Within our report [3], we identified 8 categories of potential future measures intended to prevent or reduce the likelihood of freight train derailments. These are tabulated below. In these tables those that have been classified as technical measures are shown as being subject to market assessment.

We note that the information and assessments that follow for measures that have less operational experience within Europe and therefore may be subject to more variation and uncertainty.

Table 2 List of Future Measures

Measure	Description	Market Assessment	Comment / Discussion
End-of-train device (brakes)	In the USA & Canada freight trains are installed with "end of train devices" that are in radio contact with the driver, and by radio signal to the unit the driver can apply brakes on the train in an emergency situation.	No	Based on the summary accident review completed to date, lack of braking effort / application speed has not been seen to be a significant contributory factor to freight train derailments. This measure is considered unlikely to show significant benefit.
Awareness program and improved maintenance	A concern expressed to us by several IMs was regarding the quality of freight wagons from some countries. In particular that maintenance as well as supervision of national authorities of this maintenance is of varying standards.	No	Not a technical measure
Hot Axle Box Indication	The use of thermo-sensitive chalks or similar to check for hot axle boxes	No	Not a technical measure
Machine vision devices	These products are designed to detect faults that may occur on freight vehicles when they run pass the detection site. Such devices are installed at trackside and employ hi-speed cameras to grab images of the vehicles and these images are sent to the computer for processing, comparing and analysis so any fault on the vehicle can be distinguished and detected. They detect mechanical failures of the bogie, dragging objects, coupler faults etc.	Yes	
Telematics	Devices that allow receipt and transmittal of information from / to rail freight vehicles	No	Many of the devices providing these functions are readily

Measure	Description	Market Assessment	Comment / Discussion
			available from many existing suppliers. A market assessment is not considered necessary
Anti-lock device	Antilock device for freight cars. A unit of this type is running on container wagons in the GB. Such devices may help to prevent several undesirable and contributory causes of freight train derailment, such as increased track wear, wheel flats and overheating axles. They may also provide a local power source for other monitoring systems.	Yes	
Sliding wheel detectors	Sliding wheel detectors. These systems detect wheels that are not rotating correctly and raise an alarm, with similar benefits to the antilock device for freight wagons described above. They are currently used in at least Australia, although a GB demonstration is planned for 2011.	Yes	
Handbrake interlock	Handbrake interlock. This would prevent a freight train moving off with the handbrake applied.	No	We have found no suppliers of this measure, and assume it is an engineered system.

3.0 Market Analysis[1]

This chapter is split into existing measures (Section 3.1) and future measures (Section 3.2).

3.1 Existing Measures

3.1.1 P-10: Hot Axle Box / Bearing Detector (and P-12 hot wheel and brake detectors)

Table 3 Identified Hot Axle Box / Bearing Detector Suppliers

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
D.1	Producer D	The primary function of the product is to measure the temperature of bearings on railway vehicles and raise alarms in the event the bearings temperature rises above a preset limit. The product includes temperature sensors that are mounted on the track (clamping to rail) to collect infrared heat generated from bearings on the passing train, and electronic equipment that is installed at trackside to process the signals collected by the temperature sensors. The technology employed is infrared sensor technology and computer technology. Installed about every 30 km.	The product was introduced in 1999. In 2003, the temperature sensors were updated. The producer is working on further updating the temperature sensor by importing a multi-element array photon MCT detector that is able to scan more parts of the bearing to make the detection more accurate and reliable. Such up-grading is expected to be available by mid-2012. The product is approved by the safety authority in at least one country.	World wide: ~2,100 EU: 0	Total volume of sales is above 10 M€.	The product is employed both for freight and passenger traffic.
E.1	Producer E	Hot axle box detector. No further information				
F.1	Producer F	Hot axle box detector. No further information				Did not respond.
G.1	Producer G	Hot bearing detector. No further information.				Producer G have replied to our survey but nor for these products.

[1] Under the terms of the confidentiality agreement governing this work, details about individual devices has been removed.

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
H.1	Producer H	Hot axle box detector. No further information				
H.2	Producer H	Hot axle box detector. No further information provided.				
H.3	Producer H	Hot axle box detector. No further information provided.				
I.1	Producer I	Hot axle box detector. No further information provided.				Producer I have replied to our survey but nor for these products.
J.1	Producer J	Hot bearing detector. Hot wheel detector. No further information provided.				Declined to be involved in this project.
K.1	Producer K	Hot axle box and brake detector. No further information provided.				
K.2	Producer K	Hot axle box and hot wheel detector. No further information provided.				

Our market assessment for hot axle box detectors is as follows:

- We estimate the existing market in the EU-27 countries plus the 3 candidate countries, plus Norway and Switzerland, to be in excess of 1,500 installations. This is based on the results of our IM consultation, and additional information sources, such as Network Statements.
- Other major markets are known to be the USA and China. In these two countries there are about 8,000 installations. (Based on information received from our IM consultation and from supplier responses.)
- There is an existing requirement for hot axle box detectors to be installed at certain locations in the TSI for Safety in Railway Tunnels.
- Many IMs stated that they felt this technology to be effective, and already had plans to increase the installed base of such systems.

We conclude this to be a mature and existing market, with many existing suppliers. Pricing levels are likely to be stable, and unlikely to be influenced by further EU regulation. We have noted that a number of countries do not use these devices at present, and so future EU regulation in this area is likely to be absorbed by the existing supplier base, through internal tendering processes, therefore not providing any undue advantage to any particular supplier. The acoustic bearing defect detector is a competing technology which may affect the market for hot axle box detectors. It is a more expensive (around 10 times), but does not need to be installed with the same density.

3.1.2 P-11: Acoustic Bearing Defect Detector

Table 4 Identified Acoustic Bearing Defect Detector Suppliers

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
D.2	Producer D	This product's primary function is to detect bearing defects in their early stage through analysis of acoustic characteristics of the bearings. The product is installed at trackside. Two arrays of microphones are mounted at both sides of the track to collect bearing noise. Then the acoustic signals are sent to the computer for calculation, analysis and comparison to determine if the bearing is defective.	The product was introduced in 2000. Since then, only the software has been updated. The product is approved by the safety authority in at least one country.	Worldwide: 62 EU: 0	Producer D state that they have a 100% market share in one country and consider themselves one of a few major suppliers. Their volume of sales (worldwide) exceeds 10 M€. The main competing technology is hot axle box detectors.	The product is used primarily for freight traffic.
E.2	Producer E	Acoustic bearing defect detector. No further information provided.				

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
L.1	Producer L	The product's function is to detect wheel-bearing faults on railway vehicles during pass-by, providing identification on fault type, fault severity, location of defective bearing on vehicle, monitoring and trending of fault on repeat passes. Device L.1 provides alerts to operators of diminishing condition of vehicle wheel bearings and condition trending data for maintenance scheduling purposes. Bearing fault classifications identified include Cup, Cone, Roller, Looseness Fretting and combined faults. The system employs fixed microphone arrays situated in cabinets installed at the rail track wayside, recording vehicle noise during passby. Advanced signal processing of the acoustic passby noise including beam forming technology, is employed to "direct" the microphones at each axle bearing position during train passby for the equivalent of 2.5 times wheel revolutions in post processing to filter the analysed bearing acoustic signatures and identify any faulty wheel bearings	The product was commercialised in 2003 following some 10 years of development. The product has been modified in 2006, 2008, 2009 and 2010. Several upgrades are currently planned that will enable more universal application to passenger vehicles and track systems. Customer requested updates that would enable identification of Traction Motor "Inboard mounted" bearing defects will be available within 2 years. The system has approval in one country and is manufactured to ISO9001 standards	Worldwide: 50-500 EU: 1 The market potential is considered to be < 500 (> 100 M€ in monetary terms).	Producer L estimates its market share to be 85%. Sales from this product are > 10 M€. They acknowledge there is one alternative supplier of acoustic bearing detectors (we have found two), but considers its own technology unique.	The system has been deployed for both freight and passenger vehicle applications. RFID vehicle tagging (although other telematics solutions may be possible) and axle counts are used to match faults with vehicle/axle/side locations or in some instances automated visual recognition of wagon numbers is used when tagging is not available.

Our market assessment for acoustic bearing defect detectors is as follows:

- We estimate the existing market in the EU-27 countries plus the 3 candidate countries, plus Norway and Switzerland, to be in very small at present, with only known installation in Great Britain.
- Other major markets are known to be the USA and China. In these countries there are about 80 installations. Populations in other countries are unknown but not thought to be significant, perhaps in the range 100 to 150.

- There no existing requirement for acoustic bearing defect detectors in EU regulation.

We conclude this to be a new and emerging market, dominated by a few suppliers. These suppliers seem to have different geographical foci. The potential market is though (by Producer L) to be less than 500. (Because the technology is able to detect early onset of bearing failure, these devices are installed at a much lower density compared with hot axle box detectors.)

3.1.3 P-13: Wheel Load and Wheel Impact Load Detectors

Table 5 Identified Wheel Load and Wheel Load Impact Detector Suppliers

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
M.1	Producer M	Wheel impact load detector, weighing in motion and bogie performance detector.		Used in at least Switzerland, Great Britain and The Netherlands		
N.1	Producer N	Device N.1 is a modular system for identification of railway vehicles, measurement of wheel profile, diameter, back to back distance, roundness and cracks. The technology employed is transponder technology for identification, optical measurement of wheel profile, diameter and back to back distance, tactile measurement of wheel roundness, ultrasonic detection of surface cracks. Measurement passage speed is 3 to 15 km/h.	First introduced to market in 1990. Continuous improvement of product – last modification in 2009/2010. New model allowing for measurement at higher speeds will not be available before 2013. The system has approval in one country	World wide: 23 EU: 12 The potential market size is estimated to be below 500 systems world wide (10-100 M€).	Producer N estimates their market share to be 70-80% (not specifying geography), being one of a few major suppliers. Sales are above 20 M€ world wide, above 10 M€ in the EU.	The product has so far only been used for passenger traffic. The most important future markets are considered to be EU, USA, P.R. China, Russia, and India.
E.3	Producer E	Wheel impact load detector. No further information provided.				
G.2	Producer G	Axle load measurement device. No further information provided.				Producer G has replied to our survey but nor for these products.
H.4	Producer H	Wheel impact load and bogie performance detector. No further information provided.				
O.3	Producer O	Wheel impact load detector. No further information provided.				

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
I.2	Producer I	Measuring Y-forces Measuring Q-forces Analysing Y/Q and peak forces (caused by wheel flats) Measuring Y- and Q-forces is achieved through a weighing sleeper, in place of normal sleepers in the track. Weighbeams based on strain gauges.	New product not yet updated, although updates are in the process of being implemented to detect derailed axles.	New product	Major future markets considered to be European countries with borders to east European or Asian countries.	Can detect unbalanced loads and other running defects
I.3	Producer I	Measuring Q-forces (wheel loads) Analysing Q and peak forces (caused by wheel flats)	Weighing sleeper updated 2008. Measuring electronics updated 2005. Updates are in the process of being implemented to detect derailed axles.	Sales in excess of €10,000,000	Considered by Producer I to be one of a small number of suppliers of devices of this type, with a 40% market share.	Can detect unbalanced loads and other running defects
P.3	Producer P	Wheel ovalisation measurement equipment. No further information provided.				Responded to our survey, but failed to release any information that would enable a market analysis to be performed.
Q.1	Producer Q	Wheel impact load detector. No further information provided.				

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
L.2	Producer L	Detects and monitors each rail vehicle wheel for rolling wheel surface defects such as flats and spalls, together with out of roundness of the wheel and vehicle weights and imbalances. Measurements from the system provide a real time indicator for the wheel surface condition, dynamics and weights. Auto generated alerts are able to be issued following train passby when a fault has been detected that may damage rail head or cause damage to switch points and frogs. The device comprises an array of track-mounted sensors. Mounting brackets incorporate accelerometers and strain-gauged "load bars" – the system measures the wheel impact with the accelerometers and derives a vehicle weight from the load bars. Outputs from the system are processed: this provides a centralised database for wheel condition, vehicle weights (fore/aft and left/right) and out of roundness. The device issues alerts to the operator when a pre set parameter is exceeded. In addition to the dynamic measurement it also provides trending functions for forward maintenance planning.	The product was introduced to the market in 2007. Engineering design changes have been made to brackets and load bars – periodic enhancements are also made to the database. Progressive upgrades are made to defect detection algorithms / software. Improved calibration procedures are under development to minimise installation time.	World wide: <50 EU: 0 No specific geographies of installations are indicated. Producer L estimate the market size (no geography specified) at 500-5000 units (> 100 M€ in monetary terms).	Producer L does not provide any information on market share or position. Sales of this product are in the range 1-10 M€. Producer L specify that there are several wheel impact detector suppliers, without naming them.	The product is used both for freight and passenger traffic. Installation can be made in track sections where vehicle speeds of 20 Kph to 250 Kph are available. The system is capable of being installed on networks that have RFID tagged or untagged vehicles (although we presume other telematics solutions may be available).
K.3	Producer K	Flat wheel detection system. No further information provided.				

The analysis of markets for this measure is complicated by the wide range of different solutions offered by many suppliers. Indeed a number of systems in this category are modular, whilst others fulfil single functions. What we can conclude is:

- The estimated size of the existing market is less than for hot axle box detectors; fewer IMs indicated they use such systems. We estimate the size of the existing market in the EU-27 countries plus the 3 candidate countries, plus Norway and Switzerland, to be perhaps 1/10th the market for hot axle box detectors, possibly 150.
- Other markets are known to be the USA, where 130 devices of this type are in operation [2].
- There no existing requirement for these devices in EU regulation.

We conclude this to be an existing market with many suppliers of systems offering different solutions to the same problem. Pricing levels are likely to be stable, and unlikely to be influenced by EU regulation.

3.1.4 P-15: Bogie Performance Monitoring / Bogie Lateral Instability Detection (Truck Hunting)

Table 6 Identified Bogie Performance Monitoring / Bogie Lateral Instability Detection Suppliers

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
M.1	Producer M	See description of product under *P-13: Wheel load and wheel impact load detectors*		Used in at least Switzerland, Great Britain and The Netherlands		See also Table 5.
H.4	Producer H	See description of product under *P-13: Wheel load and wheel impact load detectors*				
O.2	Producer O	Bogie performance monitor. No further information provided.				
R.1	Producer R	Device R.1 identifies trucks in need of repair and that pose a higher risk of derailment. Image data, captured by an electro-optic sensor, of passing wheel sets is processed by proprietary algorithms to extract the Angle of Attack and Tracking Position of each axle. Device R.1 also includes a truck lateral instability (truck hunting) detector. There is also a web delivery database product for viewing, analyzing and reporting collected data These systems are installed by the side of straight tracks at a safe distance from passing trains. Trains should travel over this device at a constant speed, no slower than 20 km/h. Maximum train speed is 300 km/h.	Introduced in 2000 The system has been re-engineered to a more modular architecture in 2005. An updated hardware platform will be available in 2011. Approved for use in five countries. EU safety agency approvals are pending.	Installed base not disclosed. The majority of the systems are installed in the USA. Other countries that have purchased the system include Australia, Canada, China, India, and Brazil. There are currently no installations in the EU. No potential market size has been indicated, but a single system of this type is sufficient to cover a specific traffic route.	Producer R consider themselves market leaders of laser based Truck Performance Monitoring – Truck Hunting detection systems. The competing products are strain-gauge based Truck Performance Detectors (no suppliers mentioned).	The product has been used for both passenger and freight traffic. The most important future markets are considered to be: EU, Asia, Latin America.
S.1	Producer S	Uses Wheel Sensors to evaluate the bogie performance defects and flag critical conditions, based on		Currently installed in North & South Americas, Australia and Asia		Responded to survey, but did not release market data

Our market assessment for truck hunting detectors is as follows:

- We estimate the size of the existing market in the EU-27 countries plus the 3 candidate countries, plus Norway and Switzerland, to be very small at present, probably in single figures.
- Other markets exist in the USA who operate about 30 of these installations.
- There no existing requirement for these devices in EU regulation.

We conclude this to be a new and emerging market, dominated by a few suppliers. The potential market (in terms of potential device population) is considered to be small because it is stated that only a small number of these systems are required.

3.1.5 P-16: Wheel Profile Measurement System / Wheel Profile Monitoring Unit

Table 7 Wheel Profile Measurement System / Wheel Profile Monitoring Unit Suppliers

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
T.1	Producer T	Wheel measurement system. No further information provided.				
U.1	Producer U	Wheel profile measurement system. No further information provided.				Declined to be involved in this project.
V.1	Producer V	Wheel profile measurement system. No further information provided.				
W.1	Producer W	Wheel profile measurement system. No further information provided.				Unable to respond within study timescales.
I.4	Producer I	Wheel Geometry Diagnostics Measuring and Optimising No further information provided.				Producer I has responded although did not provide details for all their devices.
N.1	Producer N	Device N.1 is a modular system for identification of railway vehicles, measurement of wheel profile, diameter, back to back distance, roundness and cracks. The technology employed is transponder technology for identification, optical measurement of wheel profile, diameter and back to back distance, tactile measurement of wheel roundness, ultrasonic detection of surface cracks. Measurement passage speed is 3 to 15 km/h.	First introduced to market in 1990. Continuous improvement of product – last modification in 2009/2010. New model allowing for measurement at higher speeds will not be available before 2013. The system has approval in one country	World wide: 23 EU: 12 The potential market size is estimated to be below 500 systems world wide (10-100 M€).	Producer N estimates their market share to be 70-80% (not specifying geography), being one of a few major suppliers. Sales are above 20 M€ world wide, above 10 M€ in the EU.	The product has so far only been used for passenger traffic. The most important future markets are considered to be EU, USA, P.R. China, Russia, and India.
F.2	Producer F	Wheel profile measurement system and wheel surface defect measurement system. No further information provided.				

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
G.3	Producer G	The system provides wheel profile data for all required parameters. Trending and level based alarms then alert the maintenance teams so rectification measures can be taken. The system is based on using camera and laser technology to captures a true 3D profile of the wheel surface. This includes the back of flange and wheel rim profile. All measured parameters are then calculated from this wheel profile. E.g. flange height, flange thickness, tread hollowness and back-to-back measurements. It is normally installed on depots, but has the capability to be installed on the main line. The system is best installed where the most trains pass frequently so that data the maximum amount of data can be collected. This is often on wash roads for passenger stock	The product was introduced in 2002. It is constantly being refined to utilise advances in technology. The profile system is part of a complete vehicle inspection system with wheel out of round technology under development. Out of round inspection should be available by the end of 2011. Data delivery to the end user is also critical and the data interface and data analysis tools are being constantly refined. The system is modular and can be supplied in individual system components e.g. wheel profile, or out of round. Additional components can be added at a later date.	Worldwide: 11 EU: 1 It is estimated that the total market (geography not indicated) will be below 500 units (10-100 M€, including complementary work).	Market share is unknown. Sales around 3 M£. Producer G consider themselves market leader in chosen markets. Main competitors are not named.	The product is used both for passenger and freight traffic. Historically the market was Australia, future sales may be greater in Europe and Asia.
P.2	Producer P	Wheel profile measurement system. No further information provided.				Responded to our survey, but failed to release any information that would enable a market analysis to be performed.

The analysis of markets for this measure is as follows:

- The size of the existing market is difficult to estimate due to the varying technologies and different functions offered by such systems, however we consider the market to be relatively small; few IMs/RUs indicated they use such systems. We estimate the size of market in the EU-27 countries plus the 3 candidate countries, plus Norway and Switzerland, to be in double figures, but not significant.

- Other markets are known to be the USA, who operate 10 devices of this type [2].
- There no existing requirement for these devices in EU regulation.

The market is relatively small, but represented by at least 8 suppliers offering different systems with systems of this type being in use for at least 2 decades. Pricing levels are likely to be stable.

3.1.6 P-17: Loading Gauge Infringement Detectors / Profile and Antenna Protruding Detection

Table 8 Loading Gauge Infringement Detectors / Profile and Antenna Protruding Detection Suppliers

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
G.4	Producer G	The Out of Gauge Detection and Dragging Equipment System raises an alarm if an item is out of gauge. The system is for both height and width loading gauge detection. It also features a dragging equipment detection system. The system uses a series lasers to detect out of gauge items. These sensors are mounted to an existing gantry or other suitable structure. When a series of laser beams are interrupted, the system analyses the precise nature of the interruption and determines if an alarm should be raised. Where required video images are also supplied to identify the infringing object(s). The system has a complex set of algorithms and utilising multiple beams paths combined with pattern analyse to ensure that false positives are minimised. Installation is normally on depot departure road or on the main line if appropriate. One installation per sidings/depot exit road only. Alternatively the system could go on the main line to reduce the number of systems	The system was introduced in 2003. The system was updated in 2008 to operate and detect 20mm objects at vehicle speeds up to 100 km/h. Improvements though evolution in technology only; no plans to remove from market.	World wide: 6 EU: 0 The potential market size is not known (has not yet performed market analysis).	Large market share in one country (not EU). Does not know competing products.	The system is primarily for freight, but also employed in a limited capacity for passenger traffic. European freight railways are considered an important future market.

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
I.5	Producer I	Scans the entire contour of the train and detects events such as foreign matter or, e.g. slipped load and alerts the operator early enough to take the necessary action. No further detail provided	New product			Producer I responded although did not provide details for all their devices.

Our analysis of measures in this category has revealed a small number of suppliers of such systems. We are aware however that other approaches exist to detecting out of gauge loads using measurement devices and bespoke engineered systems. We have classified this as an existing measure, but if may be appropriate to consider moving this measure to short / medium term as the project evolves.

3.1.7 M-1: Derailment Detector

Table 9 Derailment Detector Suppliers

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
X.1	Producer X	Derailment detector. No further information provided.				
B.3	Producer B	The objective of the derailment detector device (DDD) is to detect a wagon derailment and then apply brakes in order to bring the train to a prompt stop, thus avoiding a derailed wagon being dragged along causing infrastructure damage and a possible more severe derailment. The device detects vertical acceleration above 9.0 g ± 2.5 g (a level agreed with UIC). If the trigger level is reached then an automatic brake application is applied. This is achieved by a spring mass system which moves vertically, and if the trigger level reached an emergency valve is released and a full train brake application applied. (The DDD is fitted to both ends of a wagon.) When the unit is activated and air flows out an external indicator is visible to show which unit led to the brake application. After applying the brakes the unit automatically resets in its not-activated status, only the indicator stays in the “activated” position.	The product was introduced in 1998. Changes were made in 2006 to alter the trigger level and also different oils and greases were employed. UIC approval and approval by one NSA.	Worldwide: ~2800 (1400 wagons) This system is installed in Switzerland, Slovenia, Hungary and Romania and small number in Germany. Morocco has installed 375 pairs. In total about 1400 wagons are equipped with this system, mostly on tank wagons. The potential market size is estimated as follows (geography not given): ▪ RID2011 Application scope – 17,000 wagons ▪ All dangerous goods wagons – 100,000 ▪ All freight wagons – 720,000	Producer B estimates their market share to > 90% and consider themselves market leader. At least 3 alternative systems were known to Producer B. Fixed, stationary devices are a potential alternative technology.	The product is used for freight traffic only, primarily tank wagons.

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
Y.1	Producer Y	Derailment detector. This device is attached to both ends of a wagon and connected to the brake pipe and applies brakes on detecting vertical or horizontal accelerations above set limits. The device is self resetting, and provides an indication of the triggering of the device via an external indicator ring.	UIC approval June 2010			

There is a clear market leader in this technology, although new suppliers are entering the market. A large number of IMs and RUs indicated they were interested in the wider spread of systems such as these.

- The size of the existing market is growing, and currently about 2,000 wagons are equipped world-wide. The potential future market size is significant, and could extend in theory to every freight wagon operating in the EU-27 countries plus the 3 candidate countries, plus Norway and Switzerland.
- The technology is not new, although the application to this purpose is novel. Prices of products are relatively cheap it is not considered there is little room for further price reductions.
- There is no existing requirement for these devices in EU regulation, although this has been considered in previous studies, [6]. It is noted however that a number of high-profile wagon owners and RUs are introducing these devices.

3.2 Future Measures (short and medium term)

3.2.1 Rolling Stock Image Analysis / Machine Vision

Table 10 Image Analysis / Machine Vision Suppliers

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
D.3	Producer D	The product's primary function is to detect the faults that may occur on freight vehicles when they run past the detection site. The faults can be separation of couplers, brakes becoming loose, cracked or breakage of bogie and brake assembly, etc. The product is installed at trackside. It employs hi-speed cameras to grab images of the vehicles and these images are sent to the computer for processing, comparing and analysis so any fault on the vehicle can be distinguished and detected.	The product was introduced in 2005. It was updated in 2008. The product has been approved by the safety authority of one country.	Worldwide: 120 EU: 0	No response on market share. Producer D considers themselves one of a few major suppliers The volume of sales for this product has been in the range 1-10 M€.	The product is used primarily for freight traffic
S.2	Producer S	Uses High Speed Image capture and Automatic Image processing assessing components to perform condition assessment of rolling stock	Initial product developed in 1998, and has since been updated in 2002 – Second Generation (higher speed) 2010 – Third Generation (Speeds over 120 Km/Hr and simplification of hardware and wiring)	North & South Americas, Australia and Asia		Provided no information on market share.

We are aware of no installations within the EU-27 countries plus the 3 candidate countries, plus Norway and Switzerland. Systems exist outside of these countries however, as indicated above. It is possible that more suppliers of this technology exist, but have not currently been identified.

Potential market share/size for these systems cannot accurately be predicted. However, the functions performed by such systems are provided by other devices presently installed or other risk controls applied.

Further work in this area will be required should measures of this type show promise within Part B of this study.

3.2.2 Anti-lock Devices

Table 11 Anti-lock Device Suppliers

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
B.4	Producer B	This system acts to reduce locking of the wheels and associated wheel damage during braking on railway freight cars. In turn this may: reduce maintenance costs of re-profiling wheel sets; increase safety with reduced risk of wheel cracking or major tread damage that could increase derailment risk; reduce impact forces to track with the wheelsets in better condition; reduce noise generated with the wheelsets in better condition. The control system concepts are similar to passenger WSP, but the application to freight cars has 2 principle differences:- • The absence of electrical power, which is overcome by integrated generators driven from the axle ends • Much less compressed air available to control slide activity – this is a particular constraint with “single-pipe” braking used almost exclusively within the EU where the stored compressed air is not replenished during braking. The system has been optimised to minimise compressed air usage during operation.	Currently under trial	Producer B consider themselves market leader	Other suppliers offer systems for freight wagons that is a passenger car WSP system with the addition of a power generator and battery system. These generally are more expensive to manufacture, more complex to install and require more maintenance.	Sliding wheel detectors may offer an alternative to this technology

Our analysis of measures in this category has revealed one supplier of such systems. The potential market size is similar to the derailment detector devices, reported in Section 3.1.7. Further work in this area will be required should measures of this type show promise within Part B of this study.

3.2.3 Sliding Wheel Detector Device

Table 12 Sliding Wheel Detector Suppliers

Device	Producer	Technical Summary	Development Status	Currently Installed Base	Estimated Market Share and Main Competitors	Other Information
G.5	Producer G	The sliding wheel detector device is a mechanical device that compares wheel rotation rates between wheel sets. The system is normally installed in depots and sidings on departure roads. It detects faulty trains passing at speeds up to 30 km/h. One installation per departure road in depots or sidings where freight wagons are loaded or stabled.	The product was introduced in 2003. The system has been updated to utilise SMS-based alarming and reporting of sliding wheels. Higher speed system under development.	Worldwide: not specified. EU: 0	Has not specified market share in existing markets. Expect to become market leaders in Europe, but market would be relatively small. Competing “product” is manual inspection.	The system is primarily used for freight traffic. Europe is a potential future market

Our analysis of measures in this category has revealed one supplier of such systems. It is likely that deployment of such devices would be limited to exits from freight loading bays / routes such that defective braking could be identified prior to entering service which will define the potential market share.

Further work in this area will be required should measures of this type show promise within Part B of this study.

4.0 Conclusions and Way Ahead

Within this report we have provided statements concerning existing and estimated market share, and other information required during Part B.

DNV has made direct contact with most suppliers identified above, and some responses had been promised, but not received. We will continue to address this during and in advance of Part B.

Notwithstanding this shortcoming we feel that in most cases further supplier responses will not add a great deal of important detail. For example, although we have a small number of responses for hot axle box detectors it is possible to conclude from the data that is available many parameters concerning market conditions.

5.0 References

[1] Assessment of existing operational and technical measures against freight train derailments, ERA/2010/SAF/S-03, dated July 2010

[2] Assessment of freight train derailment risk reduction measures: A1 – Existing measures, DNV BA000777/02, dated Jan 2011

[3] Assessment of freight train derailment risk reduction measures: A2 – Functional and Performance Assessment, DNV BA000777/03, dated Jan 2011

[4] Identification of existing and new technologies for wheelset condition monitoring, Rail Safety and Standards Board, RSSB Report for Task T607, 2008.

[5] 15th annual AAR Research Review, Presentation from March 2-3, 2010, TTCI (2010), [Available at: www.fra.dot.gov/downloads/Research/15thAnnualReviewPresentations2.pdf].

[6] Impact Assessment on the use of Derailment Detector Devices in the EU Railway System, ERA/REP/03-2009/SAF dated May 2009

Appendix I Supplier Questionnaire

Assessment of existing technical and operational measures against freight train derailments in the Community's railways

DNV study for the European Railway Agency

Introduction and Common Questions

The purpose of the project

Det Norske Veritas is carrying out a study on behalf of the European Railway Agency to identify, describe, analyse and assess the most efficient options for existing or new safety measures (technical, operational or organisational) contributing to preventing or mitigating freight derailments in the Community's railways. A semi-quantitative assessment of the measures' efficiency (cost/benefit) shall be carried out and the impact of the measure on the fault/event tree shall be identified. The study was started in mid 2010 and will complete by June 2011.

The purpose of the questionnaire

The purpose of this questionnaire is to collect information on technical measures from the industry, primarily suppliers/manufacturers of such devices and systems. By technical measures we mean: "Technical devices to prevent or mitigate derailment or system monitoring the state of the railway system (rolling stock / infrastructure) to allow detection of derailment or early detection of hazardous conditions that may lead to derailment, and which upon detection takes appropriate action (recording, alarm, emergency brake)." This includes, but is not limited to, measures such as:

- Hot axle box/bearing detector (HABD)
- Acoustic bearing defect detectors
- Hot wheel and hot brake detectors
- Wheel load detectors & Wheel impact load detectors
- Derailment or dragging object detectors
- Truck lateral instability detection (truck hunting) / Truck performance detectors
- Wheel profile measurement system / Wheel profile monitoring unit
- Loading gauge infringement detectors (High car detector / Wide-load detector)

Confidentiality

The information provided will be used solely for the purposes of this study. The information may be shared with ERA but will not be disclosed to any other organization. DNV's analysis of the information provided by respondents may be published by ERA, but individual responses will not be published. Respondent's names will be kept confidential and will not be published or disclosed to any other organisation. Respondents have the right at a later date to change the answers they provide. The information will be stored and processed securely by DNV in compliance with the Data Protection Act laws of the United Kingdom and the European Union.

Interviewee

No	Question	Response
1-1	Name of organisation/company	
1-2	Name of interviewee	
1-3	What is your role in the organisation?	
1-4	Contact details of interviewee	

Identification of organisation and products

No	Question	Response	Guidance/notes
2-1	What kind of products does your company produce which can contribute to reducing the probability or consequence of derailment?		Some examples are provided above (hot axle box detector etc). For ***each product*** we are asking that you complete a separate product specific form which has also been sent to you
2-2	Has your company marketed similar products in the past which are no longer produced or marketed?		Please identify specific product names/identifiers if possible
2-3	Do you manufacture all of these products yourself or are you a reseller for some of them?		

Please see separate questionnaire for product specific questions.

Future developments

No	Question	Response	Guidance/notes
6-1	What other types of technical measures are you currently developing?		
6-2	When will these be available in the market place?		
6-3	Are you aware of other future developments with respect to technical measures for preventing/mitigating derailment?		Ongoing research in companies/research institutions/universities?

Assessment of existing technical and operational measures against freight train derailments in the Community's railways

DNV study for the European Railway Agency

Product Specific Questions

The purpose of the project

Det Norske Veritas is carrying out a study on behalf of the European Railway Agency to identify, describe, analyse and assess the most efficient options for existing or new safety measures (technical, operational or organisational) contributing to preventing or mitigating freight derailments in the Community's railways. A semi-quantitative assessment of the measures' efficiency (cost/benefit) shall be carried out and the impact of the measure on the fault/event tree shall be identified. The study was started in mid 2010 and will complete by June 2011.

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- Hot axle box/bearing detector (HABD)
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- Truck lateral instability detection (truck hunting) / Truck performance detectors
- Wheel profile measurement system / Wheel profile monitoring unit
- Loading gauge infringement detectors (High car detector / Wide-load detector)

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Product: <Please state the name/identification of the product here and fill in one of these questionnaires per product (preferably with one file per product, renaming the file to the product name)>

Market

No	Question	Response	Guidance/notes
3-1	What is the primary function of the product?		
3-2	How does the product work? Where is it installed? What technology is employed?		
3-3	Is the product employed primarily for passenger traffic, primarily for freight traffic or both?		
3-4	When was this product introduced to the market for the first time?		
3-5	Has the product since been updated? If yes, what are the major changes introduced and when were these introduced?		

No	Question	Response	Guidance/notes
3-6	Are you working on further developing this product? If yes, when is the new generation/version likely to be available in the market? What will the major improvements/changes be? If no, when is it likely to be withdrawn from the market?		
3-7	How **many items** of this product have you sold world wide/in the EU throughout its lifetime? What has the total volume of sales been **in monetary terms** (world wide/EU)?		Please provide specific information on what the numbers cover (years, countries). Number of items may also be specified in categories: • Below 50 • 50-500 • Above 500 Volume of sales may also be specified in categories: • Below 1.000.000 € • 1.000.000 – 10.000.000 € • Above 10.000.000 € Please state currency units.
3-8	Which countries constitute the most important markets for this product?		

No	Question	Response	Guidance/notes
3-9	What do you think is the potential market size for this product (world wide/EU) **in number of units** if the product were to be adopted on a more wide spread basis? What do you think is the potential market size for this product (world wide/EU) **in monetary terms** if the product were to be adopted on a more wide spread basis?		Number of items may also be specified in categories (NOTE THAT THESE ARE DIFFERENT FROM ABOVE): • Below 500 • 500-5000 • Above 5000 Volume of sales may also be specified in categories (NOTE THAT THESE ARE DIFFERENT FROM ABOVE): • Below 10.000.000 € • 10.000.000 - 100.000.000 € • Above 100.000.000 €
3-10	What do you think will be the most important market geographies in the future?		
3-11	What are the main competing products to this product?		Competing products may also include substitutes, i.e. products based on other technologies or with other functions, but serving the same purpose.
3-12	What is your market share (in %) for this type of product world wide / in EU?		
3-13	How do you assess your market position compared to the competition?		Market leader, one of a few major suppliers, one of many suppliers.

Costs and benefits

No	Question	Question/response guidance	Guidance/notes
4-1	What is the indicative price of a single product? What is the effort required to install a product (hours of work)?		Prices should be exclusive of VAT. If indicative price is not available, the following categories may be used instead: • Below 5.000 € • 5.000 - 10.000 € • 10.000 – 50.000 € • More than 50.000 €
4-2	Does the product require any regular maintenance activities? What is the effort associated with these activities (hours of work/year)? When it fails, is the whole unit replaced, or can a lower level repair be made? What is the effort on average associated with such repairs (hours of work/year)? Are there any specific disposal requirements with cost implications?		
4-3	What are the assumptions of the costs given above?		

No	Question	Question/response guidance	Guidance/notes
4-4	How should the product be deployed to maximise its benefits? Where should it be installed? How densely should it be installed?		
4-5	What operational aspects need to be considered in order to reap the benefits of the product?		

RAMS aspects

No	Question	Response
5-1	What is the estimated lifetime of the product?	
5-2	What is the estimated Mean Time Between Failure or other reliability measure of the product?	
5-3	What is the estimated Mean Time To Repair or other maintenance measure of the product?	
5-4	How will failures of the product be detected? Will all failures of the product be detected? If not, are these failure modes dangerous?	
5-5	What is the estimated rate of False Alarms of the product?	
5-6	Do you have a system for collecting reliability/availability statistics from actual installations? What is the in-service reliability performance of this equipment?	
5-7	What is the actual measured Mean Time Between Failure or other reliability measure of the product?	
5-8	What is the actual measured Mean Time To Repair or other maintenance measure of the product?	
5-9	What is the actual measured rate of false alarms?	
5-10	Has the product been approved by relevant safety authorities? Which safety authorities? What is the geographical scope of the approval?	

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MANAGING RISK

Det Norske Veritas

Assessment of freight train derailment risk reduction measures:

A3 – Functional and Performance Assessment

Report for European Railway Agency
Report No: BA000777/04
Rev: 02

12 April 2011

MANAGING RISK DNV

Assessment of Derailment Risk Reduction Measures:
A3 – Functional and Performance Assessment
for

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Summary: This document provides an assessment of the functions and expected performance of freight train risk reduction measures

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0.0 Executive Summary

0.1 Study Scope and Objectives

Det Norske Veritas (DNV) is completing a study on behalf of the European Railway Agency (the Agency), the objective of which is twofold:

1. Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation within 5 to 10 years). For these measures, Part A work is also required to assess the market status for technical measures (defined as devices or systems) and establish objective performance data for the identified measures. The work in Part A also extends to identifying, as far as is possible, potential long term measures (not expected to be ready to implement within 10 years) as an input to other research projects currently underway.
2. Part B has the objective of analysing the measures identified in Part A with a view to establishing those that show the most promise from a risk reduction viewpoint. Part B addresses such measures which are available at the short and medium terms.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland. In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

This report concerns the Part A remit associated with the identification of ***performance and function of the measures identified***. Other work in Part A deals with the other scope requirements, and is separately reported. It should be noted that this report is factual in nature and does not seek to make any assessment regarding performance or effectiveness of the identified measures - all measures reported here are to be taken forward for consideration on Part B.

0.2 Methodology and Study Results

The establishment of the information and data required for this report was largely assembled through the consultation exercises reported for our tasks A1 [2] and A2 [3], together with subsequent questions and answers with respondents to gather addition detail. In particular:

1. We consulted with infrastructure managers (IMs) or railway undertakings (RUs) to establish:
   - The types of measures (technical, operational, organisational or human) they currently use to either reduce the frequency or mitigate the consequences of freight train derailments.
   - The effectiveness of these measures.
   - Their plans for introducing additional measures in the short term and beyond.
   - Where an IM or RU had indicated the use of a technical measure, we asked them in a subsequent round of communication for their experience of the reliability performance and effectiveness of these measures.
2. Having established, from the consultation above (and further research as reported in [3]), a full list of existing and potential future measures, we embarked on a further round of consultation. This further consultation was limited to suppliers of technical measures, for which we sought information on, but not limited to:

- The reliability, availability and maintainability (RAM) performance for their technical measures.
- False alarm rates and failure mode information.
- The way in which these technical measures may influence the risk of freight train derailment.
- Cost and life cycle questions, such as special disposal requirements, the requirement for preventative maintenance etc.
- Finally, we asked suppliers for their views of how technology might evolve and new products that may be available in the future.

The study identified 47 existing preventive measures, and 13 further measures that primarily are concerned with the reduction of consequences following a freight train derailment. A further 9 measures were identified with potential medium term benefits.

The majority of technical measures are supported by costs and performance claims, from the supplier. In some cases these are supported by in-service data. In general however we have to report that end users of these technical systems do not keep their own records of performance; this issue will be addressed in Part B through the use of sensitivity analysis and conservative assumptions within the modelling methodology.

Some other measures do not lend themselves to traditional RAM analysis – human, organisational and operational measures in particular. This is addressed in the body of this report, with strategies for the collection of these data identified for each measure. In general however, these outstanding data issues will be addressed in Part B using a combination of human error prediction methods, conservative assumptions and sensitivity analysis, and also through the use of accident statistics to indicate the potential benefit that may be gained against certain derailment accident causes.

0.3 Conclusions and Next Steps

This work reported here has established performance and function (in preventing freight train derailment) for the measures identified. However future work (Part B) will supplement, if required, the information provided in this document and add any new information that is advised to the project team.

The next project step will take this information forward into Part B where it will be used to provide input to task of assessing the effectiveness of these measures (and other non technical measures) in terms of freight train derailment risk reduction, in accordance with the Part B study objectives.

Contents

1.0 Introduction

1.1 Background

This document is prepared against the requirements of the European Railway Agency's (ERA) study "Assessment of existing technical and operational measures against freight train derailments in the Community's railways", [1]. The task description for the work reported in this document is as follows:

> *The task A.3 will describe each technical and operational measures in generic functional terms associated with the description of both intrinsic performance level and actual performance (for example, based on RAMS analysis for technical measures) as well as relevant life cycle costs (investment, operation, maintenance, repair, refurbishment, dismantling...). The description shall contain the necessary and sufficient level of details compatible with the part B of the study (development of scenario tree, semi-quantitative assessment of efficiency) and also with the necessary inputs for detailed impact assessments carried out by the Agency.*
>
> *Concerning the 'technical' measures, the related devices/systems will be described with the help of information provided by the designer(s), manufacturer(s), and/or, supplier(s) about the expected performances and by users for the actual performances.*

In addition to this task report, the following additional reports are relevant and are referred to as appropriate:

- TaskA1, [2]. This document provides information about existing safety measures that are applied in the railway system to reduce the likelihood or mitigate the consequences of derailments, and more specifically freight train derailments.
- Task A2, [3]. This document provides a market analysis of technical measures that exist, or may exist in the short or medium terms.

1.2 Definitions

The following definitions are used within this document:

- Existing safety measures means currently applied for implementing a given regulation requirement, or applied on a voluntary basis, [1].
- Short term (safety) measure means that the safety measure is ready to be applied or to be introduced in EU regulation by 1st of January 2013, [1].
- Medium term (safety) measure means that the safety measure will be ready to be applied or to be introduced in EU regulation within 5 to 10 years, [1].
- A technical (safety) measure is defined as being a device or a specific technical system, [1].

Safety measures discussed within this document include:

- Human measures, defined as: Measures to improve the individual's capability to perform his/her duties in a correct and safe manner. This includes competence, knowledge, decision support information systems for the persons that have the responsibility to carry out a certain task.
- Organisational measures, defined as: Measures pertaining to the management of the organisation, including staff training, safety management system, operational planning, human resource management, handling of requirements related to independence, roles and responsibilities etc.

- Operational measures, defined as: Measures in this category include operating instructions or operational rules that are in place in part to reduce the risk of freight train derailments. Examples might include speed restrictions, rule book actions etc.
- Technical measures, defined as: Measures that are based on a device of particular technical system.

Finally, the main work for this task is listed in Section 3.0. The following terms and definitions apply:

- RAM/Effectiveness Assessment. This is the reliability, availability and maintainability (RAM) prediction allocated to the measure. The effectiveness assessment gives an indication of the benefit that measure may have in derailment risk reduction when the measure is in operation.
- Predicted / Observed. The predicted RAM/effectiveness is normally that provided to us with a supplier, whilst the observed assessment is that provided to us by an operator or equipment owner.
- Cost Information: Purchase/Life Cycle. The former represents the acquisition (or introduction) costs for the measure, whilst the later represents the on-going maintenance cost for that measure.

The objective of this report is to reliability and cost performance characteristics for existing measures currently in place for the reduction of freight train derailment safety risk, and, as far as can be established, for potential future measures. This report does not however seek to make any assessment regarding the cost effectiveness of these measures in terms of derailment risk reduction.

The work reported here will be taken forward to a further project stage (Part B) that will seek to identify the most promising measures from those identified here. The future work (Part B) referred to will supplement, if required, the list of measures discussed in this document and add any new measures that are made advised to the project team.

All identified measures will be considered in Part B.

2.0 Methodology

2.1 Time-bound Classification of Measures

In our report, [2], we considered the classification of existing measures into category types. We did not in that report have a need to allocate measures into their time-bound categories (short, medium term etc). The task of addressing the time-bound classification of measures is considered here.

It needs to be stated that it is not within the remit of the Part A tasks to make speculative assumptions about what might become useful measures in the future (this task will be performed during Part B). To avoid such unnecessary speculation we have limited our attention to measures that have been advised to us during our consultation (see Section 2.2 below). With the benefit of a risk model, Part B will provide a better opportunity to identify other potential future measures.

Subject to these limitations, we have applied the following rules:

- A technical measure is (potentially) short tem if it is in development/developed and currently has approval or is in the approval process within the EU-27 countries plus the 3 candidate countries, plus Norway and Switzerland. Any other technical measure is classified as medium term since testing and approval processes will dictate a longer timeframe (measures in the medium term category are normally those applied in the USA or other countries).
- Potential new human, organisational or operational measures are normally classified as short term, unless they require supporting technology or information systems.

2.2 Data Acquisition

Data for this report has primarily been collected through interviews and questionnaires, although literate reviews have also been used. The consultation methodology and scope has been reported in our other reports, [2] and [3] and is not repeated in detail, although in summary:

3. We consulted with infrastructure managers (IMs) or railway undertakings (RUs) to establish:
    - The types of measures (technical, operational, organisational or human) they currently use to either reduce the frequency or mitigate the consequences of freight train derailments.
    - The effectiveness of these measures.
    - Their plans for introducing additional measures in the short term and beyond.
    - Where an IM or RU had indicated the use of a technical measure, we asked them in a subsequent round of communication for their experience of the reliability performance and effectiveness of these measures.
4. Having established, from the consultation above (and further research as reported in [3]), a full list of existing and potential future measures, we embarked on a further round of consultation. This further consultation was limited to suppliers of technical measures, for which we sought information on, but not limited to:
    - The reliability, availability and maintainability (RAM) performance for their technical measures.
    - False alarm rates and failure mode information.

- The way in which these technical measures may influence the risk of freight train derailment.
- Cost and life cycle questions, such as special disposal requirements, the requirement for preventative maintenance etc.
- Finally, we asked suppliers for their views of how technology might evolve and new products that may be available in the future.

2.3 Discussion of Challenges Related to the Data Collection Process

2.3.1 Existing Measures

Except in a small number of cases, IMs and RUs were only able to provide subjective views for the performance/effectiveness of the existing measures they use. Common responses were that the measure was "*effective*", or that the derailment rate had "*significantly reduced"* since introducing the measure.

There is a further very important consideration. The accident review performed and discussed in [2] identified a number of cases where hot axle box alarms (for example) had been raised, but the freight train was allowed to proceed, leading to derailment. This of course is an important finding as the application of a measure cannot be assumed to be as effective as it could be unless accompanied by other systems. In the following tabular presentations we have added appropriate information to identify where these factors and comments apply.

2.3.2 Short and Medium Term Measures

By definition, short and medium term measures do not exist in the EU-27 countries plus the 3 candidate countries, plus Norway and Switzerland. This of course makes the collection of data more difficult as there is little/no local operating knowledge of them.

To address this, and where possible, the consultation process has sought to identify responses from the country of origin of the measure so that at least some information can be gathered.

2.3.3 Addressing Data Shortcomings

In common with most risk assessments, it is not always possible to identify quantitative figures that neatly represent the performance of a particular measure. We discuss this issue towards the end of our report, in Section 6.0.

3.0 Performance Assessment for Existing Measures

3.1 List of Measures and Functions

The list of measures provided below is extracted from our A1 report, [2] where further information can be obtained if required.

In the tables that follow, we recognise that some of the measures have a direct role as a derailment preventative or consequence reduction measure, whilst some have an indirect role to play. Examples of the former would be hot axle box detectors, whilst examples of the latter would be track and flange lubrication. In the tables that follow, these are identified as either (D) direct, or (I) indirect.

Table 1 Existing Infrastructure Preventive Measures

Type of measure	P#	Measures	Description and Function
Technical infrastructure	P-1 (D)	Installation of check rails in sharp curves	Check rails are installed to guide the wheels in rigid crossings and point crossings. Check rails may also be installed in sharp curves to prevent derailments as it will hinder flange climbing on outer rail in sharp curves. (Check rails can also be a cause of derailment in some circumstances, in particular with an excessive track width, so check rails require tight control of the track width.)
	P-2 (I)	Installation of track and flange lubrication	Lubrication of the flange and track contact point is an important measure to reduce the friction between rail and wheel flange and hence reduce the risk of derailment in difficult track geometries, i.e. in narrow curves or track sections with high cant and/or high twist. Normally the lubrication is obtained by lubrication of the wheel flange of traction units. For track sections where this is not deemed sufficient, for instance in deviated routes at turnouts, trackside flange or track lubrication points can be installed to provide the necessary lubrication. Lubrication can also be provided by special track lubrication train runs at regular intervals or under dry weather or hot temperature conditions.
	P-3 (I)	Installation of rock scree and avalanche protection structures	On track sections with high risk of rock screes and avalanches structural track protection measures are often installed to stop or deflect rock screes and avalanches. Structural protection measures can be applied in combination with detection installations and operational measures and restrictions. Various measures are used in exposed countries including protection, detection, and artificial release at convenient times, speed reductions. The selected measures are tailor made for the local topography and hazards and this is not a generic measure that might have a universal application. (Note derailment is a secondary consequence and collision the primary consequence.)
	P-4 (I)	Installation of rock scree and avalanche detectors	At line sections with a high risk of rock screes and avalanches and where structural protection is deemed too costly or not considered sufficient rock scree and avalanche detectors are installed. They can be in the form of detecting fences which will detect loads falling down on them from higher levels or as acoustic detectors detecting the noise associated with such phenomena. The last type can cover larger areas but are not as selective as a fence along the line. The measure is often combined with structural protection measures or operational restriction measures. (Note derailment is a secondary consequence and collision the primary consequence.)
	P-5 (I)	Installation of obstacle detectors	High speed collisions with heavy road vehicles are likely to cause derailment, but in such situations the derailment is a follow on consequence of another accident that may have severe consequences by itself. The purpose of obstacle detectors is to discover obstacles on the track that could be a safety critical hindrance to the train. Obstacle detectors are installed at level crossings to detect if cars are standing blocking the tracks at the crossing or at other locations where the track can be blocked by foreign objects. Typical application of obstacle detectors are at barrier protected level crossings. (Note derailment is a secondary consequence and collision the primary consequence.)
	P-6 (D)	Use of ground penetration radars (Geo radars)	Ground penetration radars are used to survey conditions of trackbed superstructure with regard to quality and water content. This is mainly used through ad hoc baseline runs to provide information for planning of maintenance and renewal, but permanent installations can also be

Type of measure	P#	Measures	Description and Function
			considered in places where the railway is located on unstable ground that is considered exposed to high water level in substructure, subsidence or landslides. Certain types of ground instability detectors can be installed which will detect high water levels subsidence and landslides outside of acceptable limits.
	P-7 (D)	Rolling stock mounted equipment for monitoring of rail profile conditions.	Suppliers are marketing rail profile measurement systems that can be mounted on commercial rolling stock and used for continuous supervision of track geometry and measurement of rail wear. This technology incorporates the latest laser and video camera technology to provide accurate and immediate report on the profile and wear condition of the rail whilst travelling at track speeds.
Infrastructure; Control Command and Signalling	P-8 (I)	Track circuit as part of signalling system may detect rail ruptures	Track circuits are applied in the signalling system of most IMs. Track circuits will detect some type of rail ruptures and prevent signals to be set for a track section with a ruptured rail and hence prevent derailments. However, supervision for rail ruptures is not the main purpose of the track circuit and there are several types of rail ruptures the track circuits cannot detect. Track circuit systems for detection of track occupation are to an increasing degree being replaced by axle counters by many IMs. Axle counters are not able to detect track ruptures. Track circuits as a derailment prevention measure will not be analysed further as its purpose of installation is different than derailment protection.
	P-9 (D)	Interlocking of points operation while track is occupied	Points at main lines and at main tracks at stations are normally interlocked to prevent operation of the point while the point section of track is occupied by rolling stock. This is not fully implemented at shunting yards even at tracks being used for train movements. Hence a number of derailments occur due to points being operated while occupied by a train. This action very often causes derailment. An existing measure is interlocking of remote controlled points to include track at shunting yards used for train movements in such a way that the switch cannot be moved while the switched is occupied by rolling stock.
Trackside rolling stock supervision	P-10 (D)	Installation of hot axle box (hot bearing) detectors	High temperature in the axle box or the bearing of an axle may be a sign of a mechanical structural defect under development. This can be in the form of high friction in the bearing or a developing rupture in the axle journal. By monitoring the temperature of axle boxes, a failure state of the bearing may be detected and an alarm raised either to the train driver or to the train control centre. Hot axle box detectors for freight trains are normally located along the track monitoring the temperature of axle box of all passing trains. Axle box monitoring devices can also be located on the vehicle, continuously monitoring the temperature of the axle boxes, but this is normally not applied on freight trains as the individual freight wagon does not have any electricity to power such monitoring equipment. Wayside detectors usually consist of one or more thermal sensors continuously measuring infrared radiation, and should be capable of detecting both normal temperature and high temperature axle boxes
Trackside installations to supervise rolling stock	P-11 (D)	Installation of acoustic bearing monitoring equipment	Acoustic bearing detectors are, like hot axle box/bearing detectors, used to detect developing mechanical structural defects associated with wheel bearings. It is, however, not based on temperature measurement, but on the analysis of the sound as wheel sets pass by. The major advantage over hot axle box detectors is that acoustic bearing detectors are able to detect developing defects much earlier as such defects will result in increased noise. Acoustic bearing detectors are placed wayside and consist of a microphone array and a system unit which analyses the sound and raises an alarm if dangerous defects are detected. Used in combination with vehicle identification systems, the system may also be used to store information on individual vehicles and wheel sets in a central database, allowing for trend analysis and preventive maintenance.
	P-12 (D)	Installation of hot wheel and hot brake detectors	Braking can increase the temperature of the wheels and brake pads. In particular this can be a problem with brakes that have not released and continuously apply braking action. The rise of temperature may itself be a problem if it leads to structural changes in the wheel material. If the wheel comes completely stuck it may skid along the rail resulting in wheel flats etc. Hot wheel detectors are positioned wayside and use the same technology as hot axle box/bearing detectors, i.e. thermal sensors measuring the temperature of passing wheels. Used in combination with axle counting devices or vehicle identification systems, the system is able to identify the vehicle and wheel of any higher than normal temperatures and raise an alarm. Cold wheels may in some situations (e.g. if positioned at the bottom of a downward slope) indicate that brakes have not been applied where they should have been, i.e. that brakes are defective or working poorly.
	P-13	Installation of wheel load and	Several different types of wheel load detectors exist. They are installed at various locations in many countries. Wheel load and wheel

MANAGING RISK

Type of measure	P#	Measures	Description and Function
	(D)	wheel impact load detectors	impact load detectors can be used to detect a range of different faults with a wagon or its loading: o By measuring the wheel loads of an axle it can detect overloading of the wheels and axles or skew loading of the wagon either due to a wrongly applied load in longitudinal or transversal direction, a shifted load or due to a wagon or bogie frame twist, suspension or spring failure. o Wheel load detectors can also detect wheel failures in terms of general out of roundness or more specifically wheel flats and wheel tread damage due to shelling and spalling. As the wheel moves around this causes wheel impact load on the rail, which again cause damage to rails (including rail breaks) or increase the temperature of bearings and lead to hot a hot axle box. Wheel load detectors are wayside detectors measuring the size and variations of the load of wheels as they pass by. Several different technologies are employed depending on the various faults to be detected. Some use strain gauges, others analyse sound or measure the deflection of rails between sleepers as trains pass using optical sensors. Accelerometers can also be used. If the situation is severe an alarm is raised and the train has to be stopped to check the wagon(s) that have triggered the wheel load detector alarm, or the train speed may be adjusted. Used in combination with vehicle identification systems, the train operator and/or wagon owner may receive a message about the out-of-limit characteristics in order for rectifying actions to be implemented prior to further operation of the wagon. Wheel load detectors can be combined with hot axle box detectors, but are often installed in departure tracks from train formation yards, or in main tracks immediately after train formation yards in order to detect the situation as soon as possible. Faults can also occur along the route. In general there are fewer trackside wheel load detectors than hot axle box detectors.
	P-14 (D)	Installation of dragging object and derailment detectors	Derailment and dragging object detectors can be installed to identify if a train has a derailed axle, or equipment that has come loose from a wagon and being dragged along the track between the rails. Such detectors may be installed in front of large stations or structures where the situation may cause major damage. Early dragging equipment detectors were of the "brittle bar" type. Fixed elements between and beside the rails would break when struck by foreign objects. Their breakage would interrupt an electric circuit that formed part of the reporting system, and the train would be stopped and inspected. The introduction of "self-restoring" dragging equipment detectors, which are hinged and sprung so they return to position after impact, have reduced maintenance requirements for such installations. The derailment and dragging object detectors will also detect derailments and are also included as a mitigating measure.
	P-15 (D)	Bogie performance monitoring/Bogie lateral in-stability detection (bogie hunting).	This wayside defect detection system is capable of detecting and identifying train bogies that exhibit poor performance. This system monitors safety performance in several regimes such as: potential of flange climb derailment, gauge spreading, and rail over. This state-of the-art system has the capability to benchmark bogie performance on a fleet-wide basis.
	P-16 (D)	Wheel profile measurement system / Wheel profile monitoring unit.	Damage to the wheel profile may be a contributing cause to derailments. Whereas wheel impact load detectors can detect some wheel profile problems, wheel profile measurement systems provide a more complete picture. They are also based on other technology: analysis of wayside digital camera images highlighting the profile using lasers or strobe light. A number of wheel profile parameters are captured, e.g. flange height, flange width, flange slope, tread hollow and rim thickness. Some measurement systems can operate with trains passing at high speeds (e.g. up to 140 km/h).
	P-17 (I)	Installation of loading gauge infringement detectors/ profile- and antenna protruding detection.	These are detector installations that can detect wagon structures or loads and objects protruding from the wagon that are to high or wide for the allowable loading profile of the line in question. Derailments or other accidents can be caused by loads protruding outside of the allowed loading gauge, and detectors can be applied to detect such situations. The situation can occur due to shifting loads or by loading the car with an object that exceeds the allowable loading gauge for the line in question. Shifting load situations can normally also be detected by wheel load detectors. Increasing volume of transport of autocars and HGVs by rail has caused interest in controlling the antenna height of cars, but more due to fire risk in tunnels than due to derailment risk. Loading gauge infringement detectors are most likely to be installed in front of track sections with reduced loading profile (e.g. tunnels) or in front of bridges with overhead bearing structure. (Note derailment is a secondary consequence and collision the primary consequence.)
Infrastructure Operational/	P-18 (I)	Make sure available maintenance resources are	If the available resources are not sufficient to maintain lines and tracks at stations according to minimum safety requirements it is from a derailment and safety viewpoint better to close the lines or tracks for operation than trying to keep lines operational in a state where all

Type of measure	P#	Measures	Description and Function
organisational		sufficient in relation to network extent and traffic levels.	safety margins are removed. Accident investigation reports from various countries have shown that many accidents occur due to known infrastructure failures that there might not be resources to repair, or such repair has not been prioritized within available resources. Such conditions increase the risk of freight derailment and if hazardous materials are transported on such lines it might be a public risk.
	P-19 (D)	Ensure that the track/train clearance gauge including the flange groove is free from obstructions	The clearance gauge should be kept free of obstructions when trains are due to arrive. This is a general inspection and maintenance task carried out by all infrastructure managers. Special focus should be given to the flange groove in level crossings. If the flange groove is obstructed by hard solid objects it can cause derailments. Level crossings with rubber elements (Strail) can reduce the risk. In countries with severe winters snow ice can pack in the flange groove and around the rail during periods of frost during night and thaw during daytime. In particular this can be a risk if free water seeps over the track, for instance in level crossings. The risk is most severe for passenger trains.
	P-20 (I)	Perform ultrasonic rail inspection of track	The IMs provide for ultrasonic inspection of the rails by various forms of wagons in order to detect cracks and fractures that can cause rail ruptures. Either the IM owns the inspection equipment or the inspection is done by contractors. The ultrasound inspection provides the IMs with information with regard to the quality of the rails and the need for rail replacements. The frequency of ultrasonic rail inspections is determined by the IMs based on the rail age and traffic loads on the actual line accounting for available resources and equipment performance.
	P-21 (I)	Perform track geometry measurement **of all tracks** in order to detect track sections requiring maintenance actions.	Regular track geometry measurements are carried out by most IMs. The track geometry of railway lines is regularly measured by track inspection wagons or trains. Among the geometric parameters measured are: track gauge variations; track cant; track twist; track height variations; track lateral position faults. In addition modern measurement wagons can inspect rail surface conditions in terms of rail wear and various rail surface defects. The completeness of the measurements with respect to track coverage at stations as well as intervals may vary. Frequency is normally dependent upon traffic load and allowable speed limit of track. The frequency of inspection is based on local conditions and environmental factors, ground stability, line speed and traffic loads accounting for available resources and equipment performance. Normal frequencies can be 2 to 6 times a year with increased frequency for lines with more traffic and higher allowable speed.
	P-22 (D)	Establish EU-wide intervention and/or immediate action limits for track twist.	Excessive track twist is among the most frequent derailment causes often in combination with other causes such as skew loading, wagon frame twist and low speed in narrow curve with high cant etc. In many cases where track twist is a major factor leading to derailment the actual track twist exceeds allowable twist limits, and in some cases the situation has also been known to those responsible for track maintenance. Track twist requirements must be looked at in combination with requirements and limitations for rolling stock flexural stiffness. An existing measure adopted by some IMs has been to impose more stringent limits for these parameters which suggest a more widespread adoption of harmonised limits may be beneficial. The reason for this is that rolling stock meeting the TSI for freight wagons is interoperable through the European Union and hence criteria for track maintenance activities should be harmonized in order to be able to maintain a high level of safety against derailment due to track twist.
	P-23 (D)	Establish EU-wide intervention and/or immediate action limits for variation of track gauge.	The immediate action limits for variation of track gauge are set out in the final draft TSI for Conventional rail. These immediate action limit are significantly less rigorous than today's action limit for many. The argument for harmonised limits is P-21.
Infrastructure Operational/ organisational	P-24 (D)	Establish EU-wide intervention and/or immediate action limit for cant variations.	Action limits for variation in cant relative to design cant is specified in the final draft TSI for Conventional Rail Infrastructure. Additional to the above some countries have general limitations of allowable excessive cant, specifically at locations where trains are expected to stop at a signal or drive slowly. This requirement is of special importance at locations with narrow curves where trains may have to stop in front of signals and where there also is high track twist when leaving out of transition curves.
	P-25 (D)	Establish EU-wide intervention and/or immediate action limit for height variations and cyclic tops which does not exist in	Among others, the railways of Norway and Britain have intervention limits for variation in track height. The intervention limits specified in Britain and Norway are relatively consistent, but with some minor variations. Variations in track height and cyclic tops may cause derailment, in particular if there are cyclic variations. A measure is for the Final draft TSI for Conventional Rail infrastructure to include quantitative limitations on height faults (in line with other countries). An interoperable rolling stock fleet will benefit from harmonised track

Type of measure	P#	Measures	Description and Function
		Final draft TSI for Conventional rail infrastructure.	intervention and safety limits.

Table 2 Existing Rolling Stock Preventive Measures

Type of measure	P#	Measures	Description
Rolling stock technical or structural	P-26 (I)	Flange lubrication of locomotives	In some countries, in particular countries with a high proportion of curved tracks, there is a requirement to fit main traction units with flange lubrication to reduce the friction of the contact between wheel flange and rail. Reduced friction between wheel flange and track also reduces the necessary traction force and energy use on curvy track sections.
	P-27 (D)	Replace composite wheels with monoblock wheels	A composite wheel consists of a wheel rim with an outer shrink fitted ring comprising the wheel tread and the flange. A tyre retaining ring helps to keep the assembly in place. Composite wheels have the advantage that the ring can be replaced once it is worn down. A disadvantage with composite wheels is that the wheel ring can come loose and be displaced, in particular due to heating in prolonged braking actions. A wheel with a displaced or lost wheel ring is likely to derail. Monoblock wheels are forged or cast from one block and have fewer failure modes, however, also for these wheels prolonged and excessive heating due to braking can cause material failure and wheel rupture with consequential derailment. Some RUs, in particular those with very mountainous lines, favour monoblock wheels and have completely exchanged all their composite wheels with monoblock wheels. An existing measure with extended application is therefore to replace composite wheels with monoblock wheels.
	P-28 (D)	Replace metal roller cages in axle bearings by polyamide roller cages	The Norwegian rail freight operator CargoNet decided approximately 10 years ago to exchange their axle bearings from brass roller cages to polyamide roller cages. The implementation of the decision has been by replacement when the wagon and axle boxes are in for overhaul. The rationale for the replacement was a number of derailments due to hot axle boxes and shearing of axle journals prior to the decision being made. The cause of many of the failures was wheel damage. The polyamide cages were considered less prone to failures due to vibration impact.
	P-29 (D)	Replace existing axles for stronger axles	At least one wagon owner with a large fleet of tank wagons recently made a decision to replace axles in most of their rolling stock to axles of higher strength. The allowable axle load of the rolling stock is not expected to be increased and the main reason for the replacement is an increased safety against axle ruptures and derailments
	P-30 (D)	Increase the use of central coupler between wagons in fixed whole train operation	In rail freight transport operations by fixed trains with bogie wagons with uniform loading use of central couplers will reduce curve forces and ensures that compression forces occur centrally in the train. This will reduce the derailment risk. An existing measure that could be given wider usage is therefore the introduction of central couplers of 4 axle rolling stock with bogies in closed train operation.
	P-31 (D)	Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis	The rolling stock of the European railways consist of a mixture of single or coupled 2 axle units with single axles or bogie wagons with 2 or 3 2-axle bogies. Normally, bogie wagons have better riding quality and a lower derailment rate. An exchange of single axle wagons for bogie wagons could therefore be a measure to reduce the number of derailments. This is already applied for most heavy bulk transport applications. For the transport of light weight goods and lightly loaded containers and swap bodies this is not the case. For such transport operations, wagons based on single axle wheel allows for a long loading basis to be obtained with a minimum of weight and cost; whilst this is advantageous commercially it is not beneficial with respect to minimising derailment risk. A review of accident reports indicates that these types of cars have an increased derailment frequency, often in combination with high track twist.
	P-32 (I)	For new rolling stock install disc brakes instead of wheel tread brakes	Existing fleets of freight wagons are to a large degree equipped with wheel tread brakes utilising cast iron brake blocks (shoes). Some modern wagons are equipped with composite brake blocks or disc brakes mainly due to new noise criteria (although we note that tread brakes fulfil the Noise TSI when equipped with composite brake blocks). To move the brake action away from the wheel tread, as is the case with disc brakes, also has a safety advantage as the wheel tread material is subject to less heat and increased braking force can be applied without the risk of overheating the wheels. This may reduce the failure rate for both composite and monoblock wheels. Application of disc brakes will increase the torsion loads on axles and the strength of existing axles must be checked before implementing it on existing wagons. Disc brakes also have some disadvantages as they does not clean the wheel tread for rub that may form in the wheel-rail contact if the wheel is blocked for a short period. The measure is applied for some new freight wagons, mainly to limit noise from train braking.
	P-33 (D)	Rolling stock should be designed to operate safely	The WAG TSI (TSI for rolling stock freight wagons) as a specific case for the Irish railways (Republic of Ireland and Northern Ireland) in § 7.7.2.2.4.5 allows a stricter requirement to twist flexibility for freight rolling stock on that network than for the rest of Europe. The relevant

Type of measure	P#	Measures	Description
		over a track twist of up to 17 per mille over a 2.7 m base	paragraph of TSI Wag reads: "Rolling stock should be designed to operate safely over a track twist of up to 17 per mille over a 2.7 m base, and up to 4 per mille over an 11.2 m base". This will make the rolling stock much less likely to derail due to track twist.
	P-34 (D)	Secure brake gear located in the underframe	In order to avoid that loose brake gear from a wagon falling down on track and causing derailment all parts of the brake, rigging that could come loose should be secured by safety springs of steel wire. This is a requirement in some countries or done by some freight operating RUs.
	P-35 (D)	Regular greasing and check of fastening of rolling stock buffers to reduce risk of a buffer falling off.	Rolling stock buffers can be lost and be a cause for train derailment. Various preventive measures are normally in place to control this possible derailment cause such as: inspection of buffer fastenings and regular greasing of buffer plates as well as buffer cylinder contact parts. If considered necessary fastening elements should be strengthened.
Rolling stock Operational / organisational	P-36 (D)	Wheel set integrity inspection (ultrasonic) programs	Wheel ruptures and damage to the wheel profile may be a contributing cause to derailments. Whereas wheel impact load detectors can detect some wheel profile problems, wheel profile measurement systems and wheel ultrasonic integrity inspection with respect to cracks can provide a more complete picture. They are also based on other technology: analysis of lasers and digital camera images highlighting the profile using lasers or strobe light. In addition wheels have to be inspected for material cracks that can cause ruptures. Various NDT methods can be used for crack detection including ultrasonic. Technology exists for supervision stations in depots that can do the necessary inspections while the train passes the supervision station in low speed. Measurements can be stored in a central database for monitoring of trends and planning of maintenance.
	P-37 (D)	Derating of allowable axle loads for type A-I and A-II axle designs	Investigations by the ERA JSSG set down after the Viareggio accident indicates that an increase of the axle load of types A-I and A-II axles has been allowed nationally for some countries even though this exceeds the intended design load. The JSSG has recommended that maximum operational axle load limitations for A-I and A-II axles are limited to 20 tonnes. A-III axles are allowed a continued operation with 22.5 tonnes axle load provided strengthened inspection and maintenance routines are introduced. Type A axles comprises more than 75 % of existing wheel axles in European rolling stock.
	P-38 (D)	Inspect axles of freight train rolling stock according to EVIC (European Visual Inspection Catalogue).	Since 01.04.2010 a European-wide voluntary program of wagon owners for visual examination of axles and wheels has started. The purpose of the inspection is partly to identify surface marks and scratches in wheels and axles that can act as crack initiators. The EVIC can be considered as a reference manual for RUs and keepers providing the criteria to freight wagon maintenance staff to visually identify, during light maintenance in workshops (i.e. without disassembling from the wheel-sets), axles with a potentially increased risk for safe operation. A wheel-set/axle which doesn't meet the EVIC-criteria will be discarded from service and undergo non-destructive tests (NDTs). Additionally, a sample of axles fulfilling the EVIC-criteria will also be subject to NDT. This program runs over the next 4 years for rail tank cars and 6 years for other railway wagons. The examination according to EVIC-catalogue will be done from April 2010 on each wagon, which enters a workshop for repair (operational maintenance) outside from revision. The inserted wheel-sets are examined and the workshop will inform the wagon owner about the result. Results with regard to inspection progress are to be reported to the ERA. All private owners announce the collected inspection results over the federation VPI (or VDV) monthly to for European-wide evaluation of the results.
	P-39 (D)	Requirement for double check and signing of safety-classified (S.-marked) maintenance operations.	CargoNet, the largest freight rail operator in Norway, has classified their maintenance activities according to whether the maintenance operation is safety critical or not. The safety critical maintenance operations, called S-marked activities, have to be double checked and signed out by 2 persons. This is considered to reduce the likelihood of faults and omissions in the maintenance work of safety critical items of the rolling stock.

Table 3 Preventive Measures applied to Train Loading and Operation

Type of measure	P#	Measures	Description
Train loading / human	P-40 (D)	Qualified and registered person responsible for loading.	In some countries it is required by law to have a qualified and certified person responsible for supervising the loading of trains.. The person designated must demonstrate sufficient knowledge in order to be deemed qualified, and the designated person is registered with the train operator. Also in Bulgaria a qualified person is to be responsible for correct train loading.
Pre-departure inspection and brake settings/ human	P-41 (D)	Locomotive and first wagons of long freight train in brake position G (Lange locomotive)	When operating long freight trains in brake position P the delayed application of pneumatic train brakes in the rear of the train compared to the front of the train causes significant compression forces. In order to limit train compression forces when operating pneumatic brakes of a freight train in position P the locomotive(s) and the first wagon(s) of a long freight train shall be put in brake position G to limit the compression forces of the train when braking with the pneumatic activated train brakes.
Train operations/ human:	P-42 (D)	Limitations on use of brake action in difficult track geometry	Regardless of type of brake activation it is important to restrict brake actions in difficult track geometries at low speed. In particular this applies when freight trains are routed through deviated point settings with narrow curves across stations. This is particularly relevant at low speed, to avoid high compression forces of the rain that could cause buffer locking and derailment.
	P-43 (D)	Perform a dynamic brake test on the route to get actual test information with regard to the train braking performance	The ATP-systems of some countries has a function to perform a dynamic brake test on the route to get actual test information with regard to the train braking performance.
	P-44 (D)	Saw tooth braking should be applied when using pneumatic brakes to limit speed in long and steep descents in order to limit heat exposure to wheels	When pneumatic brakes have to be applied to restrict the speed in long saw-tooth braking should be applied. This means that during a brake application of approximately 60 seconds the speed should be restricted so much that there can be an interval of a minimum 90 seconds without brake application until the next pneumatic brake application. By such actions the heat exposure to the wheels is limited and the risk of wheel damage is reduced and hence reducing the risk of derailment. If necessary, the speed should initially be reduced so the above specified brake actions are sufficient to maintain allowable speed during the descent.
	P-45 (D)	When passing a signal showing a reduced speed, the driver should initiate the braking or speed reduction action prior to passing the signal.	When passing a signal showing a reduced speed, the driver should initiate the braking or speed reduction activities prior to passing the signal. For a number of reasons this may reduce the risk of over-speeding and derailment in track deviations: o The braking action is initiated earlier and a gentler braking will ensure sufficient speed reduction according to signals and signs. o There is less chance of the driver forgetting the speed reduction signal if the braking action is initiated immediately.
	P-46 (D)	Traffic controllers and drivers should not be allowed to override detector alarms.	It is not uncommon that hot axle box alarms are acted upon too late so the derailment has already occurred when the train stops or reduces the speed. Further, there are several examples of accidents that seem to have occurred due to overriding of a hot axle box alarm, either because the time taken for the driver to inspect the axle box has taken too long (thus cooling has occurred), or possibly because there is not a convenient location to stop and inspect the train without delaying other traffic, etc.. Trafikverket in Sweden has recently issued a new regulation for how various alarms should be handled. The document specifies the actions to be carried out after a detector alarm registration is received and restricts the traffic controller’s and train driver’s possibility to override detector alarms.
	P-47 (D)	Wagons equipped with a balance to detect overload in visual inspection. ***Note, this measure is currently being investigated to determine the details.***	Currently being investigated. No further information at present.

Table 4 Existing Consequence Mitigation Measures

Category:	M#	Measures and motivation:	Where applied:
Rolling stock	M-1 (D)	Derailment detection detectors (valves)	The purpose of a derailment detector is to detect that a derailment has occurred and to either automatically employ brakes to bring the train to a halt or to warn the driver and allow the driver to take appropriate action. The technology employed is typically a spring mass valve measuring vertical acceleration. Acceleration above a certain threshold activates the emergency brake valve.
	M-2 (D)	Equip tank wagons with impact shield to protect tank against penetration	Tank wagon hire companies have available for hire rail tank wagons with a large number of elements for improving the safety of hazardous goods transport services. The rail tank wagons are fitted with special buffers with additional deformation elements and structural protection to prevent damage for impact speeds up to approx. 35 km/h depending upon the size of the train. It is a requirement for transport of many types of hazardous materials that the wagon is equipped with protection against buffer locking to prevent structural damage to the tank and wagon frame in an accident. RID specifies the minimum requirement for wagons used for various type of materials. The unit also features protective shields on both ends of the tank serving as a crumple zone and protecting the tank bottom from perforation in the event of buffer locking and overriding. Design improvements on the fittings provide added protection against leakage if the vehicle overturns or rolls over. The additional optional safety elements increase the tare weight by only approx. 1.2t.
	M-3 (I)	Install emergency warning lights on locomotive to warn train on neighbouring track going in opposite direction.	In Switzerland it is a requirement that locomotives are quipped with warning lights in the front that can be lit to warn trains on the neighbouring track in the opposite direction about possible dangers in terms derailed wagons etc. Installation of such warning lights can be extended to other countries. These warning lights (red flashing lights) should be activated if the train driver suspects that the neighbouring track could be blocked or interfered by a derailment or other obstruction.
	M-4 (D)	Attach mechanical guides at the bogie structure or on wagon support at appropriate position to ensure that a derailed wagon most likely is kept along the track	A number of high speed passenger trains are equipped with structures or equipment in the bogie which ensures that the wagon is kept along the track if a derailment of one axle occurs. Examples of such trains are TGV in France, X-2000 in Sweden and Shinkansen in Japan. In many cases the guiding devices has been installed for other purposes and for other functions, but their guiding effect has been proven in accidents. The above examples are passenger trains, but it should be investigated whether it is possible equip freight wagons with similar guiding devices.
Infrastructure	M-5 (D)	Safety rails (guard rails) at bridges and in tunnels.	The European railways in general install guard rails between the running rails at bridges to limit the movement of a derailed wagon. In some countries and railway lines (e.g. Øresund tunnel in Denmark) guard rails are also fitted in tunnels. The measure could be given a wider application in order to limit the free movement of a derailed wagon and hence may limit the consequences of a derailment.
	M-6 (D)	Battering rams in front of safety critical supports.	Safety critical structural supports of platform roofs, large overbridges located between tracks or close to tracks may be given additional protection in the form of battering rams or other forms of structural protection to limit the risk of damage from derailed rolling stock. The measures are used to protect special safety critical structures, although are very commonly used.
	M-7 (D)	Installation of dragging object and derailment detectors.	Derailment and dragging object detectors can be installed to identify if a train has a derailed axle, or equipment that has come loose from a wagon and being dragged along the track between the rails. Such detectors may be installed in front of large stations or structures where the situation may cause major damage. Early dragging equipment detectors were of the "brittle bar" type. Fixed elements between and beside the rails would break when struck by foreign objects. Their breakage would interrupt an electric circuit that formed part of the reporting system, and the train would be stopped and inspected. The introduction of "self-restoring" dragging equipment detectors, which are hinged and sprung so they return to position after impact, have reduced maintenance requirements for such installations.
	M-8 (D)	Installation of deviation points leading to a safe derailment place in strongly descending tracks	In order to handle runaway rolling stock in strongly descending tracks from marshalling yards, controlled derailment points may be provided to avoid that runaway rolling stock accelerating in the descending tracks and causing large consequence derailments and accidents further down the descent. Such accidents have recently occurred March 24th at Alnabru/ Sjursøya in Oslo Norway causing 3 fatalities and 4 serious injuries, and December 3rd 2005 at Salerno in Italy causing one fatality and 3 injuries
	M-9 (I)	Radio or cell phone communication installations	Emergency communication connection from between trains and traffic central and trains can reduce the time from derailment to train stop and hence reduce consequences. GSM-R is a cell phone based communication system that is specified as pert of ERTMS and will be A

Category:	M#	Measures and motivation:	Where applied:
		like GSM-R in order to transfer emergency stop orders to trains	standard system in the EU-countries.
Operational	M-10 (I)	Separate passenger and freight traffic to separate lines to a larger degree (which is also EU-policy).	In order to minimise the risk of hazardous materials rail transport, hazardous materials trains should as far as possible be separated from heavy passenger rail traffic by route or time of operation in order to minimize the consequence. Hazardous material trains should if possible also be routed around high population density residential areas.
	M-11 (D)	Restrictions on freight traffic in general or hazardous materials transport through busy passenger terminals and/or underground stations	Restrictions on freight traffic in general or hazardous materials transport in particular through certain busy passenger terminals, city centres and/or underground stations to restrict traffic and limit the consequences of a derailment. Examples are banning of general freight traffic at busy lines around Rotterdam and Amsterdam or through airport train stations as Oslo Airport and Schipol in Amsterdam.
	M-12 (D)	Develop and apply a checklist for dangerous goods transport	The Swiss have developed a checklist for use by freight train transport of dangerous goods. The checklist is meant as an operational aid in controlling freight train transports of dangerous goods. The checklist could be adopted for use in the EU and other countries.
	M-13 (D)	Requirement for activating of warning lights in driving end of train.	In Switzerland it is a requirement that safety warning lights (red flashing lights) in the front of the train are activated if there is a suspicion that a derailment has occurred and there is a chance that the neighbouring track is blocked by the derailment or other obstruction. Improved communication systems by GSM-R required by ERTMS can be an alternative to the above measure.

3.2 Performance Assessment for Existing Measures[1]

The following tables are indicative of the information that has been gathered as part of our research and consultation and summarises over 40 responses from infrastructure managers and railway undertakings, and about 30 responses from supplier organisations.

Table 5 Performance Assessment for Infrastructure Preventive Measures

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	**Observed**	**Purchase and Installation**	**Life Cycle**	
P-1	An installed check rail is expected to be at least 90 % effective in avoiding derailment due to track geometry faults in curves with radius less than 250 m.	Installation cost € 250/m of track. The lifetime is at least equal to the lifetime of the rest of track construction.	Added track maintenance and tamping cost: + 20 %	The installation is assumed restricted to curves of radius < 250 m.	Checkrails may also be installed with the joint aim of reducing track wear.
P-2	Track and flange lubrication systems are installed primarily as measures to reduce track wear. These systems do however have secondary benefits and are thought to be contribute to reducing derailments in certain cases (as reported to us during our consultation exercises), hence their inclusion here. However, as their installation is generally for track wear considerations, we have not considered them as measures in the context of derailment prevention. Further, as derailment reduction is a benefit rather than a primary function of these measures, there are unlikely to be any no specific derailment reduction effectiveness data. We will review this situation during Part B.				
P-3	Installation of rock scree and avalanche protection structures is considered close to 100 % effective where installed. But the installation is very costly and cannot cover all lines where there is a rock scree and avalanche risk. Primarily a collision avoidance measure.		Installation cost € 3- 5000/m of railway line. The lifetime equal to the lifetime of the track	Life cycle cost estimate: € 150 per annum per m of railway line with rock scree protection structure	In 2006 there were 4 serious accidents/derailments in Norway due to rockfalls / rockscrees on the railway line which occurred at places where rockfalls and avalanches were not expected and hence not protected. 2 of them affected freight trains.
P-4	Rock scree and avalanche detectors are fairly reliable in terms of detecting screes or avalanches when they have occurred, but they can give a high number of false detections which will delay trains. In Norway approximately 2 per mille of the railway line length is protected by rock scree and avalanche detection. . Primarily a collision avoidance measure.		€ 100 000 + € 500 /m of railway line protected.	Life cycle cost estimate: € 150 per annum per m of railway line protected.	
P-5	Obstacle detectors have a primary role as a collision reduction system, with secondary benefits of reducing the likelihood of subsequent derailment. It is reported [2] that where these have been installed they are effective in their primary purpose. Indeed, it is stated that in 100 installations that only 1 serious collision has occurred in 15 years. However, because the primary function is collision reduction rather than derailment reduction, we have not considered them further. We will review this situation during Part B.				
P-6	Geo radars. IMs currently employ techniques for the identification of track superstructure faults. Further, track superstructure faults appear, based on our accident review, to make only a				

[1] Under the terms of the confidentially clauses associated with this work, some derail is not provided externally and is available only to the project team.

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	**Observed**	**Purchase and Installation**	**Life Cycle**	
	minor contribution to freight train derailments. We have not considered these further at this stage. We will review this situation during Part B				
P-7	Rolling stock equipment for rail profile monitoring. This technology allows for quicker and more efficient inspection of rail profile conditions (compared with the use of specialist vehicles). The main benefits of such systems are cost and efficiency, rather than safety. These are not considered further.				
P-8	Track circuits are installed for train detection purposes, as part of the signalling system. These systems do however have secondary benefits in that they may detect rail ruptures and thus contribute to reducing derailments in certain cases. However, because the primary function is train detection rather than derailment reduction, we have not considered them further. We will review this situation during Part B				
P-9	Interlocking to prevent movement of points while the relevant track section, inclusive of point, is occupied by a train, is a common feature of railway signalling installations. The interlocking feature in railway signalling systems is normally very reliable. Among 110 derailment accidents in Europe checked for this project, approximately 4-5 accidents are caused by untimely operation of points while they are occupied by trains		A track circuit for information about track occupation across a point costs approximately € 6000 – 10 000. If the point is electrically operated centrally from a signal box interlocking can be made locally or centrally depending upon cost.	Operating cost can vary depending upon the technical solution: Coarse estimate € 1000,- per track circuit.	Interlocking functionalities are normally introduced when installations are renewed To what extent and at what cost interlocking functions can be added to an existing installation depends on the age of the installation.
P-10	Manufacturer's claim [4] is for 10,000 hours MTBF for mechanical parts and 500,000 hours MTBF for electrical parts. Repair times of 5 minutes are claimed (excluding travel time). False alarm rate of less than 40% quoted.	Claimed by one IM to achieve an availability of >99%. A repair time of 1 day (mostly travel) was also quoted together with a false alarm rate of 40% [5] All other IMs answering this question stated that the devices they used were "effective" or similar qualitative judgement, and that they saw increased coverage as a good derailment reduction option.	Costing information is confidential The cost is dependent on the type of device, as some hot axle box detectors are multi-purpose.	Manufacture's recommend a fortnightly inspection [4]. Estimated by one IM [5] at 5% of purchase cost.	We have reported at various points within the Part A work that alarms can be ignored (or possibly thought to be a false alarm) and the train allowed to continue leading to derailments. This issue would need to be addressed if the full benefit of the increased use of these systems were to be realised.
P-11	Manufacturer claims are that these offer very similar characteristics to hot axle box detectors (P-10) [4] The rate of estimated false alarms is less than 2% [7]	The systems in service have an average of 98% full system availability. [7]	Costing information is confidential Installation claimed to take 3 days.	Manufacture's recommend a fortnightly inspection [4]. A second supplier suggests that hardware maintenance is restricted in general to a six monthly periodic inspections and a system calibration as a 12 monthly routine [7]	Can be linked with RFID tagging to provide effective feedback to appropriate parties.
P-12	In most cases, these devices are integrated with hot axle box detection to provide a single solution. The data for P-10 applies.				
P-13	Manufacturer claims between 85 and 95 % with 5% false alarm rate [10].	One IM, [8], indicated that the detection of wheel anomalies through a system of this type had	Costing information is confidential	Costing information is confidential	There is a significant variance in cost depending on the functionality of the devices in this category.

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	**Observed**	**Purchase and Installation**	**Life Cycle**	
	Alternative supplier [18] claims MTBF of 3 years with a 2 day repair time. False alarm rate of 1 per 100,000 trains.	almost completely eliminated hot axle box problems for one passenger train operator.			
P-14	See mitigation measure M-7 for dragging object/derailment detector.				
P-15	Manufacturer's claim is for track and sensors to have an MTBF 8 to 10 yrs	In-service estimates show achieved levels of over 20,000 hours MTBF (manufacturer's claim [9])	Costing information is confidential	Maintenance requirement less than 15 hours per year with a repair time of 30-90 minutes.	Although similar systems are used in Turkey, we are not aware of other installations outside of the USA, Canada, Australia and India. It may be necessary to transfer this measure to short or medium term.
P-16	Manufacturer's claim is for track and sensors to have an MTBF > 10 yrs, and computer systems 5-10 yrs [10]	Availabilities range between 85 and 95 % depending on the operators skills and environmental influences [10]	Costing information is confidential Installation into the track 100 man hours (1- 2 days duration). Setup 160 man hours (2 weeks duration) (+ handover & staff training) [10].	Regular maintenance: weekly visual check / cleaning 2hrs. = 104 hrs/year Annual inspection and maintenance: 40 hrs. False alarm rate claimed to be between 5% and 8%. A weekly test measurement using a master wheel set is recommended [10]	
P-17	Manufacturer's claim is an MTBF of 8000 hours. False alarms are claimed to be rare and loss of output would cause the system to fail, rather than false alarm [11]	The five newest installed systems have operated for the past 2-3 years without failure. [11]	Costing information is confidential Installation costs not provided, but the technology requires laser mounted devices to be installed on an existing gantry. Estimate is for 2 days to install and set-up.	Annual maintenance is required, and regular cleaning depending on the environment. [11]	
P-18	Many derailments are caused by substandard track that does not meet minimum standards and where speed has been reduced, either in freight only lines or in sidetracks at stations. Examples can be found in many countries, e.g. Norway, Sweden, Finland, Switzerland, Hungary. In order to reduce the frequency of derailments such lines should be closed for traffic operation until the standard has been upgraded. The effectiveness of this measure depends on the degree to which improved maintenance is carried out, but if maintenance is carried out to levels similar to main lines, then performance matching main line performance should be possible.		The cost to upgrade and maintain track to a safe standard can be substantial.		The consequences of derailments at such tracks depend on the traffic performed. If it is only for timber traffic in rural areas the consequence risk are small. However, if substandard tracks also exist in freight only lines or station sidetracks in urban areas, the consequences may be severe.
P-19	This measure relates to the frequency of derailments caused by failure to clear the flange groove. The potential benefit and costs of a revision of				

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
	this measure can only be judged when the frequency of freight train derailments which are caused by these defects is known (i.e. during Part B).				
P-20	This measure relates to the frequency of rail inspections. The potential benefit and costs of a revision of this measure can only be judged when the frequency of freight train derailments which are caused by track defects is known (i.e. during Part B). (In particular the use of side tracks are often the cause of derailments due to poor track geometry and rail conditions.)				This measure is closely linked to others, for example P-18. If there are insufficient resources to act on the information provided by additional inspection then this measure will not be effective.
P-21	This measure relates to the frequency and coverage of track geometry inspections. The potential benefit and costs of a revision of this measure can only be judged when the frequency of freight train derailments which are caused by track defects is known (i.e. during Part B). (In particular the use of side tracks are often the cause of derailments due to poor track geometry and rail conditions.)				This measure is closely linked to others, for example P-18. If there are insufficient resources to act on the information provided by additional inspection then this measure will not be effective.
P-22	Excessive track twist, in particular in transition curves leaving a highly canted circle segment of a curve, is one of the most frequent contributions to derailments in many countries. Existing intervention and immediate action limits varies from country to country. In view of the interoperability of rolling stock across border this is not helpful in avoiding derailments. If adopted, this measure will be very effective (depending on the operating limits chosen) in reducing derailments caused by excessive track twist.		The direct track cost of reducing track twist might not be high, but a reduction in track might reduce allowable speed and hence have an influence on travel time and capacity.	Increased inspection and maintenance cost may be required to reduce frequency of excessive track twist conditions.	Derailments are in general low speed derailments with somewhat smaller consequences than derailments at high speed, but they often occur at stations or close to stations where the infrastructure damage can be higher.
P-23	Tight control of track gauge is important to reduce derailments, in particular for tracks with old wooden sleepers and old rail fastening equipment. The existing measures implied by the various EU countries vary significantly. The final draft TSI for conventional rail infrastructure specifies an immediate action limit only which is laxer than action limits by existing limits in some countries. If adopted, this measure will be very effective (depending on the operating limits chosen) in reducing derailments caused by excessive track width. (For example, among 100+ freight train derailment accidents reviewed to date for this project approximately 7-8 % are due to excessive track width. However, some of these occurred due to excessive track width which was known for a several months and no action was taken. The overall derailment frequency reduction potential for this measure is there therefore judged to be in the range 5-6 % but will be further assessed in Part B.)		This is difficult to assess as tighter action limits will increase the maintenance cost and the need for sleeper exchange. However, since it is mainly track with wooden sleepers of a certain age that is exposed to this risk, the cost should be reasonable.		It is usual that track width derailments occur at track with aged wooden sleepers and at little used sidetrack at stations or on freight-only lines. In some cases the cause has been specified as a dynamic widening of the track gauge due to the train forces in curves. In some of the cases rail compression forces due to high rail temperatures could have contributed to the dynamic widening of the gauge.
P-24	A maximum allowed cant inclusive of any variations during operation is in TSI for conventional rail infrastructure is set at 170		Small costs, but track cant might have to be reduced to limit the	Reduction in allowed train speed in curves in front of signals where freight	A very high track cant is unfortunate in positions where freight trains may have to

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
	mm for lines open for freight traffic. This is a very high cant in particular in curves where trains may need to stop regularly, e.g. in front of signals. This is particularly safety critical if some of the wagons are skew loaded within or just outside of specified limitations. Some countries have stricter cant limitations at such positions that could be wider applied. The overall derailment frequency reduction potential for a measure to put stricter cant limitations in curves in front of stop signal is approximately 3 -4 % based on derailment causes in 100+ derailments we have looked at accident reports for. If adopted, this measure will be very effective (depending on the operating limits chosen) in reducing derailments caused by excessive cant variation.		maximum possible cant including allowed variations.	trains may expect stop signals.	stop, e.g. in front of signals. In particular if there is a narrow curve at the relevant track section which can be occupied of a train stopping in front of a signal. The TSI allows as much as 160 mm design cant for lines with freight train operation but limited to R-50/1.5 in curves of R < 290 m.
P-25	The overall derailment frequency reduction potential for a measure to reduce excessive track height variations is approximately 3-4 % based on derailment causes in 100+ derailments we have looked at accident reports for. This applies to a single height variation or more cyclic effects. The overall derailment frequency reduction due to elimination of this cause therefore seems to be in this range. The degree to which this reduction can be achieved in practice is dependent on the criteria adopted, and the level to which it is implemented.		This is a track maintenance issue once the track is installed. Short length height failures are fairly easy to detect but costly to correct as their cause are often due to insufficient water drainage of the substructure. However, a speed reduction will reduce derailment risk. Long wave cyclic height failures are more difficult to detect, but once detected they can be corrected by track geometry adjustment		Derailments due to track height variations are high speed phenomena and the speed reduction would be the least costly action. Due to the high speed the cost associated with derailments cause can be high.

Table 6 Performance Assessment for Rolling Stock Preventive Measures

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	**Observed**	**Purchase and Installation**	**Life Cycle**	
P-26	Flange lubrication for locomotives – see P-2.				
P-27	In the derailment accident basis we have looked at there are twice as many derailments caused by composite wheels as for mono-block wheels. Whether one type of wheel can be said to have a higher failure rate than the other depends upon the number of wheels of each type and the traffic performance of each type of wheel. If we assume there is an equal number and equal traffic performance of each type of wheel the derailment rate could be approximately halved for the rolling stock with composite wheels if the wheels were exchanged with mono-block wheels. Wheel failures account for approximately 8 % of all derailments. The derailment frequency reduction potential for a change of all composite wheels with mono-block wheels could hence be approximately 2 %. But this value is uncertain and will be studied in Part B.		The cost of such a measure to replace composite wheels for mono-block wheels depends upon how it is carried out. The most cost-effective approach would be to make the replacement when existing wheel tires are worn out, or when the entire wheel including both rim and tire has to be replaced.	The cost of a new wheel tire is assumed to be lower than the cost of a new mono-block wheel. The operational cost of a fleet of railway cars with mono-block wheels might therefore be higher than for a similar sized fleet of wagons with composite wheels, but this depends upon the time between tire and wheel replacement and the actual cost and time of doing the replacement.	If it can be verified without significant doubt that mono-block wheels have a lower failure rate than composite wheels one could make mono-block wheels mandatory for wagons for hazardous materials.
P-28	Selection of roller cage material can influence the failure rate of bearings. Information searches on the internet seems to indicate that polyamide roller cages are less exposed to failure due to vibrations, and hence may be a better material then brass in the roller cages of railway wagon bearings. Failure of roller cages of bearings is an important cause of hot axle boxes, and hot axle boxes are among the major causes of freight train derailments. A reduced roller cage failure rate may therefore have a significant influence on hot axle box events and also on freight train derailments. It is unclear at present the numerical difference in failure rates between polyamide and brass roller cages; however the maximum potential is for a 10 % reduction in overall freight derailment frequency.		The price difference between polyamide type roller cages and metal type roller cages is hardly important. If the replacement with a new roller cage material is done when the bearing has to be opened and maintained in any case the cost is assumed to be marginal.	We do not know whether the material selection has an influence on the life time of the roller cage, but so far we have no such indication that it does. However, internet information indicates that polyamide roller cages make less noise when failures occur, and hence they might be more difficult to follow-up by trackside acoustic bearing monitors.	CargoNet the Norwegian freight train operator made a decision in 2000 to replace their brass roller cages with polyamide type roller cages. EUB of Germany has made the same recommendation to DB Schenker after a derailment between Bruchmülen and Bunde in 2009 and the recommendation has been accepted by DB Schenker. We do not know to what extent polyamide roller cages are common in other countries.
P-29	Exchange of axles for stronger axle designs is assumed to influence the frequency of axle ruptures caused by hot axle boxes. From the accident causes reported by 100+ accident investigations this measure has the potential to reduce the overall derailment frequency by 5 % were the full benefit to be realised. As a working assumption, we will assume that 50% to 90% of axle ruptures may be avoided.		The cost of this measure is partly determined by the cost of new axles, but also to what extent the wagons has to be taken out of commercial operation during the replacement	With higher strength axles the inspection frequency might be reduced and hence the operating cost reduced, but the inspection frequency is mainly to be determined by the calculated fatigue life time of the axles, which might not be proportional to the strength.	Axle ruptures are mainly due to fatigue failures and the important factor is whether fatigue life of the axles is increased by an increased strength. If the extra strength is achieved by higher strength materials, the fatigue life may not be significantly affected.
P-30	Increased use of central coupler between wagons in fixed whole train operation with 4 axle cars are likely to reduce derailment		The use of central coupler has to be motivated by other factors	Operating cost may be reduced and motivate the reduction.	

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	Observed	Purchase and Installation	Life Cycle	
	frequency due to removal of buffer forcers, but heavy whole train operations are anyhow not exposed to high derailment risk from factors that can be influenced by the central coupling arrangement		other than reduction in derailment risk.		
P-31	Bogie wagons are less prone to derailments than single axle wagons. In particular this applies to lightly loaded or empty single axle wagons with a long wheel base and long overhang. It is difficult to quantify the effect of a measure to replace single axle wagons with bogie wagons, but it is likely to have a significant influence of the derailment frequency of freight trains.		For tank cars, hopper wagons and wagons for bulk transport of heavy materials the trend is for bogie wagons and the cost may be in favour of bogie wagons. For wagons for containers, swap bodies and light manufactured objects like car single axle wagons can give a lower	If more axles are required for same loading capacity an increased inspection and maintenance cost may result but this depends upon the type of wagon and load.	For wagons for containers, swap bodies and light manufactured objects like automobiles single axle wagons can give a lower unit cost per m of loading basis and will be favoured on commercial reasons for some sort of operation. Even for timber transport we have seen that an increase in allowable axle load for heavy timber transport lines have favoured short coupled wagons with single axle running gear, as they give a higher loading capacity per m train length.
P-32	Installation of disc brakes reduces the heat load on wheels and may reduce the risk of catastrophic wheel failures, either in the form of mono-block wheel ruptures or due to displaced tyres of composite wheels. Hence, disc brakes may reduce the derailment risk somewhat. The derailment reduction potential based on existing operation is approximately 5 % were the full benefit to be realised. As a working assumption, we will assume that 50% to 90% of wheel ruptures may be avoided. The driving force behind a possible move from tread brakes to disc brakes may be the "TSI for railway system noise" that is difficult to meet by tread brakes with cast iron brake blocks.		Exchange of brakes from tread brakes to disc brakes on existing wagons is very expensive and must be motivated by other benefits. A replacement of cast iron brake blocks by composite wheel blocks is a cheaper way of meeting the noise TSI for existing wagons.	Probably not decisive in any way, but has to be investigated further.	Disc brakes also have some disadvantages as they does not clean the wheel tread for rub that may form in the wheel-rail contact if the wheel is blocked for a short period. Not being able to remove rub from blocked wheels may increase the risk of hot axle boxes.
P-33	Apply Irish track twist limitations for rolling stock. This measure is a specific case for the Irish railways (Northern Ireland and Republic of Ireland) in the TSI for freight wagons and is probably granted due to the specific track gauge in Ireland and their captive rolling stock that is designed for such track twist conditions. It is not applicable for the rest of Europe unless changes are made to rolling stock specifications which are assumed very costly. This measure will not be investigated further.				
P-34	Secure brake gear located in the underframe. Based on the accident causes of a 100+ accident basis this has a derailment frequency reduction potential of 1 %, but the measure could already be applied in more countries than Sweden. This measure is considered to be very effective where applied >90.		The cost figure depends upon actual design of wagon brake system, but is assumed to be relatively small.	The lifecycle cost in terms of inspections and replacement of failed securing straps will increase, but we are not aware of any quantification.	
P-35	This measure relates to the frequency of derailments caused by buffer failure (lack of greasing etc). The potential benefit and costs of a revision of this measure can only be judged when the frequency of freight train derailments which are caused by these defects is known (i.e. during Part B).				
P-36	This is the normal wheelset inspection program carried out to by all RUs to ascertain that the wheels and axles are free of safety critical wear				

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	**Observed**	**Purchase and Installation**	**Life Cycle**	
	damages and cracks. This is normally carried out by visual inspection as well as ultrasonic or other NDT-methods while the train is in a depot. The effectiveness of this measure will be dependent on the safety culture of the organisation, amongst other things. A review of accidents during Part B may provide further information to support an effectiveness rating.				
P-37	Derating of allowable axle load for type Ai and Aii axle designs. This is a reversal of an exemption granted by some countries to allow higher axle loads than the intended design axle load, and a recommendation to revoke such higher loads has been issued by the JSSG of ERA. To what extent this will reduce axle ruptures due to fatigue is uncertain, but to remove this exemption will lead to replacement of those axles with new and stronger axles. As a working assumption, we will assume that 50% to 90% of axle ruptures may be avoided where this exemption applies.		No direct investment cost.	Probably a reduced life cycle cost for the wagons in question, but an increased no of wagons is required to do the same amount of transport, which will increase the train operating cost.	Axle ruptures are often high speed phenomena with a large accident potential as shown by the Viareggio accident, although we do not know whether the involved wagon in the Viareggio accident has been allowed a higher axle load than the intended design load.
P-38	Implement EVIC inspection programme for axles. From the number of derailments due to this cause the measure seems to have a potential for 5 % reduction in derailment frequency, but the reduction in derailment cost and consequence is likely to be higher as these accidents are normally high speed derailments. The effectiveness of this measure however needs to be judged based on the quantity of axle failures that may have been prevented by this programme. This information is not available at the present time.		No particular purchase or installation cost.	Increased inspection cost might apply, but the EVIC inspection program may be more cost- effective than previous inspection programmes.	Axle ruptures are often high speed phenomena with a large accident potential as shown by the Viareggio accident.
P-39	Like P-36, the effectiveness of this measure depends on the safety culture of the organisation, time allowed for the task and other factors. We have previously identified, from the ARAMIS method [12] the following relating to the use of human barriers: ▪ Where the human barrier is of a preventative nature or part of a normal operation, a probability of failure on demand of 10^{-2} is suggested. ▪ Where the human barrier requires a specific intervention, a probability of failure on demand of 10^{-1} is suggested. These values perhaps provide a range, although following development of a risk model in Part B the context in which this measure applies will be clearer, allowing a better estimate of its potential effectiveness. Costs associated with a potential adoption of this measure will be relatively minor.				

Table 7 Performance Assessment for Preventive Measures applied to Train Loading and Operation

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	**Observed**	**Purchase and Installation**	**Life Cycle**	
P-40	The discussion at P-39 applies.				
P-41	Brake position G for locomotive in G and "Lange Lokomotiv" depending on train weight. Identical or similar requirements exist in many countries to reduce compression forces when braking long and heavy freight trains. The effectiveness in terms of avoiding derailments are difficult to assess, particular since this measure to a large degree is an existing measure that is applied in most countries. However, we are aware of derailment accidents which partly can have been caused by not implementing this measure contrary to the requirements.		None.	None.	This measure is to a large degree already implemented in most countries.
P-42	Limitations on brake application at low speed in difficult track geometries. Abrupt braking of long freight trains at low speed in difficult track geometries, in particular in deviated track route across stations, may cause derailments due to buffer locking. Traction control of modern electric traction units might include speed dependent limitations on dynamic braking. Otherwise this is mainly a matter of good train handling. Uncontrolled application of brakes due to an active ATP-system either due to exceeding allowable track speed or from a locomotive not being in front and passing a signal at danger may be a cause for such derailments. The potential for overall derailment frequency reduction by removing this cause is approximately 2-3 %, factored by the effectiveness of the measure. The effectiveness of the measure is a human factors issue, and will be assessed in the context of the risk model to be developed during Part B.		None	None	This is low speed derailments where the brakes are already applied and the consequences are normally low, but as such derailments often happen at stations they might involve other trains which can increase the accident consequences severely. Strong regenerative braking through s-curves for instance at crossovers also applies. If the wagons are light behind the locomotive then derailments may occur. (In some few cases even the low regenerative brake force of today is still too high).
P-43	ATP Dynamic brake test on route to get information about brake performance. Normal brake tests before train departure does not give direct information on the actual performance of the train brakes. In order to improve the information to the driver the ATP-system that is used in Sweden, Finland, Norway and possibly France has a function to test the brakes and get feedback about the actual performance of the brakes. Train drivers in Sweden and Norway are obliged to use this test at the earliest convenience after train departure from the formation yard. A similar functionality is specified for the ETCS -system of Sweden and Norway which is additional to the general ETCS-functionality.		Embedded in ATP and ETCS-system. Actual cost of adding this functionality to the ETCS is unknown.	None	The use of this measure is dependant upon the functionality of the ATP-system. Existing ATP-systems of France, Sweden, Finland and Norway supports the functionality. The functionality is not included in the general ETCS functionality, but is included in the Swedish and Norwegian application. For each brake application the driver may get information about the functionality of the brakes and if it is lower than specified in the train dossier he has to adjust the train settings accordingly. f

P#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	**Observed**	**Purchase and Installation**	**Life Cycle**	
	The overall derailment reduction potential for this measure based on an accident basis of 100+ derailments seems to be about 2 %, but it can also reduce the collision risk.				
P-44	Apply saw-tooth braking. This is a Swiss requirement specified in their train operating rules, “Fahrdienstvorschriften” The measure is only of relevance in very long and steep descents and not a measure that has a general application outside of the Alpine countries or other countries with long and steep descents, such as Norway and Spain. The overall derailment potential is low, but the measure might be important in countries where it is applied. Human reliability assessment would be required to estimate the potential benefit		None	None	The effect of this measure is to reduce overall thermal load on the wheel. It is mainly applicable in long and steep descent or in trains with low dynamic braking capability.
P-45	Initiate braking prior to passing a signal which requires brake application. The overall derailment reduction potential for this measure based on an accident basis of 100+ derailments seems to be about 1-2 %, but it can also reduce the collision risk. The potential risk reduction benefit needs to be factored by the effectiveness of the measure. The effectiveness of the measure is a human factors issue, and will be assessed in the context of the risk model to be developed during Part B.		None	Increased train running time	For a number of reasons this may reduce the risk of over-speeding and derailment in track deviations: • The braking action is initiated earlier and a gentler braking may be applied not risking derailment due to train compression at low speed. • Less risk of forgetting the speed reduction and running into an ATP brake application that might cause derailment.
P-46	The experience of one IM [5] is that it is possible to reduce to almost zero the incidence of axle failures / hot axle boxes, with suitable equipment and suitable instructions concerning dealing with alarms.		The main cost associated with this measure is potential traffic disruption dealing with false alarms. This is not estimated at present, but is addressed in general terms in Section 6.0.		See also comments in P-10.
P-47	We are waiting additional information on this measure. However, we believe that it would assist with visual inspection of wagons and possibly allow detection of incorrect loading during preparation.				

MANAGING RISK

Table 8 Performance Assessment for Mitigation Measures

M#	RAM and/or Effectiveness Assessment		Costing Information		Comments
	Predicted	**Observed**	**Purchase and Installation**	**Life Cycle**	
M-1	Manufacturer's estimate between 500,000 and 1,000,000 MTBF operational hours per detector. No known failures (despite false alarms) [13]	There have been no false alarms or known failures with latest device variant which has been in operation on 50 wagons (100 units) for about 5 years, hence 500 years of operation. [13]	Costing information is confidential Installation time on new wagons is negligible, on older wagons possibly 3 to 4 hours per wagon. [13]	No field maintained parts, repair time is to remove and replace – about one hour per unit. Periodic test required – involving inducing shock (hitting with hammer) to check operational.	Training of driver required so that he is aware of the installation of the device and what to do in case brakes applied. The application of brakes may not be an appropriate mitigation in all cases, and may increase the risk of a more serious derailment.
M-7	Dragging object / derailment detectors. In the context of derailment detection these devices offer an alternative to M-1. To be comparable however these devices would have to be fitted at a very high frequency along the track, with high installation costs and maintenance costs. On the basis that the cost would be prohibitive (compared to M-1 we have not considered these further.				
M-2 to M-56and M-8 to M-13	These measures are excluded from the scope of future assessment during Part B [1] and hence are not required to have an effectiveness assessment allocated to them.				

4.0 Performance Assessment of Future Measures

The following tables are indicative of the information that has been gathered as part of our research and consultation and summarises over 40 responses from infrastructure managers and railway undertakings, and 30 responses from supplier organisations.

Readers of this report are referred to Section 2.0 concerning our classification scheme, limitations and other assumptions regarding the identification of short and medium term measures.

Table 9 Summary of Potential Future Preventative Measures

Measure	Description	Effectiveness	Timescale
End-of-train device (brakes)	In the USA & Canada freight trains are installed with “end of train devices” that are in radio contact with the driver, and by radio signal to the unit the driver can apply brakes on the train in an emergency situation. This can be an essential safety measure in situations where the brakes of substantial rear parts of the train can not be applied from the driver’s position. Application of brakes through an end of train device can also speed up the brake application in an emergency situation.	The potential effectiveness of these devices is reduced in the area governed by EU regulation as freight trains are generally shorter than in the USA. However, we propose to establish potential effectiveness criteria based on a review of accidents and an assessment of those that such devices may have prevented. Should the measure show promise on this basis then additional information will be sought.	Medium
Awareness program and improved maintenance	A concern expressed to us by several IMs was regarding the quality of freight wagons from some countries. In particular that maintenance as well as supervision of national authorities of this maintenance is of varying standards. [8, and others]	A review of accident reports will indicate the potential improvement that could be achieved trough the implementation of a measure of this type (i.e. the reduction of derailments caused by poor maintenance of freight trains). A periodic safety check, setting of safety limits etc is a possible implementation method for this measure.	Short
Hot Axle Box Indication	The use of thermo-sensitive chalks or similar to check for hot axle boxes [14]	This measure could be useful in visual examination by RUs to detect for hot axles.	Short
Machine vision devices	These products are designed to detect faults that may occur on freight vehicles when they run pass the detection site. Such devices are installed at trackside and employ hi-speed cameras to grab images of the vehicles and these images are sent to the computer for processing, comparing and analysis so any fault on the vehicle can be distinguished and detected. They detect mechanical failures of the bogie, dragging objects, coupler faults and may also detect temperature variations etc. [6, and supplier responses]	Costing information is confidential Claimed to have MTBF of around 10,000 hours for the mechanical parts and 500,000 hours for the electric parts and an MTTR of less than 10 minutes [4]	Medium
Telematics	Devices that allow receipt and transmittal of information from / to rail freight vehicles. Using this technology it is possible to inform the Entity in Charge of Maintenance. Other benefits include verification of train consist and operational parameters. [8, 15]	The potential effectiveness of such measures will be assessed during Part B following a review of accidents. (Benefits may include for identification of train formation errors at check points, better communication of maintenance requirements etc).	Medium
Anti-lock device	Antilock device for freight cars. A unit of this type is running on container wagons in the GB. Such devices may help to prevent several undesirable and contributory causes of freight train derailment, such as increased track wear, wheel flats and overheating axles. They may also provide a local power source for other monitoring systems. [13, 16]	Costing information is confidential Such devices may reduce the incidence of derailments resulting from locked / fractured axles and overheating axle boxes. Data on reliability / effectiveness not available at this time.	Short / Medium
Sliding wheel	Sliding wheel detectors. These systems detect wheels that are not rotating	Costing information is confidential	Short / Medium

Measure	Description	Effectiveness	Timescale
detectors	correctly and raise an alarm, with similar benefits to the antilock device for freight wagons described above. They are currently used in at least Australia, although a GB demonstration is planned for 2011 [11].	These systems are described as virtually maintenance free. One supplier stated that six units have been installed, the first in 2003 with no reported failures. [11]	
Handbrake interlock	A handbrake interlock was mentioned in the [17] as a potential new measures. This followed a freight train derailment at Hatherley, near Cheltenham Spa 18th October 2005 where a freight train was running more than 100 km with a wagon with locked wheels due to a handbrake that was on (see also sliding wheel detector and anti lock device).	This measure is likely to have prevented the derailment discussed opposite. This is likely to be an engineered solution and requires further assessment regarding the costs and effectiveness.	Short

5.0 Linkage between Derailment Cause and Mitigation Safety Function

5.1 Preventative Measures

The preventive measures described Tables 5 to 7 and 9 are intended to address freight train derailment causes. Although the linkages between cause, safety function and individual measures will be studied in depth in Part B, an indicative summary is presented below. The analysis reads from left to right, starting with derailment cause, safety function (to prevent the derailment cause) and then the measure that performs this function.

Table 10 Link between Derailment Cause and Prevention Measure

Derailment Cause	Safety Function	Measure	P#	Comment
Axle failure / seizure	Monitor axle bearing temperature	Hot axle box detectors	P-10	
		Acoustic bearing monitoring	P-11	
		Machine vision device	N/A	Potential future measure
		Use of thermo-sensitive materials to detect axle temperature condition	N/A	Potential future measure
	Prevent Axle Failure	Replace metal roller cages with alternative materials	P-28	
		Use of stronger axles	P-29	
		Derating of axle loads	P-37	
		Inspect axles of freight train rolling stock according to EVIC	P-38	
Track geometry defects / failures	Maintain track geometry within acceptable limits	Track geometry tests on all tracks	P-21	
		Establish EU-wide limits for track twist	P-22	
		Establish EU-wide limits for track gauge	P-23	
		Establish intervention/immediate action limits for track cant	P-24	
		Establish intervention/immediate action limits for track height	P-25	
		Continuous supervision of track conditions via rolling stock mounted equipment	P-7	
		Adequate maintenance resources for network	P-18	Derailment is one possible consequence
	Rolling stock to be more tolerant to geometry defects	Increase rolling stock tolerance to track twist defects	P-33	
	Detection of potential superstructure defects	Ground penetration radar	P-6	
Rail ruptures / failures	Detection of potential / existing rail ruptures	Continuous supervision of track conditions via rolling stock mounted equipment	P-7	
		Track circuit to detect rail ruptures	P-8	Derailment prevention is a secondary benefit
		Ultrasonic inspection of rail to detect onset of rupture conditions	P-20	Derailment is one possible consequence
Flange climb	Prevent flange climbing	Check rail in sharp curves	P-1	
		Track and flange lubrication (infrastructure)	P-2	Derailment prevention is a secondary benefit
		Bogie performance monitoring equipment	P-15	
		Flange lubrication of locomotives	P-26	Derailment prevention is a secondary benefit
Collision with obstructions	Prevent collision with obstruction	Rock scree and avalanche protection structures	P-3	Derailment is a secondary consequence
		Rock scree and avalanche detectors	P-4	Derailment is a secondary consequence
		Level crossing obstacle detectors	P-5	Derailment is a secondary consequence
		Clear track flange from obstructions	P-19	Derailment is the primary consequence

Derailment Cause	Safety Function	Measure	P#	Comment
Points movement under train	Prevent points movement under train	Interlocking to prevent points movement whilst track occupied	P-9	
Wheel structural or profile failure	Monitor wheel / brake temperature	Hot wheel / hot brake detectors	P-12	
		Machine vision device	N/A	Potential future measure
	Detect wheel defects	Wheel load / wheel load impact detector	P-13	
		Wheel profile measurement systems	P-16	
		Machine vision device	N/A	Potential future measure
	Prevent wheel failure	Replace composite wheels with monoblock wheels	P-27	
		Replace tread brakes for disc brakes (reduce heat activation)	P-32	Derailment prevention is a secondary benefit
		Wheel set integrity inspection programme	P-36	
		Saw tooth braking to limit heat exposure on wheels	P-44	
		Anti-lock device	N/A	Potential future measure
		Use of trackside sliding wheel detector	N/A	Potential future measure
		Install handbrake interlock to prevent train movement with handbrake applied	N/A	Potential future measure
Overloading / skew loading / improper loading	Detect improper loading conditions	Wheel load / wheel load impact detector	P-13	
		Loading gauge infringement detectors	P-17	Derailment is one possible consequence
		Machine vision device	N/A	Potential future measure
	Prevent improper loading conditions	Use of registered and certified loading personnel	P-40	
		Use of wagon balance to detect overload conditions	P-47	
Loose equipment	Detect / prevent dragging loose equipment	Dragging object detector	P-14	May also detect derailed axles
		Install under-frame cages to retain brake components	P-34	
		Regular greasing / check of buffers to prevent them falling off	P-35	
		Machine vision device	N/A	Potential future measure
Wagon/ rolling stock failures	Detect bogie hunting (steering) problems	Bogie performance monitoring equipment	P-15	
	Better riding quality	Increased use of bogie wagons	P-31	Derailment prevention is one possible benefit
	Prevent safety failures of rolling stock	Safety critical maintenance activities to be checked by two persons	P-39	
Train composition failures / buffer locking	Reduce compression forces and buffer locking	Use of central couplers	P-30	
		Locomotive and first wagon to be in brake position G	P-41	
		Operational limit on brake application in certain track geometry	P-42	
		End of train device	N/A	Potential future measure
Train braking failure	Detect onset of train brake defects	Perform dynamic brake testing during operation to detect defects	P-43	
Overspeeding	Prevent overspeeding	Initiate braking prior to passing signal to reduce overspeeding risk	P-45	
Failure to take correct action when alarm raised	Alarm management	Implement / improve alarm management instructions	P-46	

5.2 Mitigation Measures

The mitigation measures described in Table 4 are intended to reduce the consequences following a freight train derailment. The analysis of those based on the derailment detection will be studied in depth in Part B, although an indicative summary is presented below. The analysis reads from left to right, and assumes a derailment has occurred.

Table 11 Link between Derailment Occurrence and Consequence Reduction Measure

Safety Function	Measure	M#
Reduce severity of derailment	Install derailment detection devices (bring train to safe stop)	M-1
	Install mechanical guides to keep derailed wagon upright	M-4
	Install guard rails to control derailed wagon movement at certain locations	M-5
	Use of checklist (to confirm correct train configuration)	M-12
	Install dragging object detectors to detect partially derailed wagons	M-7
Prevent loss of containment	Install tank shielding to prevent penetration	M-2
Prevent secondary collision / accident	Install warning lights on locomotives	M-3 / M-13
	Install battering rams to provide protection to other structures (bridges etc)	M-6
	Install deviation points to direct runaway trains to safe derailment place	M-8
	Provision of radio communications to provide advance warning to other trains	M-9
	Use of checklist (to require that communication / warning devices are operational)	M-12
	Separate passenger and freight traffic to reduce likelihood of secondary collision	M-10
	Restrictions placed on quantity and type of freight traffic in busy locations	M-11

6.0 Assumptions, Data Requirements and Shortcomings

Within this report we have provided statements concerning costs and related factors that require further detail during Part B. These include:

- Costs associated with service disruptions – for example a false hot axle box detection. The exact situation will be location specific, and will be dependent on the location of the detector and also the network configuration. It is likely we will assume that IMs have considered how such situation may be managed, and as part of their considerations they have positioned such detectors so that it is easy to remove the particular train from normal service, therefore limiting delays and knock-on effects.
- Cost parameters for accidents need to be established (at least for those not already addressed in [18]).
- Cost parameters for reductions in damage through the introduction of a particular measure.
- Average unit labour costs for the installation and life cycle aspects associated with the introduction of a measure.
- In certain cases, data is not readily available for some measures (in particular for measures such as check rails, the benefits of increased maintenance etc) – and we address each in turn within the data analysis in the analysis above. Strategies to address such shortcomings include:
    - Discussions with parties who use such measures to establish their views on the effectiveness of such measures.
    - Comparison with similar approaches used elsewhere.
    - The use of engineering judgements or data ranges.
    - Risk modelling to determine the required effectiveness of a measure to achieve a cost/benefit ration of unity.
    - Sensitivity analysis.

7.0 Conclusions and Way Ahead

This report is prepared to present the measures that have been identified to date, and also to demonstrate the data that is available for each measure. As this report is only an interim data document we do not draw specific conclusions, but make the following observations.

- Most measures are supported by data, or we have presented a strategy to identify any data shortcomings. We have established good relationships with many IMs and RUs as part of this work and we are able to contact them to address such shortcomings where required.
- The list of measures is, we believe, complete and has been advised to us by IMs, RUs, trade associations and suppliers.

This Part A task, and others within the Part A work programme, will be used as input into Part B.

We envisage the list of measures discussed within the Part A work programme being introduced into a risk model which will be developed during Part B. By allocating each measure a RAM/effectiveness weighting, the benefit that the measure may bring, if more widely introduced will be judged. Together with the cost associated with the introduction of that measure, a cost effectiveness assessment will be possible leading to the identification of those that show most promise.

8.0 References

[1] Assessment of existing operational and technical measures against freight train derailments, ERA/2010/SAF/S-03, dated July 2010

[2] Assessment of freight train derailment risk reduction measures: A1 – Existing measures, DNV BA000777/02, dated Jan 2011

[3] Assessment of derailment risk reduction measures: A2 – Markets, DNV BA000777/03 dated Jan 2011

[4] Supplier questionnaire response, respondent details confidential

[5] IM questionnaire response, respondent details confidential

[6] IM response, respondent details confidential

[7] Supplier response, respondent details confidential

[8] IM questionnaire, respondent details confidential

[9] Supplier questionnaire response, respondent details confidential

[10] Supplier questionnaire response, respondent details confidential

[11] Supplier questionnaire response, respondent details confidential

[12] The European Commission Community Research 'Accidental Risk Assessment Methodology for Industries in the Context of the Seveso II Directive' (ARAMIS), Contract No: EVG1 – CT – 2001 – 00036, dated December 2004.

[13] Supplier questionnaire response, respondent details confidential

[14] RU questionnaire response, respondent details confidential

[15] RU questionnaire response, respondent details confidential

[16] RU questionnaire response, respondent details confidential

[17] Report 08/2006, RAIB 2006

[18] Impact Assessment on the use of Derailment Detector Devices in the EU Railway System, ERA/REP/03-2009/SAF dated May 2009

[19] Supplier questionnaire response, respondent details confidential

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MANAGING RISK

Det Norske Veritas

Assessment of freight train derailment risk reduction measures:

A4 – New Technologies and Approaches

Report for European Railway Agency
Report No: BA000777/05
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MANAGING RISK DNV

Assessment of Derailment Risk Reduction Measures:
A4 – New Technologies and Approaches
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Summary: This document provides an assessment of the new technologies and approaches that may be applied in the rail freight environment to reduce the risks associated with freight train derailments

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0.0 Executive Summary

0.1 Study Scope and Objectives

Det Norske Veritas (DNV) is completing a study on behalf of the European Railway Agency (the Agency), the objective of which is twofold:

1. Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation within 5 to 10 years). For these measures, Part A work is also required to assess the market status for technical measures (defined as devices or systems) and establish objective performance data for the identified measures. The work in Part A also extends to identifying, as far as is possible, potential long term measures (not expected to be ready to implement within 10 years) as an input to other research projects currently underway.
2. Part B has the objective of analysing the measures identified in Part A with a view to establishing those that show the most promise from a risk reduction viewpoint. Part B addresses such measures which are available at the short and medium terms.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland. In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

This report concerns the Part A remit associated with ***identifying, as far as is possible, potential long term measures (not expected to be ready to implement within 10 years) as an input to other research projects currently underway.*** Other work in Part A deals with the other scope requirements, and is separately reported. It should be noted that this report is factual in nature and does not seek to make any assessment regarding performance or effectiveness of the identified measures.

0.2 Methodology and Study Results

Our methodology for establishing the potential next generation of safety measures has included the following principal activities:

- Consultation with infrastructure managers (IMs), railway undertakings (RUs), suppliers and maintenance organisations seeking their opinions on future generations of freight train derailment safety measures.
- Review of published research topics and papers addressing the topic of freight train derailment and/or new technology.
- Consolidation of the information from the above sources, and the identification of those that may provide a benefit when considering the issue of freight train derailment.

We conjectured that the potential freight railway of the future may:

1. Place a greater emphasis on dedicated freight railway lines, and railway lines more oriented towards freight traffic.
2. Require heavier, longer and faster freight trains.

The first of these parameters will enable track geometry parameters to be optimised more towards freight traffic. This will have a positive effect freight train derailment risk.

The second parameter may require additional safety measures to be considered in order for the existing safety performance to be at least maintained, and/or improved. Technical factors that need to be considered include:

- Increased axle strength to enable heavier loads to be carried.
- Better braking performance to improve braking performance and reduce in-train forces for longer trains.
- Improved suspension design to reduce track damage that might otherwise result from increasing speed.
- A more effective and condition based maintenance regime that is able to collect and deal with pre-fault / failure conditions in a more efficient manner.

We also note in Section 2.0 the emergence of new (in Europe) technology – currently being tested – which we consider may be the backbone of longer term safety measures.

Taking cognisance of the discussions above, and other issues noted within this report, we have made the following recommendations for areas that may be useful to consider in the upcoming research and development project:

1. The applicability of Electronically Controlled Pneumatic Brakes to address some of the potential requirements for improved train braking performance.
2. The consideration of an improved design solution with respect to wheels and axle boxes.
3. Improved suspension design to enable increased train speed and also with a view to reducing track wear and damage, which is also a causal factor of derailments.
4. The use of freight wagon on-board condition monitoring systems (which would require electrical power to individual wagons) and the transmission of condition based information to various actors responsible for operation, maintenance and/or train control.
5. The optimum solution, considering the likelihood of freight train derailment, concerning new brake block material as may be required by the TSI for Noise.
6. The use of acoustic and imaging technologies (as currently being tested for rolling stock monitoring) for infrastructure applications.
7. The use of integrated solutions that monitor a range of indicators and directly feed these back to the various actors responsible for operation, maintenance and/or train control.

0.3 Conclusions and Next Steps

This work reported here has established a set of options that may be applicable to the longer term development of rail freight safety performance suitable for consideration in the referenced research project.

Contents

1.0 Introduction

1.1 Background

This document is prepared against the requirements of the European Railway Agency's (ERA) study "Assessment of existing technical and operational measures against freight train derailments in the Community's railways", [1]. The task description for the work reported in this document is as follows:

> *The task A.4 will provide data on relevant technologies used for existing technical[1] measures and, as far as possible, a description of new technologies which might be used for future generations of safety measures. Advice for potential inclusion in a research and development project will be reported with justifications.*

In addition to this task report, the following additional reports are relevant and are referred to as appropriate:

- Task A1, [2]. This document provides information about existing safety measures that are applied in the railway system to reduce the likelihood or mitigate the consequences of derailments, and more specifically freight train derailments.
- Task A2, [3]. This document provides a market analysis of technical measures that exist, or may exist in the short or medium terms.
- Task A3, [4]. This document provides information relating to the expected performance, costs and other pertinent information for existing, short and medium term measures.

1.2 Definitions

The following definitions are used within this document:

- Existing safety measures means currently applied for implementing a given regulation requirement, or applied on a voluntary basis, [1].
- Short term (safety) measure means that the safety measure is ready to be applied or to be introduced in EU regulation by 1st of January 2013, [1].
- Medium term (safety) measure means that the safety measure will be ready to be applied or to be introduced in EU regulation within 5 to 10 years, [1].
- Long term (safety) measures means that the safety measure could only be applied or introduced in regulation after complementary tests, not achievable within ten years, [1].
- A technical (safety) measure is defined as being a device or a specific technical system, [1].

[1] Information on technologies for existing technical measures is included in [3] and [4] and not repeated here

2.0 Background and Context

2.1 Overview

In order to identify the most relevant and potentially cost effective measures to avoid future freight train derailments on the European rail network one should also consider the expected future trends in European rail freight.

Rail routes can be divided into three categories according to their use:

- Conventional mixed lines: Shared line between passenger and freight operators.
- Freight dedicated lines: Exclusively reserved for freight-only traffic (few exist today).
- Freight oriented lines: Passenger and freight traffic carried but planning increasingly oriented towards accommodating freight needs.

At the moment most of the freight traffic operates on conventional mixed line. That is likely to continue for the near future, but in a longer perspective an increasing amount of rail freight is likely to operate on lines more dedicated to freight trains or more oriented towards accommodating the needs of freight traffic, [17]. This is in line with European Commission recommendations.

The future rail freight market can be divided into 3 broad groups as:

- Block trains/whole trains
- Intermodal trains
- Single wagon load trains

We discuss these issues in Section 2.2 to Section 2.4.

In addition to the issues surrounding the "look and feel" of the future rail freight network, we should also be aware of the direction that actors in the freight railway sector are currently pursuing with regard to safety. We see through our research, as reported below, a move away from monitoring of fault conditions to a more condition / preventative based regime where pre-fault conditions are detected. In addition, a more integrated approach to management of this information is also being pursued. We discuss this issue in Section 2.5.

2.2 Block Trains / Whole Trains

2.2.1 Existing Situation

The customer will choose a block train when the quantity of his goods can fill a whole train. A block train therefore consists of goods from one shipper compared to the single wagon load train which can have multiple shippers. The length of a block train varies but normally it is between 400 and 700 meters. There are ongoing tests around Europe which aim to increase the maximum length of a block train up to 1,000 meters.

Common commodities for block trains include: iron ore, coal, other minerals as well as aggregates, timber, chemicals and petroleum products, agricultural products like grains and beans, steel and automotive transports. The wagons can either belong to the customer, wagon keepers' e.g. chemical wagons, or are rented by the railway undertaking; in either case, a high use of the wagons is the most cost effective since the wagons are very often dedicated to a special business.

Normally the block train transport is carried out by fixed rolling stock in dedicated operation between a small number of loading/unloading locations. No shunting (or at least a minimum) of the wagons at marshalling yards is necessary. In general these trains normally have a homogenous train composition, either full loaded or fully empty.

2.2.2 Possible Future Situation

The most likely changes in the future are:

- Increased axle load allowance with increased weight/unit train length, as applied in the example below.
- Increased use of central couplers to allow heavier trains and increased traction forces, as used for example in the USA to deal with increased load requirements.

New and specially designed wagons may be required to implement the desired changes. As an example, the Swedish/Norwegian iron ore line between Narvik and Luleå has been strengthened to allow 30 tonne axle load and 12 tonnes / meter. The crossing loops have been lengthened to allow train lengths of 750 meters. The resulting nominal train weight is 8,160 tonnes, exclusive of locomotive, with 68 wagons per train.

In terms of derailments the block trains are generally less accident prone than the intermodal trains or the single wagon trains due to a more homogenous composition[2]. ***An increase in axle load would normally require new axles dimensioned for the increased load.***

Whole train transport of automotives has many of the same performance characteristics as intermodal transports due to a high volume low weight load.

2.3 Intermodal Transport

2.3.1 Existing Situation

Intermodal transport relates to cargo that can be carried and transferred between transport modes, in particular rail, road, sea or waterway. Many intermodal trains operate nationally, but a large proportion also operate internationally over very long distances along an international route affecting many countries. Intermodal transports are a growing rail freight market.

The intermodal train has a less homogenous composition compared with the block train and is more comparable to the single wagon train.

Ports are interchange hubs between rail and ship transport. Intermodal terminals are interchange hubs between rail and road traffic. They are fitted with all the equipment required to handle and transfer loading units from one transport mode to the next in a rapid and efficient manner. These include gantries and mobile cranes, modern computer systems integrating tracks, storage areas, trans-shipment areas and connections to roads and motorways. The trans-shipment is normally by lift-on lift-off operation but can also be roll-on roll-off.

The most common cargo carriers are:

- **Lorry**. Lorries make it possible to provide a door-to-door service, as they cover the short distances separating factories and terminals. They enable the major advantages of road haulage to be tapped, i.e. a network that reaches further and is denser.
- **Container**. Containers lead to better logistical management of the areas used for loading and unloading goods, since their rigid structure enables up to six of them to be stacked in one pile. Container lengths have been standardized at between 20 and 53 feet.

[2] The situation is different with respect to auto-transport block trains with single axle wagons with a low wheel base. Experience shows that these wagons are more prone to derailment due to track geometry features.

- **Swap body**. Swap bodies are standardized loading units equally suitable for carriage on road vehicles or railway wagons. The swap body can be used in a broad range of situations, are simple in design and inexpensive. This form of conveyance has been highly successful and is currently one of the most widely used transport systems on the market.
- **Semi-trailer**. While semi-trailers are more costly and heavier, their advantage is that they can be coupled directly to a tractor and do not require a road chassis, unlike containers and swap bodies.
- **Rolling road (Rollende Landstrasse)**. In the rolling road concept lorries are carried on purpose-built low-floor wagons, while drivers travel in seated accommodation or couchettes. Transshipment between road and rail takes place at terminals where the lorries are driven onboard using mobile ramps. The lorries are subject to specific conditions resulting from the category and clearance gauge of the line worked. Rolling road services are limited to set routes, particular covering routes with difficult road conditions or high road tariffs.
- **Intermodal rail freight wagons**. There are different wagons available for combined transport purposes. Those most commonly used are flat wagons, fitted with scotching systems for swap bodies and containers, as well as base plates for swap bodies. Wagons used to carry semi-trailers have very low floors and recesses to accommodate the wheels.

The most common type of wagon for intermodal rail (combined transport) is a 60 feet 4-axle bogie wagon that is particularly useful for transport of the heavy sea containers. The same applies to various types of 6-axle bogie wagons. There also exist a high number of 2-axle wagons with a long wheel basis which are more adapted to domestic intermodal traffic with swap bodies for high volume products.

2.3.2 Possible Future Situation

A significant new building of rolling stock for intermodal transport is expected over the coming years to account for traffic growth and to replace old wagons. Hence, it is possible to introduce new solutions and technology if such can improve the competitiveness of rail freight. The expected development from 2005/08 towards 2015 is subjectively indicated in Figure 1, [16].

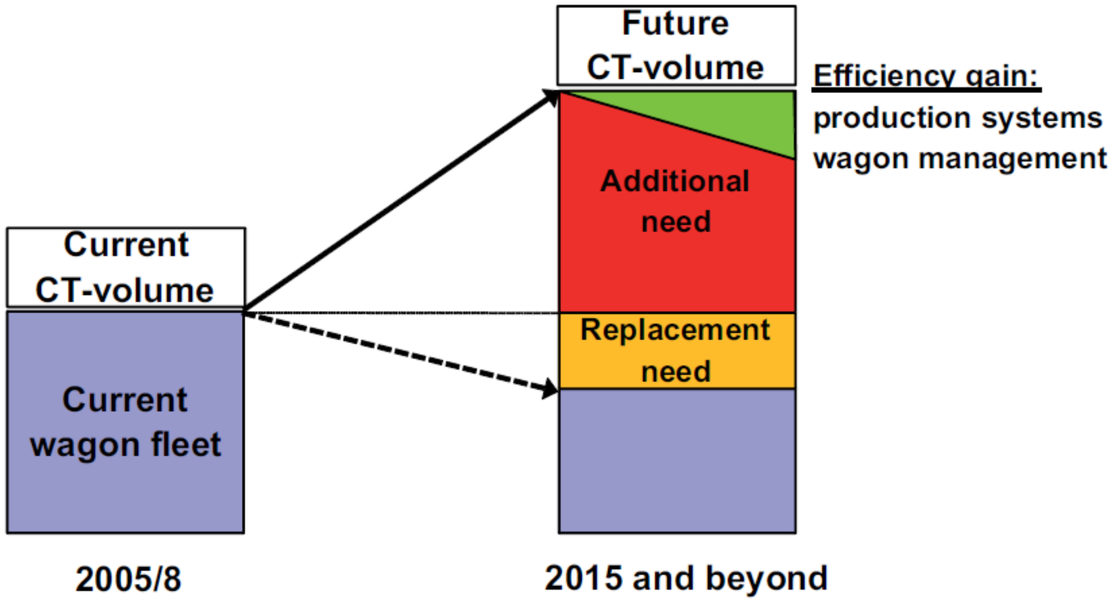

Figure 1: Expected Development of EU Rolling Stock Need for Intermodal (CT) Transport

The growth projections indicated in Figure 1 got a severe setback in 2009 due to the financial crises, but a large part of the loss is regained in 2010, and Figure 1 might still be a possible future growth scenario albeit with some delay. Continued growth is expected in the rail transport of intermodal carriers and this capacity increase can be satisfied in several ways:

- Increased train size.
- New and more effective intermodal wagons.
- Increased number of trains / Increased train speed so intermodal trains to a larger extent can follow the same overall speed as passenger trains.

2.3.2.1 Increased Train Size

The size of intermodal trains is often restricted by train length due to a low weight/unit length whereas an increased train size requires longer trains. Provided the infrastructure is suited to allow longer trains it is likely to be cost efficient for the railway undertakings to compose as long a train as is possible in order to utilise the traction capabilities of modern traction units. A long train length is attractive in order to reduce the unit cost of the transports. When increasing the maximum length of intermodal trains from today's maximum of 700 – 835 metres, depending on country, it will be beneficial to improve the braking system such that brakes are applied simultaneously along the whole train. ***A system to achieve this is electrically controlled pneumatic (ECP) brakes.***

The same situation applies for automotive wagon block trains. The available loading volume is normally more restricting than the maximum allowable axle weight or meter weight of the train. Hence, they will benefit from the same measures as the intermodal transports.

2.3.2.2 More Effective / Cost Efficient Loading Platform

The loads per unit carrier length for intermodal transports are in general much lower than for mass transport of bulk commodities and also somewhat less than for general wagon load transport. Hence, the most cost effective freight wagon for intermodal transport carriers will often be a 2-axle wagon with a long wheel base. Two-axle wagons are available today weighing 13 tonnes with a load bed length of 15.88 metres that can handle a 27 tonne load with a maximum allowable speed of 160 km/h. Even higher loading capabilities might be available for a lower maximum speed, e.g. 30-32 tonnes loading capability at 120 km/h.

Railway undertakings and shippers will normally look for the cheapest way of providing a certain length of loading platform for the various swap bodies. A two-axle wagon can therefore be a very attractive intermodal carrier platform for high volume units with low or intermediate weight. In particular if it can be combined with an increased allowable speed.

2.3.2.3 Increase Track Capacity / Number of Trains

A key factor to increase the track capacity is to reduce the speed difference between freight trains and passenger trains, in particular if passing loops are not long enough to allow passenger trains to overtake freight trains. In order to allow significantly higher train speeds of intermodal trains the following improvements seems essential:

- More effective braking systems e.g. ECP-systems.
- ***Improved suspension to limit the freight wagon dynamic loads on the track*** by increasing train speed.

Both measures may also contribute to a reduction in derailment risk (or avoid an increased derailment risk) due to increased volume of intermodal transport.

2.4 Single Wagon Load (SWL) Operation

2.4.1 Existing Situation

The single wagon load operation is the traditional operation of moving a single wagon load of rail freight from A to B. Logistically the SWL system is comparable with a "hub and spoke system" (a system where all goods are brought into a central point – the hub – for sorting and distribution out from the centre in all directions). It is a network system which consists of customer sidings, stations and marshalling yards:

- If the customer at A has railway tracks, the operator will send a feeder service to collect the wagons (and give the customer empty wagons to fill). These are then hauled or pulled to a marshalling yard (assembly point for the goods to compromise a wagon load).
- If the client at A does not have railway track access, he will transport the goods to a terminal by truck where the goods are loaded onto a railway wagon and then brought to the marshalling yard.
- In the marshalling yard further wagons (from other customers) are added and the train is built up for departure to the next hub / marshalling yard in the network. All departures within the network are scheduled and depart at predefined times.
- The wagons are transported from one hub/ marshalling yard to another and wagons are added and taken away at each stop.
- Once the wagon has reached the hub nearest to its destination, it is taken off the train and is transported either by truck or by track to the final destination B.

SWL is a very flexible system which gives the customer full adaptability in terms of dispatch volatility, with the client choosing how many wagons he wants to dispatch. From one day to another the quantity of dispatched wagons can vary. He can decide when to load the wagons, which is a major benefit compared to the intermodal concept where trucks often use a time slot loading system with penalties if they cannot dock at the right time. As the routes are fixed in advance, the customer can as soon as he needs to, add wagons to a train.

With an annual freight volume of around 100 billion tonne kilometre, SWL accounts for approximately 50% of Europe's total rail market today. Currently, the international market share is far smaller than the domestic market share.

The SWL train operation requires full interoperability between the various types of rolling stock; however, this type of freight train operation also has important unfavourable characteristics:

- The SWL train operation is characterized by high cost level with many costly shunting operations and frequent changes in train composition.
- The frequent re-composition of trains by shunting operations may also result in a high degree of damage to sensitive loads and transport of sensitive cargo is transferred to other transport modes.
- The frequent re-composition also results in a very low overall transport speed partly resulting in high cost due to low wagon productivity, partly making rail less attractive for perishable goods and for goods with a high value or just in time operation.
- Due to the above factors SWL train transport has lost market during later years, in particular in international transport.

2.4.2 Possible Future Situation

The SWL rail transport operation is not likely to grow in the future due to the high cost basis and low average speed (although there could be an increase in international SWL operation if the market is found attractive by international railway undertakings operating in several countries). Significant parts of today's SWL national market are likely to be replaced by block trains, or intermodal transport by swap bodies where the rail transport is replaced by road transport for the initial and/or last leg of the transport chain. In some countries (e.g. Norway) the general SWL transport has been abandoned apart for some international customers.

Hence, the amount of investment in this market segment is likely to be low. Significant technological changes, if any, in a 5-10 years perspective is likely to be driven by regulatory requirements, e.g. TSI for Rolling Stock Noise 2006/EC 23.12.2006 L 37 (2006) and TSI of Telematic Applications for Freight Services 62/2006/EC 23.12.2005 L13 (2006). If the regulatory driven measures are costly to apply the result may be removal of services and further reduction in the amount of single wagon freight transport.

2.5 Freight Train Derailment; Technology Status

In our report [2], we identify the existing technological solutions that seek to minimise freight train derailments. We note that most of this technology has been in existence for a long period of time (for example, hot axle box detection systems have been used since the 1960's and are still used extensively today).

In our reports [3] and [4] we identify the recent emergence of new technological solutions that seek to address the problem of freight train derailments in the short and medium terms. This includes

- Acoustic bearing monitoring installations.
- Machine vision devices.
- Telematics installations.

We have no reason to suspect that these emerging technologies will not be around for a long period of time, and therefore it is likely that these technologies and variants of them will be the backbone of longer term developments in the railway sector.

One development is that these new systems are more focussed on condition monitoring, the automation of data acquisition and efficient transfer of information between actors. In this respect it is noteworthy that our analysis of freight derailments has indicated a significant number that are caused by defects which are known about, but have not been rectified in sufficient time. Better use of condition based information, and the direct transfer of this information to the organisation responsible for dealing with these defects, may help in this respect.

3.0 Study Methodology

3.1 Summary

Our methodology for establishing the potential next generation of safety measures has included the following principal activities:

- Consultation with infrastructure managers (IMs), railway undertakings (RUs), suppliers and maintenance organisations seeking their opinions on future generations of freight train derailment safety measures.
- Review of published research topics and papers addressing the topic of freight train derailment and/or new technology.
- Consolidation of the information from the above sources, and the identification of those that may provide a benefit when considering the issue of freight train derailment. This consolidation is made taking cognisance of the discussion provided in Section 2.0 above.

3.2 Consultation

Our first approach to establishing the possible existence of future safety measures was to ask the railway industry for their views of developments in the area of freight train derailment.

We did this through a questionnaire, with each questionnaire providing recipients with the opportunity to indicate their views on future generations of freight train derailment safety measures. To date we have received 72 consultation responses, although not all respondents took the opportunity to respond to this question. Where positive responses have been received in relation to this question we report these in the following sections of this document.

However in order to present a balanced view, we also need to report that a significant number of respondents have stated their opinion that:

- Technology and products to prevent derailments are already in the market, and the only action required is the more widespread use of these.
- It is not a technological problem that needs to be addressed; rather it is an information management issue that needs to be addressed (i.e. the better handling and prioritisation of precursor safety information that is already available).
- The further reduction of freight train derailments is a matter of maintenance – and a consistent approach to maintenance standards and compliance should be the focus - not new technology.
- That the situation is currently satisfactory and no new mandatory measures are warranted.

3.3 Internet Research and Other Information Sources

In addition to the views of the railway industry, we have sought to identify solutions and technology that may be emerging in the academic and research fields. This work has involved internet searches and the interrogation of railway safety research databases, for example:

- Study of railway research organisations web-pages to identify programmes and initiatives.
- Examination of research sponsors web-pages and review of completed research programmes.
- Internet searches using keywords and phrases for doctoral research thesis and other relevant papers and articles.

4.0 Potential New Safety Measures

4.1 Freight Train / Wagon Based Developments

4.1.1 Electronically Controlled Pneumatic (ECP) Brakes

Application status of ECP-brakes:

We have noted the possible benefits of this technology in Section 2.3.2.1, and have received questionnaire responses discussing this technology, [5], [6].

Application of ECP-brakes in freight trains is a technology that can reduce derailment frequency. The technology for ECP-brakes is mature and such brakes are applied in passenger trains and in block trains for freight in Spoornet, South Africa and by Burlington Northern Santa Fe (BNSF) and Norfolk Southern (NS) in the USA. ECP-brakes in freight trains would reduce the longitudinal forces in the train during braking and brake release, and in particular for low speed braking it would significantly reduce the risk of derailment.

Economic benefits of ECP-brakes:

The safety advantages are unlikely to be sufficient to motivate a change to ECP-brakes, but there are significant operational cost benefits of an ECP-system. Assessment reports by Federal Railroads Administration (FRA) in the US indicates a good economic rate of return for transition to ECP-brakes, in particular for high performance rolling stock, e.g. freight wagons and traction units for fixed block trains in heavy haul or similar operations, [7].

However, since investment costs and economic rewards may not be equally distributed among infrastructure holders, railway undertakings and wagon keepers it is indicated by the FRA that regulatory support might be necessary to help the implementation of an otherwise financially and logistically sound measure, in particular for general freight, [7].

The highest benefit cost ratio is for high performance train units with fixed train composition which requires few coupling/decoupling operations.

Implementation strategy of ECP-brakes:

An implementation of ECP brakes will probably be carried out along the following sequence:

1. Heavy haul and/or block trains with little or few changes in train composition. Spoornet (SA) uses ECP-brakes for all coal trains operations between Ermelo - Richards Bay, the world's largest coal export facility. BNSF & NS are applying ECP-brakes for long distance heavy coal trains in the US.

2. Intermodal trains with relatively fixed composition where loads are lift off lift on or drive on drive off. Intermodal trains have a very low unit length weight (approximately 2 tons/metre. Train size for intermodal trains is more likely to be restricted by train length than by weight and traction capacity. Use of ECP-brakes may allow longer train lengths and hence also higher train weights.

3. General single wagon freight operations where the trains are built up and broken down at shunting yards for each and every run is where the cost of introducing ECP-brakes are the highest and the benefits the least. Single wagon load operation involves a high number of low utlilisation freight wagons, and the normal operation requires frequent coupling/decoupling of wagons. Depending on the signal transmission solution this may require frequent coupling/decoupling of a control cable with the risk of functional problems.

A general application of ECP-brakes in European freight traffic requires that ECP-braking is covered by the TSIs for rolling stock wagons and traction units in order to maintain the interoperability features.

Interface with existing pneumatic brakes:

Today there exist a number of different technologies and solutions in relation to the control interface with existing brake systems as well as for transmission of control signals.

Three different solutions exist with respect to the interface with existing brake systems:

1. Overlay (Add on)

With an overlay ECP the pneumatic brake system can operate as prior to the ECP-installations. After a train has been coupled together a decision can be made with respect to selection of brake system operating mode. An ECP-equipped train can be hauled by a non-ECP-equipped traction unit and vice versa. This is very convenient in a conversion phase when all freight wagons already have the pneumatic installations.

While an overlay system's dual mode capability provides significant flexibility, railroad operators must purchase, install, and maintain equipment to support both types of brake systems for as long as dual mode capability is required.

2. Emulating

The emulating solution is a more complex transition solution, but can render savings for new rolling stock.

Emulation configurations use a control device capable of operating in either ECP or conventional mode without requiring conventional pneumatic controls. One manufacturer has provided an emulation ECP brake valve that monitors both the digital communications cable and the brake pipe for a brake command. If an electrical signal is present, the ECP brake valve operates in ECP brake mode. If the electrical brake command signal is not present, then the valve will monitor the changes in the brake pipe pressure like a conventional pneumatic control valve and the control device will use a software program to emulate the function and response of a conventional pneumatic valve. An emulation ECP brake system can be operated in any train with any mix of emulation ECP and conventional brake systems. In a mixed train, the emulation ECP brake system will monitor the brake pipe for pressure changes and set up brake cylinder pressure like a conventional pneumatic valve. /8/.

3. Stand alone (Pure ECP or all Electric)

For the stand alone solution one could do away with the compressed air system altogether, replacing this with a Pure ECP or all Electric system. (However the complete removal of the compressed air system may involve a large task to qualify the new technology for freight applications. Therefore the compressed air main line of the train may be maintained for safety reasons and emergency brake operations.)

In a stand alone ECP-system there are no requirements for interoperability with today's pneumatic brakes. We note that all electric systems have so far only been implemented as a test operation on a small scale.

Technology for signal transfer:

Two technologies exist for transfer of ECP-brake signals:

1. Control signal transmitted on cable, which can also transmit electric power along the train.
2. Wireless (radio transmitted) control signal.

The first is clearly advantageous for fixed train compositions with few coupling/uncoupling operations. The wireless solution will have an advantage for general wagon load freight operation with frequent train building and train brake up operations. Trackside repeater stations might be necessary in rugged terrain and in tunnels with wireless control signal technology.

4.1.2 Improved Design Specifications and Maintenance Methods and Programs for Wheel Sets

In Section 2.2.2 we identified a possible requirement for an increase in axle load. Further, a significant proportion of today's freight train derailments are due to failures of wheel sets, comprising wheels, axles and axle boxes.

In most European countries many of today's axles also limit the axle load that can be utilised for freight wagons. The time therefore seems ripe for replacement of axles and development work in order to improve axle design standards, as well as methods for inspection and maintenance of axles.

In this respect a group of 23 partners under the leadership of UNIFE – the European rail industry association - has recently initiated a 3 year R&D project named Euraxles, [9]. Partners in the project include: 6 axle manufacturers, 4 RUs/IMs, 2 system integrators, 2 technology suppliers, 5 universities, 2 rail sector association and 1 consulting firm.

Among the objectives of the Euraxles project are:

1. To commonly agree at the European level on an innovative axle design approach, including a risk analysis method which, similar to limit state analysis, could offer a simple design route by combining loads with difference occurrences including loading specificity of vehicles and service conditions together with the axles' resistances (fatigue limit, fatigue life, fatigue under corroded conditions due to coating failure), including new materials and methods in order to predict the 'failure probability'.
2. To develop:
   - improved axle protection against corrosion, including ex post facto protection of already corroded axles;
   - improved adhesion of coatings with a study of the roughness influence (adhesion and fatigue behaviour); and
   - new, innovative coating solutions, developed in public-private partnership between companies and universities. The new solutions have also to fulfil environmental requirements to avoid or limit Volatile Organic Compound emissions.
3. To evaluate new/improved Non Destructive Testing inspection methods that allow the in-service inspection of axles in order to guarantee safe service conditions with a low impact on the vehicle availability. This work will mostly be based on a benchmark of existing and/or innovative solutions.

RAMS and LCC analyses undertaken in the Euraxle project will allow a cost benefit comparison of the proposed solutions for an optimised market uptake.

With the achievement of its objectives, Euraxles will allow reliable decisions to be made on axle maintenance and critical safety service intervals. This will also have positive impacts on the environment and on the European industries' competitiveness as highlighted in the European Rail Research Advisory Council's Strategic Rail Research Agenda 2020: "The safety of the European railways is of prime importance not just in terms of the loss of life when a major rail accident causes, but also in terms of the operational cost of degraded mode after accidents and incidents even when no one is injured which undermines the business case for railways".

Similar multiparty research projects to the Euraxle project could be developed for ***wheels and axle boxes*** in order to develop improved design solutions, dimensioning criteria, inspection methods and operating limitations for the above mentioned objects. Such a project is likely to be able to provide new standards for within a time span of 5 – 10 years.

4.1.3 Improved Freight Wagon Suspension

In Section 2.3.2.3 we noted the possible requirement for improved suspension.

The most frequently utilised suspension types on today's freight wagons are generally of a relatively old design with less than optimal performance, in particular at high speed, but also under curvy track conditions.

With today's calculation models it is possible to improve the freight wagons suspension significantly both for an increased speed as well as for curvy track. As an example Green Cargo has acquired a new type of 2 axle container wagon for mail transport weighing 13 tonnes with a loading base of 15.88 metres, with a design speed of 160 km/h, [10].

Even though the main effect of an improved suspension system for freight wagons will be reduced rail and wheel wear, it may also reduce the derailment frequency, in particular under the following conditions:

- Track height failures and cyclic tops under high speed conditions
- Track with narrow curves, also covering high cant and twist conditions.

Among the changes that can be foreseen are:

- New or improved suspension damping elements improving the damping conditions of the suspension while reducing suspension friction.
- Axle supports that allow an improved radial orientation of axles through curves (particularly welcome for two axle wagons with long wheel base).

4.1.4 Telematic Supervision of Freight Wagon Performance

We have included the use of Radio Frequency Identification (RFID) tagging and alternative telematic solutions in our reports [3], [4] as a potential medium term measure. Further possibilities exist for longer term measures, as discussed below.

Based on present day IT-technology there are possibilities for improved supervision of on route performance of train rolling stock, [11], [12]. Existing solutions have mainly been towards trackside detectors but, if freight wagons can be provided with a reliable source of electric power, parts of the existing supervision could be moved from trackside to rolling stock with improved supervision performance. Further the number of parameters to supervise can be increased.

Electricity supply can be provided by various solutions:

- Solar panels with battery package onboard every car.
- Power generator attached to one of the wagon axles with battery package.
- Electric cable along train as part of ECP-brake solution.

Among the parameters to supervise can be:

- Load distribution in order to detect overload or skew loading.
- Bearing temperatures and vibrations.
- Brake functioning in relation to brake tests.

- Vibrations and wheel impact loads due to wheel out of roundness, wheel damage and wheels flats.
- Blocked wheels when train is moving.
- Level, temperature and pressure of liquids and compressed cargos including hazardous materials cargo.

Communication about the individual freight wagon performance is sent to the locomotive and train driver and other relevant parties:

- Traffic controller
- Railway Undertaking
- Entity in charge of maintenance (ECM)
- Wagon keeper

In order for such technology to be utlised for the maximum benefit a communication protocol is required. The communication protocol developed through TSI for TAF (Telematics Application for Freight services) and the RFID-technology has an interoperability objective and is not sufficient to serve the communication needs of an extended telematics application, but it is a start that could be extended over time.

4.1.5 Other Important Future Technology and Regulation Changes

4.1.5.1 Train Braking

The approved TSI for Noise will require changes in braking equipment for new and existing wagons. Existing tread brakes with cast iron brake blocks are not able to meet the TSI noise requirements at stations and in cities. Alternative solutions are:

- Tread brakes with composite blocks of the following types:
    - LL-blocks, which can directly replace existing cast iron blocks.
    - K-blocks, requiring some modifications to the brake system.
- Disc brakes for new wagons.

The latter is the most costly solution, also for new wagons, but with lower operating costs.

Even though the brake type is not directly a derailment factor it can affect the derailment risk in many ways by having an influence on the following factors:

- Velocity independent retardation values.
- Wheel temperature and risk of wheel damage.
- Wheel locking and development of wheel flats that can cause hot axle boxes.

Advantages and disadvantageous exist for all solutions but it is not obvious what is the best solution with regard to derailment risk.

4.2 Infrastructure Developments

Infrastructure developments / installations fall into two categories:

1. Installations that monitor rolling stock.
2. Equipment that monitors / checks the status of the infrastructure itself.

4.2.1 Rolling Stock Monitoring

We have noted in Section 2.5 the longevity of installed technological solutions in this category, and also the recent testing of new safety measures based on novel technology (acoustic bearing monitoring and machine vision devices) in the railway environment.

These new technologies are, to the best of our knowledge, the nearest to (voluntary) implementation in the European context. Should such systems be installed they are likely to form the next generation of safety measures and evolve and improve over a long time period. Other than these, we are not aware of revolutionary new safety measures based on different technologies.

4.2.2 Infrastructure Monitoring

Advances in electronics, component reliability and wireless technology make it possible for Unmanned Measuring Systems (UMS) to operate autonomously on standard rolling stock in regular revenue service. Data is automatically collected and transferred via cellular or Wi-Fi networks to a central data storage where it is processed and key information is reported to staff.

New technologies, such as the automatic recognition of rail and track surface defects using vision systems, enhanced ultrasonic and laser-based inspection of rails for internal defects, are able to provide information on hundreds of parameters to control the railway infrastructure from permanent way to overhead line and from bridges to tunnels.

Such technologies may work with or in part replace traditional technology in the longer term.

4.3 Integrated Solutions

4.3.1 Information Management

An interesting opportunity is the ability for the linking together of a number of existing and new technologies to provide real-time, fully integrated railway solutions.

For example, the *Inte*RRIS® [14] system collects and analyses 170 wayside detectors world-wide (acoustic bearing detectors, angle of attack detectors and machine vision wheel profile monitoring systems) and produces event alerts for trains passing these detection installations. It is claimed that the total fleet size of subscribers to *Inte*RRIS® exceeded 1 million rail vehicles in 2009.

It is further claimed that freight train derailments caused by broken wheels have reduced by 16% and derailments caused by roller bearing failures have reduced by 35% since this system was introduced.

The introduction of such a system in Europe may require:

- RFID tagging (or similar, see [3]) of freight wagons enabling their identification when passing a detection site.
- Detection systems wayside to detect defective rolling stock at discrete points
- Transmission systems wayside to capture and transmit running information to the appropriate organisations.

An alternative approach may be the use of on-board the rolling stock condition monitoring (see Section 4.1.4) and wireless communication or through the possible use of satellite tracking systems such as the GaWaLoc / GALILEO wagon tracking system, [15].

4.3.2 Rolling Stock Development

Considering the integration of rolling stock solutions, it may be appropriate to consider a package of solutions that may include:

- A change to ECP brakes (most likely for fixed formation trains).
- A move towards automatic central couplers similar to those used in passenger traffic in order to limit the amount of additional couplings that have to be carried out.
- As electricity would be available along the train it would be worthwhile to consider increasing the amount of onboard supervision (e.g. bearings, wheels) and the sider use of telematics equipment.

However, problems that may have to be overcome include:

- Present day automatic central couplers used for passenger trains may not be strong enough to be used in heavy freight trains.
- Reliability considerations in relation to the higher number of couplings of freight trains compared with a passenger train.

5.0 Conclusions

5.1 Summary of Possible Future Requirements and Observations

In Section 2.0 we identified the framework in which future freight train derailment safety measures may need to operate. These were considered to be:

3. A greater emphasis on dedicated freight railway lines, and railway lines more oriented towards freight traffic.
4. A requirement for heavier, longer and faster freight trains.

The first of these parameters will enable track geometry parameters to be optimised more towards freight traffic. This will have a positive effect freight train derailment risk.

The second parameter may require additional safety measures to be considered in order for the existing safety performance to be at least maintained, and/or improved. Technical factors that need to be considered include:

- Increased axle strength to enable heavier loads to be carried.
- Better braking performance to improve braking performance and reduce in-train forces for longer trains.
- Improved suspension design to reduce track damage that might otherwise result from increasing speed.
- A more effective and condition based maintenance regime that is able to collect and deal with pre-fault / failure conditions in a more efficient manner.

We also note in Section 2.0 the emergence of new (in Europe) technology – currently being tested – which we consider may be the backbone of longer term safety measures.

5.2 Railway Industry View

The requirements and observations presented above are partly informed by the industry research and consultation we have discussed in Section 3.0. However in order to present a balanced view, we also need to report that a significant number of respondents to our consultation have stated their opinion that:

- Technology and products to prevent derailments are already in the market, and the only action required is the more widespread use of these.
- It is not a technological problem that needs to be addressed; rather it is an information management issue that needs to be addressed (i.e. the better handling and prioritisation of precursor safety information that is already available).
- The further reduction of freight train derailments is a matter of maintenance – and a consistent approach to maintenance standards and compliance should be the focus - not new technology.
- That the situation is currently satisfactory and no new mandatory measures are warranted.

5.3 Our Recommendations

Taking cognisance of the discussions above, we have made the following recommendations for areas that may be useful to consider in the upcoming research and development project:

1. The applicability of Electronically Controlled Pneumatic Brakes to address some of the potential requirements for improved train braking performance. (See Section 4.1.1.)

2. The consideration of an improved design solution with respect to wheels and axle boxes. (See Section 4.1.2.)
3. Improved suspension design to enable increased train speed and also with a view to reducing track wear and damage, which is also a causal factor of derailments. (See Section 4.1.3.)
4. The use of freight wagon on-board condition monitoring systems (which would require electrical power to individual wagons) and the transmission of condition based information to various actors responsible for operation, maintenance and/or train control. (See Section 4.1.4.)
5. The optimum solution, considering the likelihood of freight train derailment, concerning new brake block material as may be required by the TSI for Noise. (See Section 4.1.5.1.)
6. The use of acoustic and imaging technologies (as currently being tested for rolling stock monitoring) for infrastructure applications. (See Section 4.2.2.)
7. The use of integrated solutions that monitor a range of indicators and directly feed these back to the various actors responsible for operation, maintenance and/or train control. (See Section 4.3.)

6.0 References

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MANAGING RISK

Det Norske Veritas

Assessment of freight train derailment risk reduction measures:

Part B Final Report

Report for European Railway Agency
Report No: BA000777/09
Rev: 02

20 October 2011

MANAGING RISK

Assessment of derailment risk reduction measures:
Part B Final Report
for

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Summary: This document provides is the final project document summarising the findings related to the assessment of efficient derailment risk reduction measures.

Prepared by:	*Name and position* Gavin Astin – Principal Consultant	*Signature*
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Project No:	BA000777	

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0.0 Executive Summary

0.1 Introduction

In 2009 the European Railway Agency (the Agency) issued a recommendation (ERA/REC/01-2009/SAF) on a specific proposal, made by the RID Committee of Experts, for a new harmonised rule aimed at reducing the consequences of freight train derailments, potentially involving dangerous goods (DGs). The recommendation concerned the potential use of a Derailment Detection Devices (DDD[1]). This device automatically applies the brakes on a freight train when a derailment of a wagon equipped with that device is suspected.

Although the Agency's recommendation was that the DDD should not be adopted in the RID it was agreed that alternative prevention based measures should be further explored before deciding on imposing, by law, measures based on derailment detection.

Therefore recognising that freight train derailments remain a safety and operational concern, and following a request made by the European Commission, the Agency has commissioned further work with the objective of which is to carry out an exhaustive analysis of all prevention and mitigation measures which could reduce the risks related to freight train derailments.

Det Norske Veritas (DNV) was selected by the Agency to contribute to this work, the results of which are presented in this and related documents.

0.2 Project Scope and Objectives

The study is divided into two distinct research stages: Parts A and B.

Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be voluntarily applied or to be introduced in EU regulation within 5 to 10 years).

Part B has the objective of analysing the measures identified in Part A with a view to identifying those that are the most efficient. Part B is scoped to include all prevention measures but is limited to mitigation measures based on derailment detection.

The scope has been directed towards identifying preventive and mitigation measures related to freight train operation. Shunting or marshalling operations have not been considered to the same degree as such operations have a lower consequence potential.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries (Turkey, Macedonia and Croatia), Norway and Switzerland (hereafter called the target countries). In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

0.3 Methodology

0.3.1 Part A: Measure Identification

Part A work sought to identify the existing use of freight train derailment risk reduction measures (technical, procedural or organisational) through a range of activities. These included:

- Direct consultation with a large number of Infrastructure Managers, Railway Undertakings, Wagon Owners, supplier organisations, industry bodies and other actors.

[1] DDD is an acronym used to refer to a type of detector which automatically activates train brakes when a derailment is detected based on detection of wagon acceleration. Device type EDT-101 is an example of such a device.

- In-house knowledge, literature and internet research.

Activity in this work package also included the identification of the existing application scope of identified measures, and also the collection of market and performance data for these measures.

0.3.2 Part B: Measures Assessment

Part B considered the problem of freight train derailment and its causes, and then how the measures identified in Part A could be used to improve the situation. This room for potential improvement can be achieved either through the wider use of existing measures, or the application of new measures.

These objectives were achieved through a series of tasks that included the following:

- Comprehensive review of freight train derailment accidents to establish their causes and consequences.
- The development of risk models to quantify the causes and consequences of freight train derailment accidents.
- The development of cost-benefit models to enable economic indicators of each measure's efficiency to be established.
- The identification of other advantages or drawbacks for each measure thus allowing a final consideration of the most promising measures to be made.

0.4 Study Conclusions

0.4.1 Opening Remarks and Context

It is important to clarify that this report looks at the ***potential for improvement***, and is not an absolute assessment of the efficiency of all measures that are applied today. Therefore it follows that if a measure is applied extensively already there is little room for improvement through the further application of that measure. For this reason some measures that are extensively applied already are not considered in this work. Their omission should not be considered as suggesting such measures are not efficient.

In this context the measures listed in this section can be seen as efficient in addressing the potential reduction in risks associated with freight train derailments and providing the detailed background against which public policy can be formulated.

The assessment of measures does not consider the way or the order in which these interventions should be pursued, for example it is not considered whether these interventions should be introduced in a mandatory or voluntary way or whether the measure should be introduced as an EU harmonised measures or only within certain member states or only certain companies.

0.4.2 Efficiency Assessment of Measures

0.4.2.1 Technical Preventative Measures

We consider the following technical measures as being efficient (they have a positive or unity benefit / cost ratio in our reference case and all sensitivity studies):

- P13-Wheel Load Impact Detectors / Weighing In Motion (a measure that addresses a number of common freight train derailment causes such as wheel defects, loading anomalies).
- P28-Replacement of Brass for Polyamide Roller Cages (a measure that addresses hot axle box caused freight train derailments).

- P15-Bogie Hunting Detectors (a measure that addresses problems associated with lateral instability, caused by wheel or other defects).
- P11-Bearing Acoustic Monitoring (a measure that addresses hot axle box caused freight train derailments).

Since several of the preventive measures are addressing the same hazard the introduction of one of them will influence the benefit of the others, e.g. implementation of measure P28 “Exchange of brass roller cages with polyamide roller cages” will make measure P-11 “Bearing Acoustic Monitoring less attractive in cost efficiency terms.

Considering measure P28, we have considered an immediate replacement of brass for polyamide roller cages. We have also discussed an alternative option which is for the replacement of brass for polyamide roller cages at the next scheduled maintenance interval for axles / axle boxes. This is almost a zero cost option, although the benefits would take longer to materialise, and be a function of the maintenance cycle for freight wagons.

Potential drawbacks to the use of these measures (excluding measure P28) relate to the rate of false alarms. To some extent these can be overcome by the use of good alarm management processes. Further false alarms from those technical measures that are based on early defect detection are unlikely to have an immediate operational impact.

In addition the following two measures are efficient based on the parameters in our reference case:

- F7-Sliding Wheel Detectors (a measure that addresses problems associated with handbrakes which may be left on, seized axles and similar events).
- P16-Wheel Profile Detectors (a measure that addresses problems associated with wheel defects).

Potential drawbacks include false alarms as reported above. Finally, measure F7 is to the best of our knowledge a market with only a small number of suppliers. This may give rise to market advantage to existing suppliers of these systems if they were to form the basis of formal recommendation.

0.4.3 Technical Mitigation Measures

We consider the following mitigation measure as potentially efficient if the significant identified drawbacks could be solved:

- M1a-Derailment Detection (with automatic brake application) applied to All Freight Trains

This present assessment is fully in line with the previous assessment made by the Agency [1]. The significant drawback previously identified is confirmed by the present study and the related accident analysis. A false alarm of such a device may lead to train compression which is a contributory cause of freight train derailments (and also a significant operational disruption). In this respect we note that CSM Regulation, Annex I, point 2.5.4 states:

For technical systems where a functional failure has credible direct potential for a catastrophic consequence, the associated risk does not have to be reduced further if the rate of that failure is less than or equal to 10^{-9} per operating hour.

(Measure P1: Check rail has similar disadvantages, although this is not considered efficient by our assessment.)

Finally, we acknowledge an alternative type of derailment detection device which provides an alarm to the train driver when a derailment is suspected, but without an automatic brake application (type M1b). We are however not aware of these being available on the market (for freight application). We consider that an assessment of these devices, considering the human factors issues involved and their costs would be required before these could be formally assessed.

0.4.4 Organisational Measures

We note that the measures above are technical measures that are aimed at addressing, in some cases, organisational problems. Therefore we would add the following organisational and supervision items:

- F-2: Awareness Programme for Rolling Stock Maintenance. This measure may serve to address the problem of poor maintenance standards of rolling stock. This may include training that sought to concentrate on main rolling stock maintenance derailment causes, as documented in this report, and best practice. This measure may be followed by increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.
- P-18: Track Geometry (all tracks). Although the case for improvements in this area are not conclusively made from a quantified perspective, the problem of poor track geometry (in particular track twist), and the possible requirement to improve this aspect just to maintain current performance levels (see Section 8.6.3.1) should be considered. This is of course an area for each IMs own management system. However a specific measure in this regard must be concerned with increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.

The two measures above represent significant contributors to the derailment problem and organisational failures of individual IMs and RUs in fulfilling their obligations.

Contents

1.0 Introduction

1.1 Background

In 2009 the European Railway Agency (the Agency) issued a recommendation (ERA/REC/01-2009/SAF) on a specific proposal, made by the RID Committee of Experts, for a new harmonised rule aimed at reducing the consequences of freight train derailments, potentially involving dangerous goods (DGs). The recommendation concerned the potential use of a Derailment Detection Devices (DDD[2]). This device automatically applies the brakes on a freight train when a derailment of a wagon equipped with that device is suspected.

Although the Agency's recommendation was that the DDD should not be adopted in the RID, the joint meeting of RISC and Inland TDG EU regulatory committees agreed that considering the low potential benefit in terms of avoided fatalities and injuries expected with DDD type devices, as well as some other problems related to the operation of trains equipped with these types of detectors, more efficient prevention measures should be further explored before deciding on imposing, by law, measures based on derailment detection.

Therefore recognising that freight train derailments remain a safety and operational concern, and following a request made by the above mentioned EU Committees, the Agency commissioned further work the objective of which was to carry out an exhaustive analysis of all prevention and mitigation measures which could reduce the risks related to freight train derailments.

Det Norske Veritas (DNV) was selected to deliver this work, the results of which are presented in this and related documents.

1.2 Overall Project Scope and Objectives

The study was divided into two research stages: Parts A and B.

Part A had the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation within 5 to 10 years). This was achieved through the following schedule of activities:

- Task A.1 - identification of existing operational and technical measures.
- Task A.2 - description of the markets and technologies covered by the devices/systems in use or which may be used at the short or medium term.
- Task A.3 - description of the rules (including specific devices/systems used) in generic functional and performance terms.
- Task A.4 - advice on innovative longer term measures (unlikely to be available within 10 years) which might be considered in a future R&D project.

Part B had the objective of analysing the measures identified in Part A (excluding those identified in Task A.4) with a view to identifying those that are the most efficient. Part B was scoped to include all prevention measures, but limited to mitigation measures based on derailment detection.

[2] DDD is an acronym used to refer to a type of detector which automatically activates train brakes when a derailment is detected based on detection of wagon acceleration. Device type EDT-101 is an example of such a device.

Part B objectives have been achieved through the following schedule of activities:

- Task B.1 – construction of detailed fault and event trees[3] describing freight train derailments and showing which derailment cause or impact the identified safety functions act on.
- Task B.2 - semi-quantitative assessment of benefits and drawbacks of existing safety rules, and of new or improved measures at short and medium terms, using data on actual/targeted performance as well as conservative assumptions.
- Task B.3 - top ten ranking of potentially efficient new safety measures or improvements at short and medium terms, including practical and legal implementation aspects.

It is important to clarify that our work looks at the ***potential for improvement***, and is not an absolute assessment of the efficiency of all measures that are applied today. Therefore it follows that if a measure is applied extensively already there is little room for improvement through the further application of that measure. For this reason some measures that are extensively applied already may not be considered in this work. Their omission should not be considered as suggesting such measures are not efficient.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland (hereafter called the target countries). In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term. For Part B however, our measures are assessed on the basis of their potential implementation in the EU railway system only.

This document is the Final Part B project report, and provides a summary of the work completed and the results of this project.

[3] The technical scope excludes intentional acts and derailments during civil works. Marshalling operation incidents are also excluded as the impacts arising from such events are normally more limited than from train operation. Collisions leading to derailment are also excluded from the study scope; however consequences of collisions that occur pursuant to a derailment are included.

2.0 Project Abbreviations Used

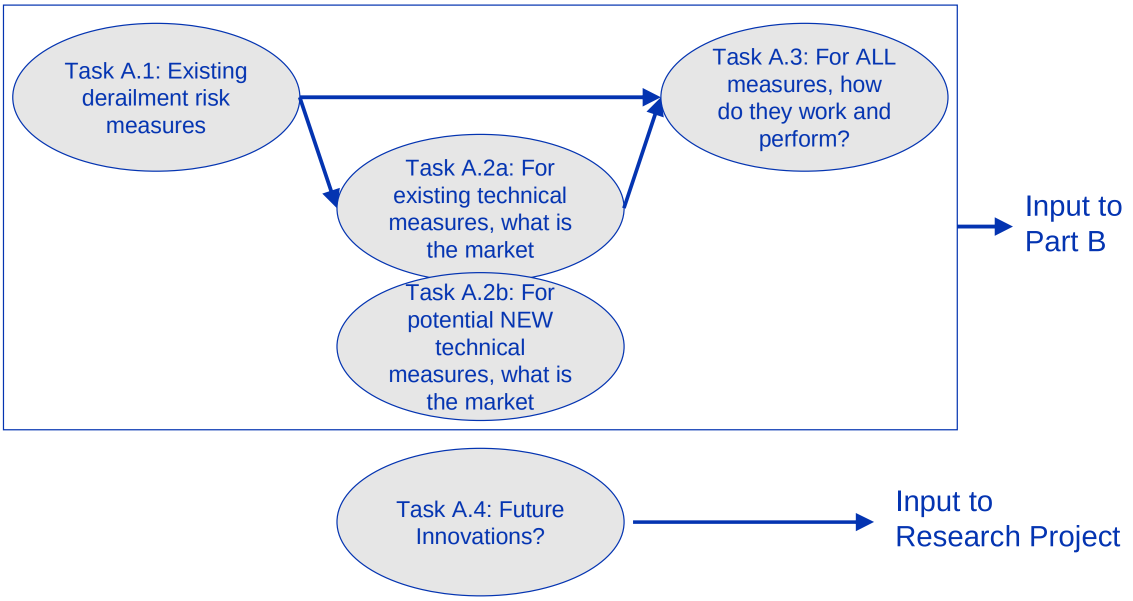
Term	Description
(the) Agency	European Railway Agency
CSI	Common Safety Indicator
CSM	Common Safety Method
CST	Common Safety Target
DDD	Derailment Detection Device of a type similar to EDT 101
DG	Dangerous Goods
DNV	Det Norske Veritas
Effectiveness	The extent to which options (measures) achieve the objectives of the proposal
Efficiency	The extent to which objectives can be achieved for a given level of resources/at least cost (cost-effectiveness)
EVIC	European Visual Inspection Catalogue
HS	High speed (>40km/h)
IM	Infrastructure Manager
Immediately Severe	A derailment with a mechanical impact that may cause a leak or material from a Dangerous Goods wagon.
JSSG	Joint Sector Support Group
Long Term	Measures that are unlikely to able to be introduced before 10 years
LS	Low speed (40km/h or less)
Measure	A control that may be put in place to either reduce the likelihood or minimise the consequence of a freight train derailment
Medium Term	Measures that could be introduced within 5 to 10 years
NDT	Non Destructive Testing
NSA	National Safety Authority
RAM	Reliability, Availability and Maintainability
RID	Regulations Concerning the International Carriage of Dangerous Goods by Rail
RIV	Regolamento Internazionale Veicoli
RU	Railway Undertaking
Short Term	Measures that could be introduced before 1st of January 2013
SMS	Safety Management System
Target countries	EU-27 countries plus the 3 candidate countries (Turkey, Macedonia and Croatia), Norway and Switzerland
TDG	Transport of Dangerous Good Regulations
TSI	Technical Specification for Interoperability
UIC	International Union of Railways

3.0 Part A Summary and Linkage to Part B

3.1 Part A Identification of Measures - Work Summary

Part A work consisted of tasks directed towards the identification of existing measures applied in the target countries together with market and performance data relating to these measures. The work completed to achieve these objectives is fully reported in our documents [2, 3, 4, 5, 6] and summarised in the diagram below.

Figure 1 Part A Task Linkage



Underpinning the completion of these tasks were the following project activities:

1. An extensive series of surveys / consultations with Infrastructure Managers (IMs), Railway Undertakings (RUs) and other actors with the objective of establishing the range of existing measures (and potentially new measures) used as controls against freight train derailments.
2. An extensive series of surveys / consultations with suppliers regarding existing technical measures (and potential new measures), market share, costs and benefits.
3. Internet and other research to supplement our survey responses.

The results of this Part A work, in terms of the measures identified and the respondents to our surveys / consultations are presented below. Other aspects of our Part A activities, such as performance data and current deployment rates for identified measures, are used directly in our efficiency assessments and therefore can be seen as input parameters to individual Part B activities.

3.2 Part A Summary Results and Outputs

3.2.1 Surveys / Consultations with Railway Actors

We invited railway actors to contribute to the measures identification process through a questionnaire concerning their operations. A summary of the question categories is provided below, and the full questionnaire is provided at [2].

Table 1 Railway Actor Survey / Consultation Question Categories

Railway Undertakings and Wagon Owners	Infrastructure Managers
• What is currently done to prevent or mitigate freight train derailments: – What measures are currently applied and why do you apply them? – Are the measures you apply effective?	• What is currently done to prevent or mitigate freight train derailments: – What devices are used to supervise trains (hot axle box detectors etc) and what is their density? Are these installed to meet a requirement (international, national or company)? – How is the information provided by these devices used? – Are the condition monitoring measures you apply effective? – Do you use some form of speed supervision on your freight lines? – What type of speed supervision is used?
• Maintenance: – Who performs maintenance on your wagons and locomotives? – What controls and competency standards are in place to ensure that maintenance is performed correctly?	• Design and Maintenance: – For mixed traffic, are the track parameters optimised for passenger or freight? – What is the maximum axle load/speed? – What is your preventative maintenance philosophy? – How is maintenance funded and are freight lines given equal priority? – How are conflicts of interest dealt with? – What controls and competency standards are in place to ensure that maintenance is performed correctly?
• Current performance / short term measures: – What is your experience and what are your views on your own performance with regard to freight train derailments? – Where do you consider improvements are most needed? – Are you aware of any new measures that could be applied in the short term to improve the situation and what are your views on the costs that might be associated with these measures? – Are there any changes that could be made to instructions such as TSIs that you consider would be beneficial?	• Current performance / short term measures: – What is your experience and what are your views on your own performance with regard to freight train derailments? – What is the approximate division between derailment causes by rolling stock, infrastructure and operational failures? – Are you aware of any new measures that could be applied in the short term to improve the situation and what are your views on the costs that might be associated with these measures? – Are there any changes that could be made to instructions such as TSIs that you consider would be beneficial?
• Future advances: – Are you aware of/have plans to test new technology that could form the basis of a longer term solution to the problem of freight train derailments – What are your views of the provision of electrical power to wagons/	• Future advances: – Are you aware of/have plans to test new technology that could form the basis of a longer term solution to the problem of freight train derailments
• Other comments	• Other comments
	• What is the size and nature of your network: – Proportion TEN classified? – Proportion mixed traffic/freight only/passenger only?

We thank the following railway actors for responding.

Table 2 Railway Actor Survey / Consultation Respondents

Country	RUs / Wagon Owner	IMs	Country	RUs / Wagon Owner	IMs
Austria	Yes (+NSA)	Yes (+NSA)	Luxembourg	Yes	
Belgium		Yes	Macedonia		
Bulgaria	Yes (+NSA)	(+NSA)	Netherlands		Yes
CER	Yes	Yes	Norway	Yes	Yes
Croatia		Yes	Poland		Yes
Czech Republic	(+NSA)	Yes (+NSA)	Portugal		Yes
Denmark	Yes	Yes	Romania		
Estonia			Slovakia	Yes	Yes
Finland	Yes	Yes	Slovenia	Yes	
France		Yes	Spain	Yes (+NSA)	(+NSA)
Germany	Yes (+NSA)	(+NSA)	Sweden	Yes	
Greece	(+NSA)	(+NSA)	Switzerland	Yes	Yes
Hungary		Yes	Turkey		
Ireland			UIP	Yes	
Italy			UNIFE	Yes	Yes
Japan			United Kingdom	Yes	Yes
Latvia	Yes	Yes	United States	Yes	Yes
Lithuania	Yes	Yes			

Note: National Safety Authorities (NSAs) were also invited to contribute to a range of questions relating to measures applied to freight trains, infrastructure and operations. Where responses were received from NSAs this is indicated by (+NSA) in the table.

We point out that in some cases the responses from trade associations provide the views of a number of their members, some of whom have chosen not to respond individually. The combined coverage (based only on individual country responses, not trade associations) covers approximately 80% of the total freight traffic volume in the target countries.

We considered this to be a good response rate which, when combined with our other research activities, provided a comprehensive coverage and identification of existing (and potential future) freight train derailment prevention and mitigation measures.

3.2.2 Survey / Consultation with Suppliers

Further to our survey / consultation with railway actors, we approached the market to establish the range of products offered, and details relating to those products. A summary of the question categories is provided below, and the full questionnaire is provided at [2].

Table 3 Supplier Survey / Consultation Question Categories

Question Category	Question Detail (Summary)
Interviewee	Details of the role, responsibility of the respondent and the Company they are responding for
Organisation and products	Details relating to the range of products marketed and previous products
Future developments	What other types of technical measures are you currently developing? When will these be available in the market place? Are you aware of other future developments with respect to technical measures for preventing/mitigating derailment?
Market	What is the primary function / technology associated with the products offered? Where are they installed? Are the products employed primarily for passenger traffic, primarily for freight traffic or both? What is the existing and potential future market for the products? What is the market share (financial or quantity)?
Costs and benefits	What is the indicative price of a single product? What are the life cycle costs / requirements for the products? How should the products be deployed to maximise their benefits? What operational aspects need to be considered in order to reap the benefits of the product?
RAM	What is the estimated lifetime of the products? What is the estimated Mean Time Between Failure or other reliability measure of the products? What is the estimated Mean Time To Repair or other maintenance measure of the products? How will failures of the products be detected? Will all failures of the product be detected? If not, are these failure modes dangerous? What is the estimated rate of False Alarms of the product? What is the in-service reliability performance of this equipment? What is the actual measured rate of false alarms? Has the product been approved by relevant safety authorities?

The survey / consultation reported here received over 30 detailed responses for technical measures.

3.2.3 The Identified Measures

We present the culmination of the measures identification activities, reporting measures in the following categories:

- Preventive infrastructure, rolling and operational measures currently applied.
- Preventive measures not currently applied.
- Mitigation measures (currently applied and potential future).

In these tables we also present our assessment of the time category in which the measure may be implemented. More detailed information on all these aspects is provided at [2].

Table 4 Existing Infrastructure Preventive Measures

Type of measure	P#	Measures and motivation:	Where applied:	Category
Technical infrastructure	P-1	Installation of check rails to prevent derailments, in particular in sharp curves, as it will hinder flange climbing on outer rail in sharp curves. Check rails are also used in other conditions and have a wear reducing effect also.	In points in most countries. In line track with sharp curves GB and republic of South Africa.	Medium
	P-2	Installation of track and flange lubrication in front of track sections with narrow curves to reduce rail flange friction and limit the risk of flange climbing on rail with subsequent derailment consequences.	Several countries including Austria. Great Britain	Medium
	P-3	No longer used – related to collision events.		
	P-4	No longer used - related to collision events.		
	P-5	No longer used - related to collision events.		
	P-6	Use of ground penetration radars (Geo radars). Ground penetration radars are used to survey conditions of track bed superstructure with regard to quality and water content. This is mainly used through ad hoc baseline runs to provide information for planning of maintenance and renewal, but permanent installations can also be considered.	Several countries including US and Norway.	Medium
	P-7	Rolling stock mounted equipment for monitoring of rail profile conditions.	Product supplied by railway supplier organisations.	Medium
Infrastructure; Control Command and Signalling	P-8	Track circuit as part of signalling system may detect rail ruptures.	Most countries	Medium
	P-9	Interlocking of points operation while track is occupied. This is not fully implemented at shunting yards. Hence a number of derailments occur due to points being operated while it is occupied by a train. This action very often causes derailment. Extend use of interlocking of remote controlled points to include tracks at shunting yards used for train movements. Interlocking of switch movement if the switched is occupied by rolling stock.	The protection measure is utilised and applied in most countries. The degree of application of point interlocking at shunting yards varies.	Medium
Trackside rolling stock supervision	P-10	Installation of hot axle box (hot bearing) detectors for detection of faulty and hot bearings and axle journals in order to remove them from train prior to derailment.	Several European countries.	Medium
Trackside installations to supervise rolling stock	P-11	Installation of acoustic bearing monitoring equipment (This is partly an alternative to hot axle box detectors). The purpose of the installation is to detect faulty bearings by sound analysis and implement bearing maintenance prior to bearing seizure and hot temperature development.	US, GB, Norway (installation plans).	Medium
	P-12	Installation of hot wheel and hot brake detectors.	Several countries.	Medium
	P-13	Installation of wheel load and wheel impact load detectors.	Several countries.	Medium
	P-14	Installation of dragging object and derailment detectors.	US and other countries	Medium

Type of measure	P#	Measures and motivation:	Where applied:	Category
	P-15	Bogie performance monitoring/Bogie lateral in-stability detection (bogie hunting).	US and other countries, including Turkey.	Medium
	P-16	Wheel profile measurement system / Wheel profile monitoring unit.	US and other countries	Medium
	P-17	No longer used – related to collision events.		
Infrastructure Operational/ organisational	P-18	Make sure available maintenance resources are sufficient in relation to network extent and traffic levels. If not possible to ensure sufficient resources a measure could be to close low traffic lines or take little used tracks out of operation. Lines and tracks where the minimum infrastructure safety requirements cannot be maintained should be closed down.	Low traffic line closure has been common in several countries.	Short
	P-19	Ensure that the track/train clearance gauge including the flange groove is free of obstructions that can cause collisions or derailments. Special focus to flange groove in level crossings.	Normal inspection and maintenance in most countries.	Short
	P-20	Perform ultrasonic rail inspection of track at sufficient frequency in order to detect rail cracks before dangerous ruptures occur. This is an activity carried out by most infrastructure managers with frequencies dependent upon rail age and traffic loads.	The activity is performed by most infrastructure managers. Frequency varies according to track loading.	Short
	P-21	Perform track geometry measurement **of all tracks** in order to detect track sections requiring maintenance actions. Regular track geometry measurements are carried out by most infrastructure managers. The completeness of the measurements with respect to track coverage at stations as well as intervals may vary. Frequency normally dependent upon traffic load and allowable speed level of track.	Most infrastructure managers but frequency may vary. Mixed coverage of sidetracks.	Short
	P-22	Establish EU-wide intervention and/or immediate action limits for track twist. The final draft TSI for CR Infrastructure specifies safety limits for track twist but intervention limits are left to the NSA or infrastructure managers of the various countries and they vary to a certain extent. Since the rolling stock are to be interoperable across all infrastructures the track intervention limits should also be corresponding.	Lack of consistency between countries, e.g. GB & Norway with regard to track twist intervention limits.	Medium
	P-23	Establish EU-wide intervention and/or immediate action limits for variation of track gauge. Present limits varies among infrastructure managers and the intervention limit specified in the final draft TSI for CR Infrastructure is less stringent than what is presently applied in many countries.	Variation in maximum gauge width between countries and towards TSI CR INF.	Medium
Infrastructure Operational/ organisational	P-24	Establish EU-wide intervention and/or immediate action limit for cant variations. In addition it should be considered to introduce a limit for excessive cant in track positions where trains are likely to stop or operate at low speed. Many derailments occur in track sections with narrow curves and high cant at low speed.	Swiss & Norwegian track regulations	Medium
	P-25	Establish EU-wide intervention and/or immediate action limit for height variations and cyclic tops which does not exist in Final draft TSI for Conventional rail infrastructure.	GB and Norway at least.	Medium

Table 5 Existing Rolling Stock Preventive Measures

Type of measure	P#	Measures and motivation:	Where applied:	Category
Rolling stock technical or structural	P-26	Flange lubrication of locomotives. Requirement for installation of on-board lubrication of locomotive flanges to be able to provide necessary track/flange contact lubrication. The measure must be seen in relation to the application of trackside installed lubrication in curves. Reduces friction available for wheel flange climbing.	US, Austria, Switzerland, Norway and others	Medium
	P-27	Replace composite wheels with monoblock wheels. Composite wheels have a more complex inspection and maintenance requirements and seems to have a higher failure rate causing derailments.	Several countries or companies are prohibiting use of composite wheels for new and existing rolling stock.	Medium
	P-28	Replace metal roller cages in axle bearings by polyamide roller cages.	CargoNet & DB Schenker freight wagons.	Medium
	P-29	Replace existing axles for stronger axles or axles with improved material properties with regard to crack initiation and crack propagation.	VTG exchanges axles for tank wagons. EURAXLES project.	Medium
	P-30	Increase the use of central coupler between wagons in fixed whole train operation. With an integrated draw gear and buffer function in a central coupling the rolling stock side buffers becomes superfluous. This will reduce side buffer loads and reduce risk of derailment due to buffer locking and couples that are too loose or too tight between wagons.	Australia, US, former USSR including Baltic states in EU. 1520/24 mm gauge lines in Eastern Europe. Train for iron ore transport from Kiruna towards Narvik and Luleå.	Long
	P-31	Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis.	US & Europe	Medium
	P-32	For new rolling stock install disc brakes instead of wheel tread brakes. Major motivation may be less noise in relation to Noise TSI, but also less heat activation of wheels, which may reduce derailment risk. For existing rolling stock, exchange wheel tread brakes with disc brakes for existing rolling stock.	Employed for many new wagons and is the dominating brake type for new passenger rolling stock.	Medium
	P-33	Rolling stock should be designed to operate safely over a track twist of up to 17 per mille over a 2.7 m base, and up to 4 per mille over an 11.2 m base. This will reduce derailment frequency due to track twist.	Republic of Ireland and Northern Ireland.	Long
	P-34	Secure brake gear located in the underframe of the wagon to ensure that braking components that become loose does not fall to the ground and cannot provoke a derailment.	Sweden, Norway and Germany and possibly other countries.	Medium
	P-35	Regular greasing and check of fastening of rolling stock buffers to reduce risk of a buffer falling off and causing derailment. Alternatively, strengthen fastening elements.	Routinely greased and inspected in most countries.	Short

Type of measure	P#	Measures and motivation:	Where applied:	Category
Rolling stock Operational / organisational	P-36	Wheel set integrity inspection (ultrasonic) programs.	Most wagon owner and train operating companies.	Short
	P-37	Derating of allowable axle loads for type A-I and A-II axle designs.	Applicable countries, ref recommendation from ERA JSSG.	Short
	P-38	Inspect axles of freight train rolling stock according to EVIC (European Visual Inspection Catalogue).	Most European countries Program implemented by ERA JSSG	Short
	P-39	Requirement for double check and signing of safety-classified (S.-marked) maintenance operations.	Norway	Short

Table 6 Existing Preventive Measures applied to Train Loading and Operation

Type of measure	P#	Measures and motivation:	Where applied:	Category
Train loading / human	P-40	Qualified and registered person responsible for loading. The person must show sufficient competence and be registered by the train operator.	Spain & Bulgaria	Medium
Pre-departure inspection and brake settings/ human	P-41	Locomotive and first wagons of long freight train in brake position G (Lange locomotive). Various countries have operational requirements that the locomotive and the first wagons of a train shall be put in brake position G to limit the compression forces of the train when braking with the pneumatic activated train brakes.	Germany, Austria and Switzerland, as well as Norway and Sweden to a lesser degree.	Short
Train operations/ human:	P-42	Limitations on use of brake action in difficult track geometry, particularly at low speed, to avoid high compression forces of train that could cause buffer locking and derailment (includes re-generative braking).	Switzerland, Austria & possibly other countries	Short
	P-43	The ATP-system of some countries including Norway, Sweden and Finland, called ATC, has a function to perform a dynamic brake test on the route to get actual test information with regard to the train braking performance.	Sweden	Medium
	P-44	Saw tooth braking should be applied when using pneumatic brakes to limit speed in long and steep descents in order to limit heat exposure to wheels.	Switzerland	Short
	P-45	When passing a signal showing a reduced speed, the driver should initiate the braking or speed reduction action prior to passing the signal. This could reduce the risk of over-speeding in track deviations.	Switzerland	Short

Type of measure	P#	Measures and motivation:	Where applied:	Category
	P-46	Trafikverket in Sweden (former Banverket) has recently issued a new regulation for how various alarms should be handled. Traffic controllers and drivers should not be allowed to override detector alarms.	Sweden	Short
	P-47	Wagons equipped with a balance to detect overload in visual inspection.	Switzerland	Medium

Table 7 Preventive Measures Not Currently Applied (but which could be applied in the short or medium term)

Measure Number	Description	Category
F-1	**End-of-train device (brakes)**. In the USA & Canada freight trains are installed with "end of train devices" that are in radio contact with the driver, and by radio signal to the unit the driver can apply brakes on the train in an emergency situation. This can be an essential safety measure in situations where the brakes of substantial rear parts of the train cannot be applied immediately from the driver's position. Application of brakes through an end of train device can also speed up the brake application in an emergency situation, and also may reduce compression forces in a train. Note: This measure is not to prevent collisions but to allow a better quality of brake application, limiting the possibility to induce a derailment due to a non-uniform application of the brakes especially in the case of long trains. This measure should be distinguished from the brake tests before departure which have the objective to ensure that the brake performance is correct and therefore to help to prevent over-speed which can lead both directly to a derailment and to a collision.	Medium. The introduction of such devices would require complementary tests and agreement regarding issues such as the transmission of signals between the driver and the end of train device. Such work is likely to require a timeframe within the 5-10 year window relating to the definition of medium term.
F-2	**Awareness program and improved maintenance**. A concern expressed to us by several IMs was regarding the quality of freight wagons from some countries. In particular that maintenance as well as supervision of national authorities of this maintenance is of varying standards.	Short. This is an issue relating to the safety management systems and culture of RU / keepers / wagon owners as well as the supervision of this by NSAs. It is certainly the case that renewed emphasis on this matter could be recommended in the short term, although a full implementation of this may take longer.

Measure Number	Description	Category
F-3	**Hot Axle Box Indication**. The use of thermo-sensitive paint / chalk or similar to check for hot axle boxes. This may provide visual indication to train driver of the presence of a hot axle box. (Possibly a hot axle box alarm may have been triggered, but on inspection some minutes later the axle box has cooled – this may provide indication that the alarm was genuine, and avoid accidents where the driver continues.) We understand that this measure is applied in at least one RU within the target countries.	Short. This is a simple measure which is likely to be quick and relatively easy to implement.
F-4	**Machine vision devices**. These products are designed to detect faults that may occur on freight vehicles when they run pass the detection site. Such devices are installed at trackside and employ hi-speed cameras to grab images of the vehicles. These images are sent to a computer for processing, comparison and analysis so any fault on the vehicle can be distinguished and detected. They detect mechanical failures of the bogie, dragging objects, coupler faults and may also detect temperature variations etc. This measure is applied in countries which include the USA and China, but not within the target countries.	Medium. The introduction of such devices would require complementary tests. Such work is likely to require a timeframe within the 5-10 year window relating to the definition of medium term.
F-5	**Telematics**. Devices that allow receipt and transmittal of information from / to rail freight vehicles. Using this technology it is possible to inform the Entity in Charge of Maintenance of defects for rectification. A number of the measures described in this document require the positive identification of a train in order for emerging issues to be identified (for example acoustic bearing monitoring). Other benefits include verification of train consist and operational parameters. This measure is partly implemented in some target countries.	Medium. The scale of the implementation programme, and the supporting infrastructure required to collate the information would mean this was not achievable within the short term. Note that this measure does not have a direct impact on derailment rates and is not considered further.

Measure Number	Description	Category
F-6	**Anti-lock device.** Systems of this type reduce locking of the wheels and associated wheel damage during braking on railway freight cars. In turn this may reduce maintenance costs associated with re-profiling wheel sets, improve safety with reduced risk of wheel cracking or major tread damage that could increase derailment risk, reduce impact forces to track with the wheel sets, reduce noise generated with the wheel sets. The control system concepts are similar to passenger Wheel Slip Protection, but the application to freight cars has 2 principle differences:- • The absence of electrical power, which is overcome by integrated generators driven from the axle ends • Much less compressed air available to control slide activity – this is a particular constraint with “single-pipe” braking used almost exclusively within the EU. They may also provide a local power source for other monitoring systems. Currently a system of this type is being tested in one of the target countries.	Medium. The scale of the implementation programme would mean this was not achievable within the short term.
F-7	**Sliding wheel detectors**. These systems detect wheels that are not rotating correctly and raise an alarm, with similar benefits to the antilock device for freight wagons described above. They are currently used in at least Australia, although a GB demonstration is planned for 2011.	Medium. The introduction of such devices would require complementary tests. Such work is likely to require a timeframe within the 5-10 year window relating to the definition of medium term.
F-8	**Handbrake interlock.** This would prevent a freight train moving off with the handbrake applied and therefore reduce the likelihood of subsequent issues like wheel flats, overheating and track damage.	Medium. The scale of the implementation programme would mean this was not achievable within the short term.

Table 8 Mitigation Measures (existing and future)

Category:	M#	Measures and motivation:	Where applied:	Category
Rolling stock	M-1a	Derailment detection detectors (valves) to avoid derailed wagons from being dragged along for long distances – these devises apply train brakes automatically.	By train operators in Switzerland & Slovenia. Similar system in use in RWE Rheinbraun	Medium
	M-1b	Derailment detection detectors to provide an alarm to the train driver indicating a suspected derailment – these devises do not apply train brakes automatically.	Future measure	Medium
	M-2	Equip tank wagons with impact shield to protect tank against penetration (US-requirement also used in Sweden).	RID requirement for some materials, e.g. chlorine. Country requirements: US, Sweden	Not assessed – outside of project scope.
	M-3	Install emergency warning lights on locomotive to warn train on neighbouring track going in opposite direction.	Switzerland	Not assessed – outside of project scope.
	M-4	Attach mechanical guides at the bogie structure or on wagon support at appropriate position to ensure that a derailed wagon most likely is kept along the track and does not overturn or become hit by other wagons.	High speed trains in France, Sweden and Japan. Similar system in use in RWE Rheinbraun	Not assessed – outside of project scope.
Infrastructure	M-5	Existing requirement for safety rails (guard rails) at bridges and in tunnels.	Several countries for bridges. Denmark for to tunnels	Not assessed – outside of project scope.
	M-6	Battering rams in front of safety critical pillar supports of roof structures and over bridges in order to prevent derailed rolling stock damaging such safety critical structures.	Germany	Not assessed – outside of project scope.
	M-7	Installation of dragging object and derailment detectors. The detector will detect both dragging objects and derailments.	US and other countries	Not assessed – outside of project scope.
	M-8	Installation of deviation points leading to a safe derailment place in strongly descending tracks from marshalling yards and train formation stations.	Norway, Sweden, United Kingdom etc.	Not assessed – outside of project scope.
	M-9	Radio or cell phone communication installations like GSM-R in order to transfer emergency stop orders to trains.	To be implemented as part of Interoperability directive and TSIs command, control and signalling.	Not assessed – outside of project scope..
	F-9	Harmless infrastructure. This relates to the removal of obstructions on or near the track that may make penetration of a dangerous goods tank wagon less likely.	Future measure.	Not assessed – outside of project scope.
Operational	M-10	Separate passenger and freight traffic to separate lines to a larger degree (which is also EU-policy).	High speed lines for passenger traffic. Betuwe route (NL) for dedicated freight	Not assessed – outside of project scope.

Category:	M#	Measures and motivation:	Where applied:	Category
	M-11	Restrictions on freight traffic in general or hazardous materials transport in special through certain busy passenger terminals and/or underground stations to restrict traffic and limit the consequences of a derailment.	Examples are banning of general freight traffic through airport train stations (e.g. Oslo and Schippol)	Not assessed – outside of project scope.
	M-12	Develop and apply a checklist for dangerous goods transport as the Swiss checklist for dangerous goods transport by freight trains.	Switzerland	Not assessed – outside of project scope.
	M-13	Requirement for activating of warning lights in driving end of train.	Switzerland	Not assessed – outside of project scope.

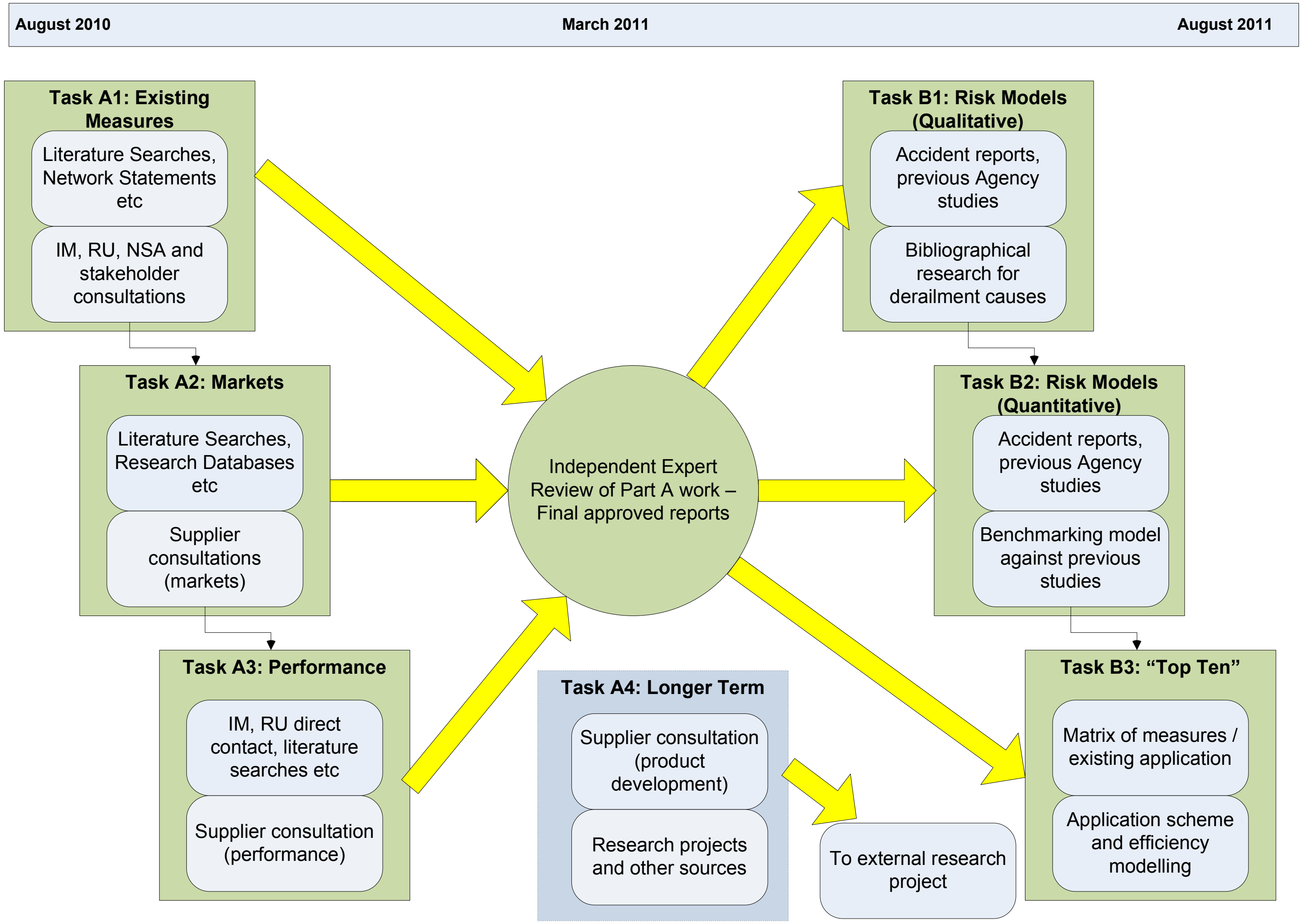
3.3 Part A to Part B Linkages and Part B Work Overview

The objective of Part B was to consider the measures identified and to establish the potential room for improvement relating to freight train derailment risk reduction. This room for improvement was to be measured in terms of their efficiency (the consideration of costs to apply the measure, compared with the benefits secured by that measure). The individual tasks completed in Part B to achieve this objective were:

- An activity to develop a safety risk model describing the causes and consequences of a freight train derailment.
- An activity to quantify the developed safety risk model thus enabling an assessment of the magnitude of the potential benefits of introducing new measures, or extending the scope of existing measures, to be established.
- An activity to quantify the costs required to implement each measure, thus enabling the efficiency of each measure, and an ordered list of the most efficient measures to be established.

We show the key project linkages in Figure 2. The remainder of this report discusses the activities above.

Figure 2 Task Linkages

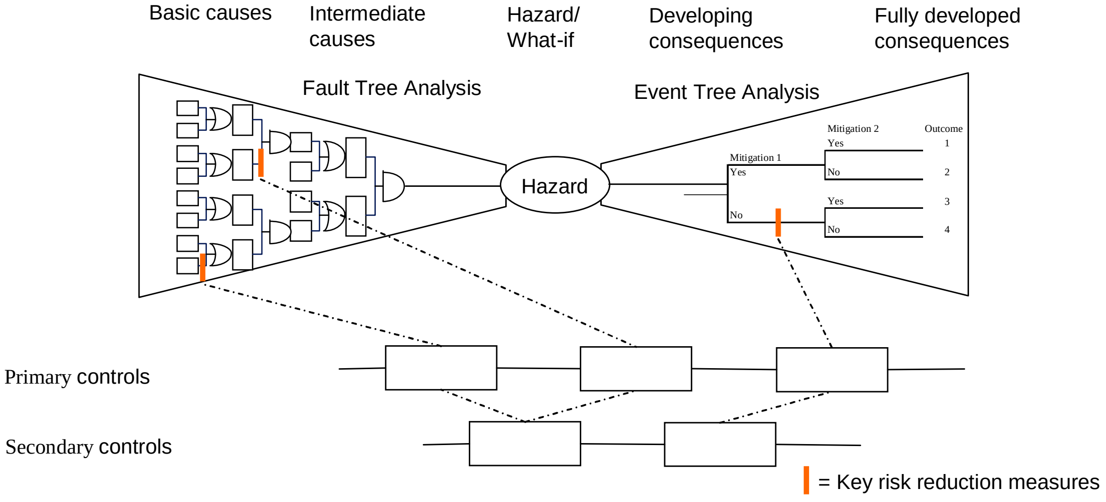


4.0 The Safety Risk Model

4.1 Risk Model Concept

The risk model concept revolves around the "bow-tie" approach. In this approach the frequency of a hazard (in this case a freight train derailment) is established, followed by the consequences that may develop following realisation of that hazard.

Figure 3 Bow-tie Model Structure



The identified measures (from Part A) can then be mapped onto the bow-tie to determine their contribution to reducing the frequency or mitigating the consequences of that hazard. Ultimately this is established by quantifying the safety losses associated with the existing situation and comparing those with the revised (reduced) safety losses following the introduction of a new measure, or a wider application of an existing measure.

4.2 Accident Analysis

An important part of the development of our safety risk model related to the study of previous freight train derailment accidents. In this respect, DNV studied [7, Annex 1] 201 freight train derailment accident reports and from these we have established the primary, secondary and additional combinational accident causes and consequences.

In addition, and as a supplement to our accident analysis, we have also studied a further 400+ accident summaries reported to the Agency as part of their work [1]. After elimination of duplicates, those which were not derailments etc. the usable Agency data was 355 accident summaries from a range of European countries.

A total of 556 accident reports were therefore considered in our analysis.

The majority of accidents studied have been recent (i.e. occurring 2000 onwards) so that the results can be considered current.

4.2.1 Causal Analysis

Based on our accident analysis we were able to classify derailments by category and cause as follows:

4.2.1.1 Infrastructure Derailment Causes

Derailments caused by infrastructure failures and defects are classified as follows:

1. Failed substructure, comprising:
    a. Subsidence
    b. Earth slide / tunnel collapse (leading to derailment, not collision)
    c. Substructure wash-out due to flooding etc
    d. Bridge failure (leading to derailment)
2. Structural failure of the track superstructure, comprising:
    a. Rail failures
    b. Joint bar & plug rail failures
    c. Switch component structural failure
    d. Failure of rail support and fastening
    e. Track superstructure unsupported by substructure
    f. Other track and superstructure failure
3. Track geometry failure, comprising:
    a. Excessive track twist
    b. Track height/cant failure
    c. Lateral track failure
    d. Track buckles (heat-curves)
    e. Excessive track width
    f. Other or unspecified track geometry causes
4. Other infrastructure failures

4.2.1.2 Rolling Stock Derailment Causes

Derailments caused by rolling stock failures and defects are classified as follows:

1. Wheelset failures (wheels and axles), comprising:
    a. Axle ruptures:
        i. Hot axle box and axle journal rupture
        ii. Axle shaft rupture
        iii. Axle rupture, location not known
    b. Wheel failure:
        i. Rupture of monoblock wheel
        ii. Failure of composite wheel with rim and tyre

iii. Excessive flange or wheel tread wear (wrong wheel profile)

2. Bogie and suspension failures, comprising:
    a. Failure of bogie structure and supports
    b. Spring & suspension failure
    c. Other
3. Twisted or broken wagon structure/frame
4. Wagon with too high twist stiffness in relation to length
5. Brake component failure
6. Other or unknown rolling stock derailment cause

4.2.1.3 Operational (including Train Control) Derailment Causes

Derailments caused by operational failures and defects are classified as follows:

1. Train composition failures, comprising:
    a. Unfavourable train composition (empties before loaded wagons)
    b. Other
2. Improper loading of wagon, comprising:
    a. Overloading
    b. Skew loading
        i. Wagon wrongly loaded
        ii. Wagon partly unloaded
    c. Insufficient fastening of load
    d. Other incorrect loading
3. Train check and brake testing, comprising:
    a. Un-suitable brake performance for route characteristics
    b. Brakes not properly checked or tested
    c. Brakes not correct set with respect to load or speed of brake application
4. Wrong setting of points/turnouts, comprising:
    a. Wrong setting in relation to movement authority
    b. Point switched to new position while point is occupied by train
5. Mishandling of train en route, comprising:
    a. Overspeeding:
        i. Too high speed through turnout in deviated position
        ii. Too high speed elsewhere
    b. Other mishandling of train
6. Brake shoe or other object left under train
7. Other operational failures

4.2.2 Consequence and Impacts Analysis

Our primary mechanism for understanding the consequences associated with freight train derailments and the scenarios that lead to these consequences has also been our accident analysis, supported by work completed by the Agency [1].

We have observed the following important considerations that have a significant impact on the consequence and impacts of a freight train derailment:

- The location at which the derailment occurs.
- The immediate consequence at time of initial derailment (does the wagon overturn, for example). (A derailment that leads to a wagon overturning or to suffer a mechanical impact sufficient to potentially lead to a loss of containment is classed as “severe”.)
- The method and speed of detection of derailments that are not immediately severe, and the subsequence management of the situation.
- The presence of traffic on adjacent lines.
- The material / product that the freight train is carrying.

These factors are used to develop the freight train derailment impacts, as we shall discuss in subsequent report sections.

5.0 Freight Train Derailment Frequency

5.1 Overview

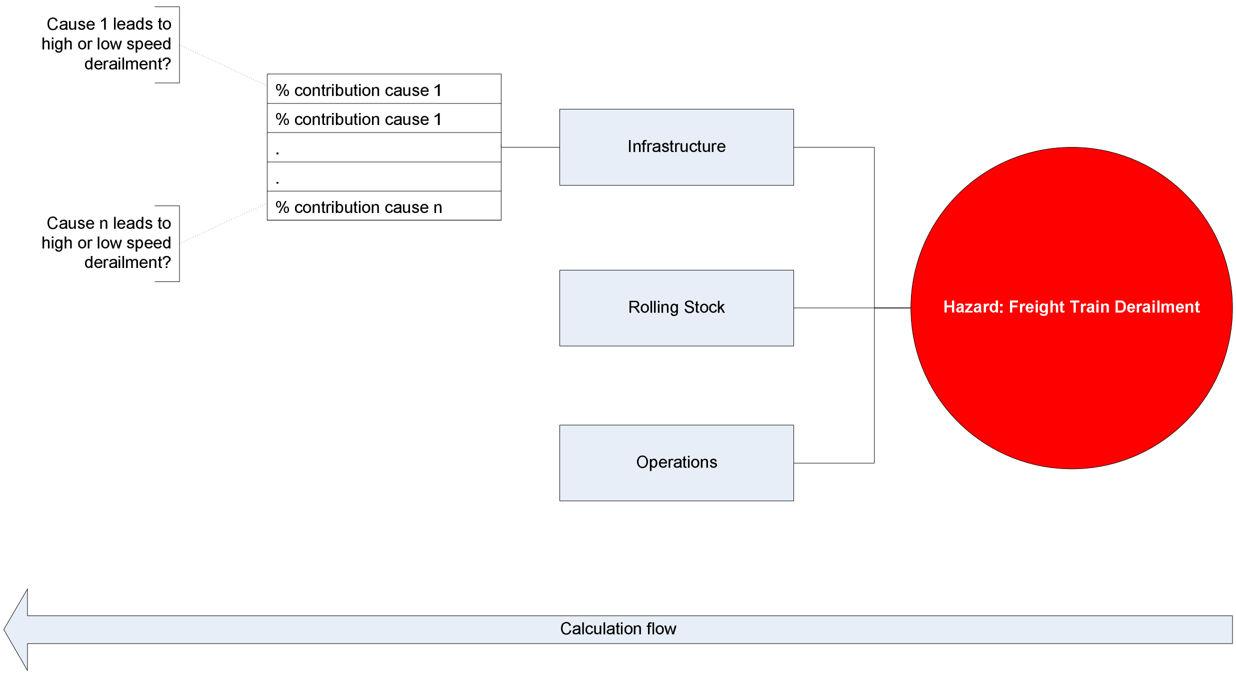
Although we developed fault models to show pictorially the combination of events that may lead to a freight train derailment, we used alternative means for the quantification process[4]. Our alternative approach was based on an apportionment technique which we summarise below (our reports [7, 8] provide full details.)

The technique works as follows:

1. Establish the annual quantity of freight train derailments.
2. Establish the percentage contribution from each freight train derailment cause. This includes whether the cause is more likely to result in a high or low speed derailment[5].
3. Calculate the frequency contribution per cause as the product of 1 and 2.

We summarise our approach in the diagram below.

Figure 4 Establishing Freight Train Derailment Frequency Parameters



We consider first the quantity of freight train derailments.

5.2 Annual Number of Freight Train Derailments

The Agency work on this subject [1] presented an analysis based on an assumed quantity of freight train derailments. The starting point used was 500 significant train derailments per year. This information was used by the Agency as follows to calculate the annual number of freight train derailments [1]:

> *"The 500 significant derailments/year that were used in the study concern both passenger trains and freight trains. It is assumed in the study that about 60% of all*

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[4] Fault trees were not used due to a lack of low level modelling data to enable their quantification.
[5] We define high speed as being in excess of 40km/h. This is in line with CPR-18E, Guidelines for Quantitative Risk Assessment [10]

derailments are freight train derailments. This gives an estimate of about 300 significant freight derailments per year. It was then further estimated (…) that about 50% of all open line derailments will be significant, to the point that they would be included in the EUROSTAT statistics[6]. This finally yields about open line 600 freight train derailments per year."

Since that date however a significant decrease in derailments is reported, as follows:

Table 9 Annual Numbers of Train Derailments

	2006	2007	2008	2009
Eurostat (EU-27)	549	452	***247***	***141***
Agency [9] (EU-27+NO+CT)	***477***	***346***	***319***	***177***

The reported numbers of derailments in 2009 (and 2008 to a lesser extent) should however be taken with caution, as indicated by green shaded cells. In 2007, the threshold for reporting accidents changed: the threshold of EUR 50,000 of damage increased to EUR 150,000 in line with the UIC recommendation. As a consequence, the number of derailments reported to Eurostat in 2008 and 2009 reduced considerably.

Similarly, a more stringent definition of a significant accident was introduced by the Railway Safety Directive (49/2004) and the Directive 149/2009 has been gradually put in place by several Member States since 2006, leading to the distortion of the picture depicted by the reported figures. In this regard, the Agency [9] state:

…the number of train derailments dropped significantly in 2009, to 177 reported events. The main reason is that in several countries shunting movements were previously reported under this category. Nevertheless, on average a derailment is reported every second day in the EU, causing significant traffic disruptions."

Beside the changes in reporting requirements, it should be noted that the EU aggregate available at the Agency is strongly influenced by the high figures reported by Poland and France, accounting together for more than half of all derailments in the EU. These numbers are very high when compared with figures in countries with comparable train-km performance such as Germany, UK or Italy and suffers from important fluctuations over time. Reflecting the Agency's position Eurostat advised us that:

"More particularly, the EU aggregate is especially influenced by the Polish figures, accounting for 40-45% of the total number of derailments observed at EU level. Poland has reported a significant decrease over the 2007-2009 periods, and this had consequently a significant impact at total EU level."

And Poland advised us that:

"…the improvement was illusionary. The explanation is the change of derailment categories (according to current regulations)."

On balance, we support the Agency view that train derailments are reducing in number slightly, along with the number of all train accidents. For the purposes of our analysis we have used a conservative estimate of a 6% year on year reduction.

Using these data, and from a starting point of 600 freight train derailments per year in 2008 (as used by the Agency [1]), we estimate the 2011 equivalent train derailment value to be about **500 per year**.

[6] Table: RAIL_AC_CATNMBR - Annual number of accidents by type of accident

This reduction in the annual quantity of freight train derailments will result in it becoming more difficult to identify future cost-effective solutions as the available benefit is reducing. However this will not affect the ranking of measures.

5.3 Analysis of Causes and Likelihoods

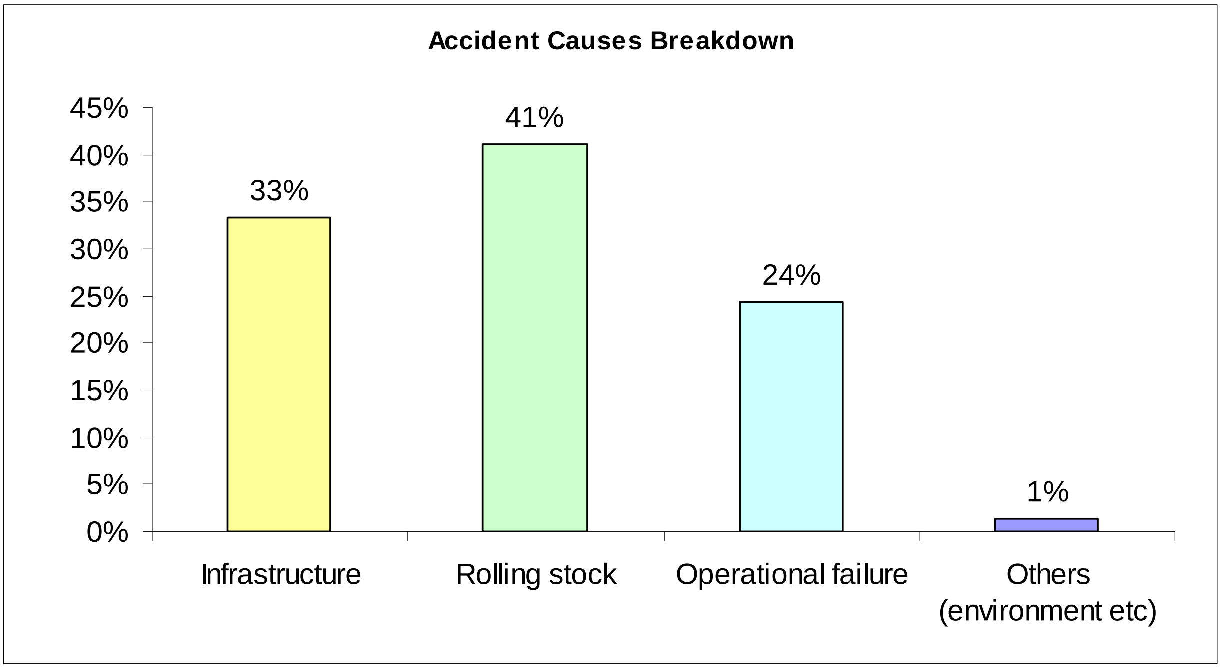
Freight train derailment accidents can result from a single failure[7] or a combination of defects[8]. The former may be something that is out of specification to the extent that it can be considered the only or dominant cause of the derailment (a broken axle may fit into this category). The latter may consist of combinations of equipment / systems that are outside their ideal operating tolerances, but not so much as to be solely responsible for a derailment (a combinational cause may be track geometry which is outside its intervention limit, but within its safety limit, AND a wagon which is skew loaded).

We consider these in turn.

5.3.1 Single Derailment Causes

Derailments which have been assessed as having a single or dominant cause we have estimated to account for 78% of derailments, [7, Annex 1]. Our analysis of single cause derailment accidents, by sub-system, is presented below (in the figure below, 41% of single cause failures result from sub-system rolling stock).

Figure 5 Freight Train Derailment by Sub-System (Single Causes)



We break these down further in the following two sections and we again present the information relative to the category the failures belong to. We only show those causes that more than 3% to derailments in the category.

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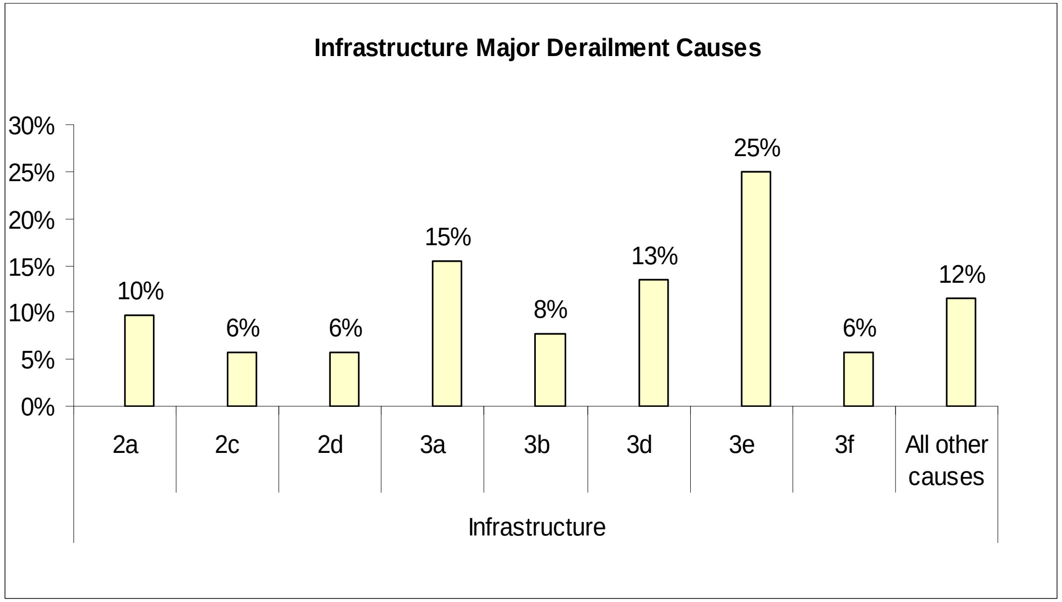
[7] We define a failure as a condition that leads to the system not being fit for purpose and outside allowable tolerances

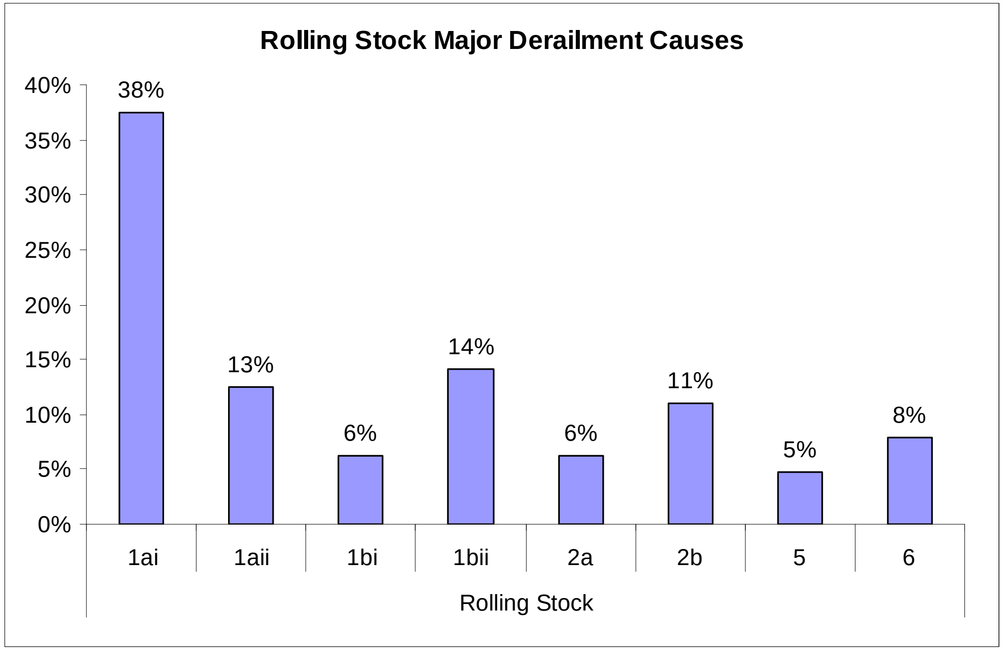
[8] We define a defect as a condition that leads to the system being outside its optimal operating condition, but within working tolerances

Figure 6 Freight Train Derailment - Infrastructure



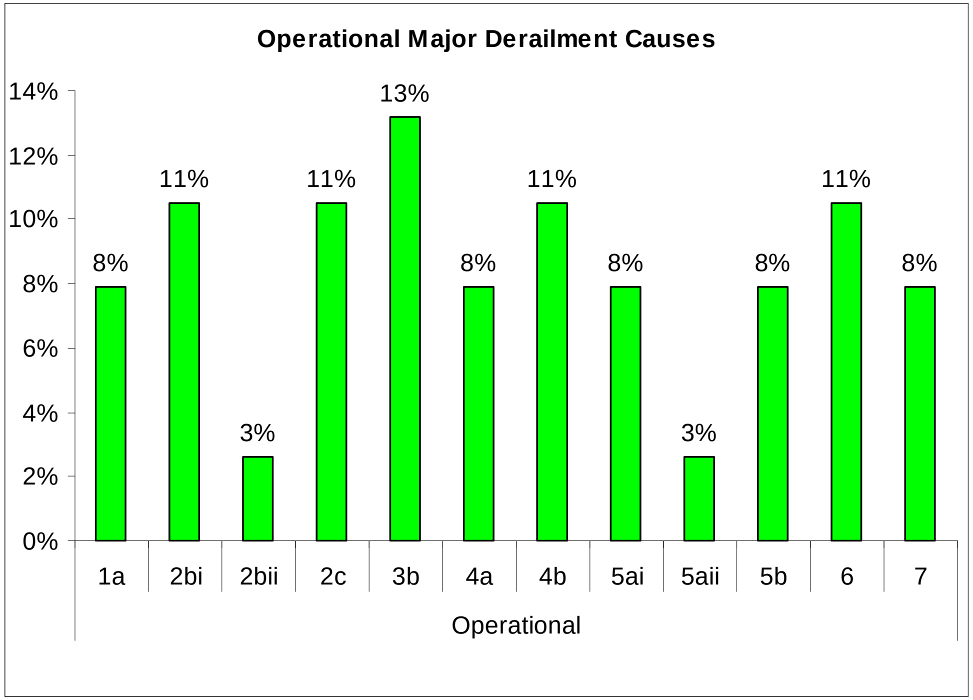
#	Description (only those contributing >3% shown in diagram)
2	Structural failure of the track superstructure, comprising:
a.	Rail failures
c.	Switch component structural failure
d.	Failure of rail support and fastening
3	Track geometry failure, comprising:
a.	Excessive track twist
b.	Track height/cant failure
d.	Track buckles (heat-curves)
e.	Excessive track width
f.	Other track geometry failures
Oth	All other causes

Figure 7 Freight Train Derailment – Rolling Stock



#	Description (only those contributing >3% shown in diagram)
1a	Wheelset failures (wheels and axles), comprising:
i.	Hot axle box and axle journal rupture
ii.	Axle shaft rupture
1b.	Wheel failure:
i.	Rupture of monoblock wheel
ii.	Failure of composite wheel with rim and tyre
2	Bogie and suspension failures, comprising:
a.	Failure of bogie structure and supports
b.	Spring & suspension failure
5	Brake component failure
6	Other or unknown rolling stock derailment cause

Figure 8 Freight Train Derailment – Operational



#		Description (only those contributing >3% shown in diagram)
1		Train composition failures, comprising:
	a.	Unfavourable train composition (empties before loaded wagons)
2		Improper loading of wagon, comprising:
	b.	Skew loading
	i.	Wagon wrongly loaded
	ii.	Wagon partly unloaded
	c.	Insufficient fastening of load
3		Train check and brake testing, comprising:
	b.	Brakes not properly checked or tested
4		Wrong setting of points/turnouts, comprising:
	a.	Wrong setting in relation to movement authority
	b.	Point switched to new position while point is occupied by train
5		Mishandling of train en route, comprising:
	a.	Overspeeding:
	i.	Too high speed through turnout in deviated position
	ii.	Too high speed elsewhere
	b.	Other mishandling of train
6		Brake shoe or other object left under train
7		Other operational failures

5.3.2 Link between Cause and Speed (for single cause derailments)

Although it is not possible to provide a clear linkage between freight train derailment cause and speed of derailment, it is the case that some derailment causes occur more often at higher speed; this is partly due to the type of failure and partly due to the operational constraints that may be in place. For example, track geometry derailment causes may lend themselves to lower speed derailments. This is not necessarily because of the specific failure per-se (although in some cases operating at lower speed may make a derailment more likely), but possibly because the track geometry defect / failure is known about and therefore trains are operating at a lower speed.

Conversely, hot axle box (HAB) derailments are more likely to occur at higher speed because higher train speeds may induce the condition, and also because an impending HAB failure is not usually known about in advance (and hence is unlikely to be operating at a reduced speed).

We have made our own assessment in the following tables, using the following nomenclature:

- High Speed – greater than 40 km/h - (HS) indicates that derailments from these causes are more likely (although not exclusively) to be at higher train speeds.
- Low Speed (LS) indicates that derailments from these causes are more likely (although not exclusively) to be at lower train speeds.
- Speed Independent (SI) means that there is no observed pattern.

Using this scheme our models produce derailment frequencies for both high and low speed freight train derailments. We have tested this hypothesis as far as is possible against the accident data we have both individually and collectively. (In this regard, our accident data shows that freight train derailments occur slightly more frequently at low speeds – 40km/h or less - and this is replicated by our models.)

Table 10 Allocation of Cause and Speed (Infrastructure Failures)

Infrastructure	**E(nvironment)**	SI
	1. Failed substructure	
	a. Subsidence	SI
	b. Earth slide/tunnel collapse	SI
	c. Substructure wash-out due to flooding etc	SI
	d. Bridge failure	SI
	2. Structural failure of the track superstructure	
	a. Rail failures	SI
	b. Joint bar & plug rail failures	SI
	c. Switch component structural failure	SI
	d. Failure of rail support and fastening	SI
	e. Track superstructure unsupported by substructure	SI
	f. Other track and superstructure failure	SI
	3. Track geometry failure	
	a. Excessive track twist	LS
	b. Track height/cant failure	HS
	c. Lateral track failure	HS
	d. Track buckles (sun-curves)	HS
	e. Excessive track width	SI
	f. Other or unspecified track geometry causes	SI
	4. Other infrastructure failure	SI

Table 11 Allocation of Cause and Speed (Rolling Stock Failures)

Rolling Stock	**1. Wheelset failures (wheels and axles)**	
	a. Axle ruptures	
	i) Hot axle box and axle journal rupture	HS
	ii) Axle shaft rupture	HS
	iii) Axle rupture, location not known	HS
	b. Wheel failure	
	i) Rupture of monoblock wheel	HS
	ii) Failure of composite wheel with rim and tyre	HS
	iii) Excessive flange or wheel tread wear (wrong wheel profile)	LS
	2. Bogie and suspension failure	
	a. Failure of bogie structure and supports	SI
	b. Spring & suspension failure	SI
	c. Other	SI
	3. Twisted or broken wagon structure/frame	SI
	4. Wagon too high twist stiffness in relation to length	LS
	5. Brake component failure	SI
	6. Other or unknown rolling stock derailment cause	SI

Table 12 Allocation of Cause and Speed (Operational Failures)

Operations	**1. Train composition failure**	
	a. Unfavourable train composition (empties before loaded wagons)	LS
	b. Other	SI
	2. Improper loading of wagon	
	a. Overloading	LS
	b. Skew loading	
	i) Wagon wrongly loaded	LS
	ii) Wagon partly unloaded	LS
	c. Insufficient fastening of load	HS
	d. Other incorrect loading	SI
	3. Train inspection and brake testing	
	a. Speed not according to brake performance	HS
	b. Brakes not properly checked or tested	HS
	c. Brakes not correct set wrt. load or speed of brake application	HS
	4. Wrong setting of points/turnouts	
	a. Wrong setting in relation to movement authority	LS
	b. Point switched to new position while point is occupied by train	LS
	5. Mishandling of train en route	
	a. Overspeeding	
	i) Too high speed through turnout in deviated position	HS
	ii) Too high speed elsewhere.	HS
	6. Brake shoe or other object left under train	LS
	7. Other operational failure	SI

5.3.3 Combinational Causes

Derailments which have been assessed as having several equally important contributing causes account for 22% of derailments, [7, Annex 1]. For combinational causes we present a list of defects appearing most frequently:

1. Track geometry defects appear in about 50% of accidents where more than one cause is present, with track twist the most significant appearing in about 30%.
2. Wheel profile defects appear in about 20% of accidents where more than one cause is present.
3. Wagon wrongly loaded appears in about 10% of accidents where more than one cause is present.
4. Train mishandling appears in 10% of accidents where more than one cause is present.

For the purposes of our assessment, we have made the assumption that all accidents as a result of combinational defects are speed independent.

We also need to ask the question whether removal of one of the defects in the defect chain will prevent the accident. The answer to this is "probably", but will depend on the exact circumstances of each accident.

For the purposes of our quantification we have taken two approaches to modelling these factors:

- If we assume that removal of one defect will eliminate all accidents containing that cause then removal of track twist defects will remove 30% of combinational cause accidents. This is termed the ***maximum*** risk reduction potential in the sections below.

  This assumption must be applied with care as it can imply that more than 100% of accidents can be eliminated. To illustrate this point let us assume there are 10 accidents each having two causes. Let us further assume that five of these accidents have track twist as a causal factor, another five have wagon loading as a causal factor and the remaining 10 causes are all unique. By assuming that removal of one defect removes the accident then it follows that removal of track twist eliminates five of the 10 accidents (50%). Removal of wagon loading similarly eliminates 50% of accidents and removal of each of the 10 unique causes removes one in 10 accidents (100%). The total is 200%. We can assume removal of each cause individually will remove the percentage of accidents in which it appears (i.e. track twist removes 50% of combinational accidents). We cannot however summate the total of all causes and apply this as doing so would imply removal of 200% of accidents, which is not correct.

- As a ***reference*** case we have taken the percentage of times each cause appears amongst all combinational causes. Using this measure track twist defects for example contributes 12%.

5.4 Causal Frequency Model Usage, Summary and Outputs

We have described our approach to establishing freight train derailment frequency in the sections above. For the data used, our model produces the following:

- Derailments at HS (above 40km/h) = 235 per year
- Derailments at LS (40km/h and below) = 265 per year

To use our model, we apply measures to a cause that it acts on. As an example we consider HAB failures, which contribute as follows:

- 14 low speed derailments (LSD), and
- 49 high speed derailments (HSD).

If a measure could be found to eliminate say 90% of these, then the risk benefit would be:

- 14 * 0.9 = 12.6 prevented LSD, and
- 49 * 0.9 = 44.1 HSD

We use our model in this way to establish the potential benefit that each measure may secure.

In Table 13 we present output from our frequency model, showing the annual quantity of derailments attributable to each cause. In this table we have combined the total contributions from single and combinational cause contributions to provide one ***reference*** value. For the major combinational causes discussed above we show the ***maximum*** risk reduction potential that the elimination of each cause may give rise to.

We also present, at Table 14, the maximum potential annual benefit available from each measure. ***This assumes that the measure can be 100% effective in eliminating the causes that it is targeted towards.***

Table 13 Failure Contribution to Freight Train Derailments[9]

		Reference		Maximum	
	Failure	**LSD**	**HSD**	**LSD**	**HSD**
Infrastructure	**E(nvironment)**	5	2		
	1. Failed substructure				
	a. Subsidence	2	1		
	b. Earth slide/tunnel collapse	Negligible			
	c. Substructure wash-out due to flooding etc	1	1		
	d. Bridge failure	2	1		
	2. Structural failure of the track superstructure				
	a. Rail failures	10	4		
	b. Joint bar & plug rail failures	3	1		
	c. Switch component structural failure	6	3		
	d. Failure of rail support and fastening	8	3		
	e. Track superstructure unsupported by substructure	3	1		
	f. Other track and superstructure failure	3	1		
	3. Track geometry failure				
	a. Excessive track twist	26	8	37	13
	b. Track height/cant failure	4	9		
	c. Lateral track failure	2	1		
	d. Track buckles (sun-curves)	4	14		
	e. Excessive track width	25	11		
	f. Other or unspecified track geometry causes	6	3		
	4. Other infrastructure failure	3	1		
	U(nspecified)	3	1		
Rolling Stock	**1. Wheelset failures (wheels and axles)**				
	a. Axle ruptures				
	i) Hot axle box and axle journal rupture	14	49		
	ii) Axle shaft rupture	4	16		
	iii) Axle rupture, location not known	1	2		
	b. Wheel failure				
	i) Rupture of monoblock wheel	2	8		
	ii) Failure of composite wheel with rim and tyre	5	18		
	iii) Excessive flange or wheel tread wear (wrong wheel profile)	7	3	16	7
	2. Bogie and suspension failure				
	a. Failure of bogie structure and supports	9	4		
	b. Spring & suspension failure	15	6		
	c. Other	4	2		
	3. Twisted or broken wagon structure/frame	3	1		
	4. Wagon too high twist stiffness in relation to length	1	1		
	5. Brake component failure	5	2		
	6. Other or unknown rolling stock derailment cause	7	3		
	U(nspecified)	4	2		
Operations	**1. Train composition failure**				
	a. Unfavourable train composition (empties before loaded wagons)	8	3		
	b. Other	Negligible			
	2. Improper loading of wagon				
	a. Overloading	2	1		
	b. Skew loading				
	i) Wagon wrongly loaded	11	3	15	5
	ii) Wagon partly unloaded	3	1		
	c. Insufficient fastening of load	3	8		
	d. Other incorrect loading	Negligible			
	3. Train inspection and brake testing				
	a. Speed not according to brake performance	1	1		
	b. Brakes not properly checked or tested	3	10		
	c. Brakes not correct set wrt. load or speed of brake application	1	2		
	4. Wrong setting of points/turnouts				
	a. Wrong setting in relation to movement authority	6	1		
	b. Point switched to new position while point is occupied by train	9	2		
	5. Mishandling of train en route				
	a. Overspeeding				
	i) Too high speed through turnout in deviated position	1	6		
	ii) Too high speed elsewhere.	1	2		
	b. Other mishandling of train including driver caused SPAD	5	7	9	9
	6. Brake shoe or other object left under train	8	2		
	7. Other operational failure	4	2		
	U(nspecified)	6	2		

[9] In this table derailments are rounded to the nearest whole number, hence the reference total exceeds 500.

Table 14 Potential Maximum Benefit for Each Measure

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-1	Check rail in sharp curves (radius less than 250 metres)	Short - Medium	Check rails are normally installed at in rigid crossings in turnouts and as such are a requirement of most European countries. Additionally check rails may be used in curves, although to a lesser extent. They may act to prevent flange climbing which is a cause of derailments. Check rails may therefore be appropriate where other conditions (such as dry rails, inappropriately loaded wagons etc) have led to the possibility of flange climbing. Check rails are not effective against one specific failure cause listed in Table 13; rather they are engineered features that may help to prevent derailments in some cases. We cannot therefore say that check rails will mitigate derailments from a specific cause. In place of this, we have reviewed the accident database [7, Annex 1], and from this we estimate that check rails fitted to sharp curves could have reduced derailments in 5% of derailment cases (based on accident reports which state this, or extrapolation). We believe this benefit to be achievable by a wider application of this measure.	**25 (mainly LSD)**
P-2	Track and flange lubrication (installed on track)	Short - Medium	The situation here is similar to that presented in P-1 above. We further note that in many countries traction unit based lubrication is an applied measure (certainly in the major freight carrying countries) and this provides a degree of protection from dry rails on main lines. The major additional benefit from this measure is therefore likely to be at locations that are not frequently operated, hence sidetracks and lightly used locations. As a conservative assumption we have used the same 5% value derived for check rails. We believe this benefit to be achievable by a wider application of this measure.	**25 (mainly LSD)**
P-3 to P-5	Not used			
P-6	Geo radars	Short - Medium	High water content and other superstructure failures (conditions that geo radars are able to detect) are contributors to track geometry failures. However, Infrastructure Managers (IMs) currently have other means to detect both the causes and consequences of such events. Whilst geo radars could make for a more cost-efficient identification of these conditions, we cannot conclude that they would detect more cases than traditional means. We therefore cannot conclude that such measures will lead to a measureable or quantifiable decrease in freight train derailment frequency/elimination of existing causes.	**N/A**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-7	Rolling stock mounted equipment for monitoring of rail profile conditions.	Medium	Equipment for monitoring rail profile (and more recently track geometry) that can be mounted on commercial rolling stock is being introduced to the market. However, IMs currently have other means, including special wagons or trains, to detect both the causes and consequences of such events. Whilst new equipment could make for a more cost-efficient identification of these conditions. Notwithstanding this discussion, it could be feasible that such equipment is able to detect rail profile and track geometry defects that occur between scheduled inspection intervals. Also, by application of such equipment on rolling stock travelling on infrequently used lines (often the places where freight train derailments occur), which perhaps have a longer inspection interval, such equipment may offer some safety benefit. For the purposes of providing an approximate assessment, we have assumed that a small number of rail profile and track geometry defects may be detected sooner than they would have using existing means, and that this may reduce the reduce the number of derailments accordingly. What is clear is that in the majority of cases track geometry / rail profile defects are known about, and so the potential benefit is relatively small. For illustrative purposes, we have assumed that this benefit may lead to a 5% reduction in derailments caused by rail profile or track geometry defects (on the basis that they are detected sooner). This would equate to 5% of I2a, I2b and I3. In general we conclude that such measures offer a commercial rather than safety benefit and they will not be considered further.	**Ref:** **5% * 131 (80 LSD and 51 LSD) = 7** **Max:** **5% * 147 (91 LSD and 56 LSD) = 7**
P-8	Track circuit	Medium	Track circuits are installed for train detection purposes although in some cases they may detect rail ruptures which can be a cause of derailments. However, because track circuits are not relied upon for the detection of rail ruptures we cannot suggest or propose that they are installed for this purpose. We therefore cannot conclude that such measures will lead to a measureable or quantifiable decrease in freight train derailment frequency/elimination of existing causes. **Note:** It may be prudent, in cases where track circuits are to be removed, for the IM to take into account this loss of secondary functionality.	**N/A**
P-9	Interlocking of points operation while track is occupied	Medium	Our accident analysis [7, Annex 1] indicates that approximately 2% to 3% of derailments are caused by points that are moved under a freight train. This is a phenomenon largely associated with old infrastructure in particular entries and exits from marshalling yards. This measure is likely to be effective against cause O4b, which is predicted to lead to 11 derailments, based on our risk model outputs (9 LSD, 2 HSD) We believe this benefit to be achievable by a wider application of this measure.	**11 (9 LSD and 2 HSD)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-10 P-12	Hot axle box (hot bearing) detectors Hot wheel and hot brake detectors	Medium	Theoretically the potential risk reduction associated with this measure is to eliminate all derailments that are caused by hot axle box conditions. (However, for this to be the case such devices need to be installed at a very high density and would need a side track for trains to stop.) These are coded RA1ai which our risk model predicts to result in 14 LSD and 49 HSD. In addition to the detection of hot axle boxes discussed above, hot wheel and brake detectors may help to prevent wheel failures (RS1bi and RS1bii), where these are caused by excessive heat. We do not have a root cause breakdown for wheel failures; however we have assumed that 50% result from this cause. Our estimate here is 50% * 33 ~ 17 (made up of 4 LSD and 13 HSD). This measure is already applied widely throughout the European Community, thereby limiting the potential benefit somewhat.	**63 (14 LSD and 49 HSD)** **17 (4 LSD and 13 HSD)**
P-11	Acoustic bearing monitoring equipment	Medium	As P-10. The European Community has invested heavily in measures such as P-10 and others to protect against hot axle box caused derailments. In this case, this limits the potential benefit that may be achieved by this measure.	**63 (14 LSD and 49 HSD)**
P-13	Wheel load and wheel impact load detectors	Medium	These devices potentially address derailment causes as follows: • HAB and axle journal rupture: RS1ai (as P-10) • Spring and suspension failures: RS2b, (15 LSD and 6 HSD) • Wheel flats that can cause rail breaks: I2a and I2b (combined total 13 LSD and 5 HSD) – we have assumed that rail breaks are caused on 50% of occasions by this cause; hence values of 6 LSD and 3 HSD are used. • Overloading and skew loading: O2a and O2b (16 LSD and 5 HSD) The European Community has invested heavily in measures such as P-10 and others to protect against hot axle box caused derailments. In this case, this limits the potential benefit that may be achieved by this measure.	**Ref:** **114 (51 LSD and 63 HSD)** **Max:** **120 (55 LSD and 65 HSD)**
P-14	Dragging object and derailment detectors	Not considered here – dragging objects, in the form of underframe equipment are considered elsewhere. Derailment detectors are considered as M1.		
P-15	Bogie performance monitoring/Bogie lateral instability detection (bogie hunting)	Medium	These are likely to be effective against incorrect wheel profile (RS1biii) and skew loading (O2bi and O2bii). Our risk model predicts contributions of 21 LSD and 7 HSD from these causes. We believe this benefit to be achievable by a wider application of this measure.	**Ref:** **28 (21 LSD and 7 HSD)** **Max:** **47 (34 LSD and 13 HSD)**
P-16	Wheel profile measurement system / Wheel profile monitoring unit	Medium	Incorrect wheel profile (RS1biii) is likely to cause derailments in combination with track geometry failures. Our risk model predicts a contribution from these conditions, amounting to 7 LSD and 3 HSD. We believe this benefit to be achievable by a wider application of this measure.	**Ref:** **10 (7 LSD and 3 HSD)** **Max:** **23 (16 LSD and 7 HSD)**
P-17	Not used			

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-18	Sufficient availability of maintenance resources (for Infrastructure maintenance)	Short	This is principally an organisational / funding issue. In theory all infrastructure failures could be significantly reduced through the application of greater resources, in particular to side tracks at stations and other locations where maintenance is perhaps less stringent. In particular track geometry failures that we have recorded under the category I3 fall into this category. The total contribution of all other causes is 67 LSD and 46 HSD.	**Ref:** **113 (67 LSD and 46 LSD)** **Max:** **129 (78 LSD and 51 LSD)**
P-19	Clearance of obstructions from flange groove (particularly at level crossings)	Short	This is a potential cause of derailment, although we have positively identified only one derailment attributable to this cause. In general we do not consider this benefit to be achievable without significant resource.	**Less than 5 derailment per year (no speed allocation)**
P-20	Ultrasonic rail inspection	Short	Rail failures (I2a and I2b), which this measure is aimed at detecting, contribute 13 LSD and 5 HSD as calculated from our risk model. This measure is already applied widely throughout the European Community, thereby limiting the potential benefit somewhat.	**18 (13 LSD and 5 HSD)**
P-21	Track geometry measurement of all tracks	Short	As P-18.	**Ref:** **113 (67 LSD and 46 LSD)** **Max:** **129 (78 LSD and 51 LSD)**
P-22	EU-wide intervention/action limits for track twist	Medium	Track twist is a major contributor to track geometry caused derailments. Further, there is an increasing use of single axle wagons with a very long wheel base which makes the derailment risk in twisted track even larger, and with an increased containerization the control of skew loading is more of a challenge. Both the above make it more important to have good control of track twist geometry aspects. We have noted also that accidents occur within the stated safety limit for this parameter. This measure would require the introduction of a stricter safety limit together with guidance regarding intervention limits for track twist. However, it is clear from our commentary in P-18 and P-21 that there is still a challenge regarding adherence to existing limits, hence a new – presumably stricter – limit would place additional burden on maintenance resources. European wide intervention and action limits should be considered, otherwise track twist could be an increasing problem due to increased use of long wheelbase wagons for specific purposes. From risk model we predict 26 LSD and 8 HSD are attributable to this cause (I3a).	**Ref:** **34 (26 LSD and 8 HSD)** **Max:** **50 (37 LSD and 13 HSD)**
P-23	EU-wide intervention/action limits for track gauge variations	Medium	As P-22. From our risk model we predict 25 LSD and 11 HSD from this cause (I3e).	**36 (25 LSD and 11 HSD)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-24	EU-wide intervention/action limits for cant variations	Medium	As P-22 From our risk model we predict 4 LSD and 9 HSD from this cause (I3b).	**13 (4 LSD and 9 HSD)**
P-25	EU-wide intervention/action limits for height variations and cyclic tops	Medium		
P-26	Flange lubrication - locomotives		The friction at the contact area between the wheel flanges of railway vehicles and the rails determine wheel and rail wear and the driving effort / energy required. Flange lubrication (on locomotives or track) is applied to reduce such wheel and rail wear (and hence maintenance costs), to reduce noise and also to reduce energy consumption. The main potential benefit from a safety point of view is lubrication in curves (see P-2). However, locomotive based lubrication is not likely to be as effective as fixed track based lubrication systems. Whereas track based lubrication can be fitted and ensure effective lubrication at specific locations, locomotive lubrication is applied as a function of speed and other parameters. In lightly used side tracks (which may be operated at low speed) locomotive based lubrication systems may not deposit sufficient (or indeed any) lubricant and therefore be much less effective than other solutions. As a derailment prevention measure we have assumed that this system may be, as a maximum, 50% as effective as track based alternatives. This measure will not be assessed further by this project.	**50% * 25 (mainly LSD) = 13**
P-27	Replace composite wheels with monoblock wheels	Medium	As can be seen from Figure 7, composite wheels contribute to derailments approximately twice as often as monoblock wheels. However, it is not clear the proportion of each wheel type in existence, and we have no reliable data to help us estimate these proportions. If we assume a 50/50 split then the potential benefit is equal to a halving of the number of derailments caused by failure of composite wheels (0.5 * 25 ~ 13). Although this could be used as a working assumption, we propose not to consider this further, because: • We already address many technical measures aimed at addressing the causes of wheel failures • A probable cause of composite wheel failures is the more complex maintenance programme, which is addressed implicitly by measures such as P-36 and F-2, etc • The potential benefit are likely to be relatively small (compared to the costs, unless done on an opportunistic basis)	**N/A**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-28	Replace metal roller cages in axle bearings by polyamide roller cages.	Medium	The potential benefit is of a reduction in hot axle box failures and derailments, P-10. (This is likely to be integrated with the maintenance cycle of axles / wheel sets and be implemented on an opportunistic basis. Therefore it would not be achieved within the short term, although would be at minimal cost.) This measure is partly implemented at present thereby limiting the maximum future potential somewhat. We are not aware of any authoritative research regarding the safety differential between roller cages of different materials (brass, polyamide, stainless steel); although we are aware that many RUs are replacing brass for polyamide on an opportunistic basis. (Internet information indicates that bearings with polyamide roller cages are more robust to vibrations.)	**63 (14 LSD and 49 HSD)**
P-29	Replace existing axles for stronger axles or axles with improved material properties with regard to crack initiation and crack propagation	Medium	Axle ruptures (RS1aii and RS1aiii) account for about 5 LSD and 18 HSD. The use of stronger materials has a maximum potential for reducing the quantity of derailments in this category A European wide research and development program is currently ongoing, EURAXLES with 23 partners. We do not feel that this project should comment on this on-going work programme,	**23 (5 LSD and 18 HSD)**
P-30	Increase the use of central couplers between wagons in fixed whole train operation	Long	The application scope for a measure of this type is probably currently limited to bulk material block trains composed of uniform standard wagons where it can be beneficial in many ways. However, it is noted that the White Paper on Transport recommends that (for reasons other than safety) *"New rolling stock with silent brakes and automatic couplings should gradually be introduced."* If an automatic central coupler with sufficient strength for rail freight operations can be identified then a possible reduction of derailment frequency may be an added benefit, see also our report [6]. In terms of potential safety benefit (if applied to freight train in general), the introduction of central couplers may reduce the likelihood of buffer locking derailments and also of derailments associated with compressive forces under braking. Buffer locking is a contributory cause in a number of derailment accidents. The data used for our risk model indicates at least 5% of derailments have this as a contributory cause. Train compression corresponds to failures O1a from our risk model which contributes 11 derailments, and it is a contributory in at least the same number. Because fitting to bulk material block trains worked by single operators on set routes is not consistent with an interoperable railway and because the alternative of fitting to a large part of the freight fleet comes at massive cost (and is probably a long term measures), we have not considered this measure further.	**47 (no speed allocation)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-31	Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis.	Medium	Bogie wagons offer better riding qualities that are more tolerant to sub-standard track conditions, thereby having a lower derailment rate. It is a measure generally applied for heavy bulk transport applications. For light weight goods and swap bodies this is not the case. For such operations, single wagons based on single axles allow a longer loading basis to be obtained at minimum weight and cost. Whilst this is advantageous commercially it is not beneficial with respect to minimising derailment risk (particularly in relation to track twist). It may be appropriate to assume that from a derailment safety perspective, many track twist derailments may be avoided. Whilst the exact number of avoided derailments cannot be precisely estimated, we have assumed that all track twist defects (contributing to combinational cause derailments) may be eliminated, and 50% of the remaining track twist single cause derailments may be eliminated. (For these assumptions to apply as stated, the majority of the freight fleet would need to have this measure applied.) Notwithstanding this, we have discounted this measure from further consideration, because: • The maximum potential benefit is relatively small compared to the cost of implementing the measure • It includes possibly lost business costs and other commercial issues which we are not considering and therefore the cost versus benefit assessment will be missing some important information	**Ref:** **24 (18 LSD and 6 HSD)** **Max:** **40 (29 LSD and 11 HSD)**
P-32	Install disc brakes instead of wheel tread brakes for new wagons.	Medium	The main motivation for this measure is likely to be in relation to achieving the Noise TSI. However, it may lead to less heat activation of wheels with a corresponding reduction in wheel failures. In that respect, the same reduction claimed for P12 is applicable here. This measure is already applied within the European Community (but to a limited extent by present rolling stock), although limiting the potential benefit somewhat.	**17 (4 LSD and 13 HSD**
P-33	Rolling stock design for track twists	Long	A requirement to have more fault tolerant rolling stock design could be applied for new wagon purchases. The benefits of this measure however may not be realised until the long term, governed by the time (and investments) necessary for the renewal of the targeted wagon scope. In terms of potential derailment safety benefit, we apply the same assumptions as discussed under P-31. (For these assumptions to apply as stated, the majority of the freight fleet would need to have this measure applied.) Whilst we have estimated a potential maximum risk reduction potential, this measure is not to be considered further in this project.	**Ref:** **24 (18 LSD and 6 HSD)** **Max:** **40 (29 LSD and 11 HSD)**
P-34	Secure brake gear underframe	Medium	This measure would address RS5, which we predict to result in 5 LSD and 2 HSD This measure is already applied within the European Community, thereby limiting the potential benefit somewhat.	**7 (5 LSD and 2 HSD)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-35	Regular greasing and checks of rolling stock buffers.	Short	Measures of this type could be introduced quickly, in the form or recommendation or other formal notification. These could be applied rapidly by RUs, Entity in Charge of Maintenance (ECMs) etc. This may involve greasing of the mechanical springs inside buffers and of the external buffer plates. The potential safety benefit is prevention of buffers becoming loose and / or falling off. This is a small contributor to freight train derailments, contributing no more than 1% of derailment causes. Renewed emphasis of this measure has the potential to reduce this contributory cause.	**Less than 5 (no speed allocation)**
P-36	Wheel set integrity inspection (ultrasonic) programs.	Short	Wheel sets failures are a major contributor to freight train derailments. They account for RS1a and RS1b categories with a contribution of 33 LSD and 96 HSD. This measure is already applied very widely, and other measures such as P-10 are also in place against these failures. This will limit the achievable risk reduction significantly.	**Ref:** **129 (33 LSD and 96 HSD)** **Max:** **142 (42 LSD and 100 HSD)**
P-37	Derating of allowable axle loads	Short	The Agency Joint Sector Support Group (JSSG) has identified an increase in allowable axle loads has been allowed nationally and has made a limiting recommendation. In this contest, axle ruptures (RS1aii and RS1aiii) account for about 5 LSD and 18 HSD. We do not feel this project should comment further on this on-going work programme.	**23 (5 LSD and 18 HSD)**
P-38	EVIC (European Visual Inspection Catalogue)-based inspection of freight train rolling stock axles	Short	The European Visual Inspection Catalogue for Axle Inspections is being applied on a voluntary basis and we have identified 23 countries that are using this programme. From our risk model, failures that may be avoided are RS1a and RS1b (with the likely exception of hot axle box conditions). These account for 19 LSD and 47 HSD. We do not feel this project should comment further on this on-going work programme.	**Ref:** **66 (19 LSD and 47 HSD)** **Max:** **79 (28 LSD and 51 HSD)**
P-39	Double check and signing of safety-classified maintenance operations	Short	There are a small number of accidents in our database that could be attributed to this cause, although this is not always stated. As a conservative estimate we have used a value of 5 per year Benefits are limited by the relatively small number of relevant derailments.	**5 (no speed allocation**
P-40	Qualified and registered person responsible for loading	Medium	Loading failures are calculated by item 02 within our risk model. They account for 19 LSD and 13 HSD. In practice this measure is widely applied (through the use of internal training or external qualification) thereby limiting the potential benefit somewhat. Extensions to this may include the use of checklists or other sign-off systems to ensure the process is applied correctly. We consider there to be some potential for realising some of these benefits.	**Ref:** **32 (19 LSD and 13 HSD)** **Max:** **38 (23 LSD and 15 HSD)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-41	Locomotive and first wagons of long freight trains in brake position G	Short	Train compression under braking is a derailment cause or contributory cause (especially with trains comprising loaded and empty wagons). In terms of direct causes, this corresponds to failures O1a from our risk model which contributes 8 LSD and 3 HSD. Additionally it is a contributory in at least the same number. Some forms of driver mishandling of the train may also be partly mitigated by this measure, hence O5b contributing 5 LSD and 7 HSD. The requirement for the use of the G position is in place in many countries, although it is apparent that it is not always applied.	**Ref:** **34 ((8 LSD and 3 HSD) * 2) + (5 LSD and 7 HSD)** **Max:** **40 ((8 LSD and 3 HSD) * 2) + (9 LSD and 9 HSD)**
P-42	Limitations on use of brake action in difficult track geometry	Short	As P-41	**Ref:** **34 ((8 LSD and 3 HSD) * 2) + (5 LSD and 7 HSD)** **Max:** **40 ((8 LSD and 3 HSD) * 2) + (9 LSD and 9 HSD)**
P-43	Dynamic brake test on the route	Medium	Risk model 03b and O3c applies which suggests 4 LSD and 12 HSD may results from failure to test brakes correctly. Such functionality could be applied to the new ETCS and ERTMS train control systems,	**16 (4 LSD and 12 HSD)**
P-44	Saw tooth braking to limit heat exposure to wheels	Short	We have identified no such derailments that are attributable to this cause, although heat activation of wheels is a potential cause of wheel failure. However, we consider this measure to be applied where it is required and will not consider it further.	**N/A**
P-45	Initiation of braking or speed reduction prior to passing signal showing reduced speed	Short	We have identified one derailment directly attributable to this cause. We consider this to be part of existing driver practice and will not consider it further.	**N/A**
P-46	Not allowing traffic controllers and drivers to override detector alarms	Short	Alarm management is an important issue, and increasingly so should more equipment be installed. It is also apparent that a number of derailments occur after passing a hot axle box which in some cases has identified the condition. We have made a conservative assumption that failures in this area contribute about to 15 derailments per year. The use of newer equipment with better alarm handling and lower false alarm rate is likely to secure benefits.	**15 (no speed allocation)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-47	Wagons equipped with a balance to detect overload in visual inspection.	Medium	Loading failures are calculated by item 02 within our risk model. They account for 19 LSD and 13 HSD. This specific measure was advised as a local solution used by one RU. The use of this measure has some potential for improving the current situation, although it is unlikely that the maximum potential can be realised.	**Ref:** **32 (19 LSD and 13 HSD)** **Max:** **38 (23 LSD and 15 HSD)**
F-1	End of train device (brakes)	Medium	This measure is principally indented to speed up brake application in long trains, give more reliable brake application in emergencies as well as reduce train compression when braking long trains as the brakes are applied both from the front and rear of the train. If train lengths are increased this may become a more significant issue for the European railways than it is at the moment. But is not seen as an important element today and has been eliminated.	**N/A**
F-2	Awareness program and improved maintenance for Rolling Stock	Short	This is an issue relating to the safety management systems and culture of RU / keepers / wagon owners as well as the supervision of this by National Safety Authorities (NSAs). The identification of key maintenance issues that have led to derailment could facilitate this process at a national level. Excluding wheelset maintenance which is covered at various places above, other benefits include those quantified at RS2, RS3, RS4 and RS5. These account for approximately 37 LSD and 16 HSD The use of this measure has some potential for improving the current situation, although it is unlikely that the maximum potential can be realised.	**53 (37 LSD and 16 HSD)**
F-3	Heat sensitive material to reveal hot axle box conditions	Short	The effectiveness of this measure is limited by the chance that an indication provided by this measure can be detected in time for a derailment to be prevented. This measure may be effective for routes in which a HABD is not installed or where a HAB alarm has been raised – in this case providing assistance to the driver in identifying the defective axle box. In addition, it may be able to detect cases where a HAB is present, but below the detection threshold of HABDs. The effectiveness of this measure depends on the speed in which a HAB develops, which is variable and is based on train speed, track and wheel quality, wagon loading conditions amongst others. Of course this measure could be effective against most situations if wagons were inspected frequently (perhaps every 40 km) whilst on a journey. Such an inspection requirement however this is not feasible; our assumption is that a measure of this type may have a maximum risk reduction potential possibly 25% of the total number of HAB caused derailments. Given the significant investment in technical and other measures to address this problem, we cannot foresee a measure of this type being of significant benefit and it will not be considered further.	**25% * 63 (14 LSD and 49 HSD) = 16**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
F-4	Machine Vision Devices	Medium	3-D image capture systems are used in at least the USA and China, and at some test sites within Europe. They may detect loading errors, open hatches (which are the cause of a small number of derailments) and may be equipped with other modules including hot axle box and other heat sensing devices. They are also used to detect profile violations and fires, although these are not direct derailment causes. They may also detect some suspension failures. Loading failures are calculated by item 02 within our risk model. They account for 19 LSD and 13 HSD. Suspension failures are assessed (RS2b) to account for 15 LSD and 6 HSD	**Ref:** **53 (34 LSD and 19 HSD)** **Max:** **59 (38 LSD and 21 HSD)**
F-5	Telematics	Medium	Improved telematics solutions could enhance the capture of information and aid the maintenance function by providing better and more timely information provision. To be of use however these systems require trackside (or on-board) equipment able to capture this information. We conclude that this is not a measure in its own right and are not going to consider it further.	**N/A**
F-6	Anti-lock devices	Medium	These devices may reduce the instance of wheel locking under braking or other fault conditions, thereby potentially reducing the incidence of wheel flats. Wheel flats that can cause rail breaks: I2a and I2b (combined total 13 LSD and 5 HSD) – we have assumed that rail breaks are caused on 50% of occasions by this cause; hence values of 7 LSD and 3 HSD are used. Other potential benefits may include improved axle fatigue life due to less fatigue, although this potential improvement is not readily quantifiable. Anti-lock devices may help to prevent wheel failures (RS1bi and RS1bii), where these are caused by excessive heat. We do not have a root cause breakdown for wheel failures; however we have assumed that 50% result from this cause. Our estimate here is 50% * 33 = 17 (made up of 4 LSD and 13 HSD).	**27 (11 LSD and 16 HSD)**
F-7	Sliding wheel detectors.	Medium	These systems detect wheels that are not rotating correctly and raise an alarm, with similar benefits to the antilock device for freight wagons described above.	**27 (11 LSD and 16 HSD)**
F-8	Handbrake interlock.	Medium	This would prevent a freight train moving off with the handbrake applied and therefore reduce the likelihood of subsequent issues like wheel flats, overheating and track damage accounting for 7 LSD and 3 HSD as F-6. Handbrake interlocks may help to prevent wheel failures (RS1bi and RS1bii), where these are caused by excessive heat. We do not have a root cause breakdown for wheel failures; however we have assumed that 50% result from this cause. Our estimate here is 50% * 33 = 18 (made up of 4 LSD and 13 HSD). This however has to factored by the amount of times where the cause is a handbrake that is applied. For the purposes of this assessment we have used a conservative assessment that this is the case 50% of occasions.	**19 (9 LSD + 10 HSD)**

6.0 Derailment Scenarios and Consequences

6.1 Analysis of Derailment Consequences

6.1.1 Factors Affecting Derailment Consequences

In terms of consequences of a freight train derailment a number of factors apply. These include but are not limited to:

- The presence of controls to reduce (mitigate) the consequences. These may include: technical measures such as physical protection of tank wagons, operational measures such as speed restrictions, and "harmless infrastructure" (i.e. absence of sharp objects), etc[10].
- The type of freight being carried.
- Route selection to separate passenger and freight traffic or to avoid stations and places with large numbers of people and other sensitive locations, etc.
- Layout and geography of the infrastructure and surrounding environment.

"Luck" and circumstance on the day may also contribute to one accident having few consequences, whereas a very similar accident can result in very significant losses.

6.1.2 Location of Derailment and Train Type

Our first observation when studying accident reports [7, Annex 1] was the predominance of freight train derailments that occur in stations[11]. In fact about 50% of accidents we have studied occur at these locations. This is an important parameter to consider because stations are potentially densely populated areas which of course has a bearing on freight train derailment impacts. We therefore started our analysis by considering location, and have considered the following:

- Stations
- Urban densely populated areas outside stations
- Countryside

At this point of our analysis we identified that the next factor to influence the impacts was the type of freight train that has been derailed, specifically if it involved dangerous goods. This is linked directly to the preceding discussion because the derailment of a dangerous goods train in a station has potentially more severe impacts than elsewhere.

6.1.3 Type of Derailment

Our next consideration relates to the type of derailment, and whether it is immediately severe (defined as a derailment with a mechanical impact that may cause a dangerous goods leak or cargo spill) or not. An immediately severe derailment will normally involve a wagon overturning, or being unable to move therefore confining the incident to the derailment location.

In this case, there is a high likelihood that the contents will be lost, which in the case of dangerous goods may have immediate consequences to people and the environment. This is modelled within our event tree as:

- Contents spill / load lost.

[10] Note that this part of the project is only required to assess mitigation measures related to the detection of a derailment – other mitigation measures are not considered further by this work.
[11] We allocated a derailment to a location based on the location stated in the accident report.

As an alternative, the derailment may not be immediately severe. In this case the train may continue if the driver (or other observer) has not identified the situation. Should the train continue (without detection of the initial derailment) we have assumed that a severe derailment[12] will occur at some time in the future. Conversely, if the initial non-severe derailment is detected then the driver has an opportunity to bring the train to a safe stop.

We have discussed here the branches on our event trees as follows:

- Derailment immediately severe?
- Is partial derailment detected?
- Partially derailed train brought to a safe stop?

The discussions presented above deal with the direct outcomes of the initial derailment. The final part of our analysis considers the possibility of secondary outcomes and impacts.

6.1.4 Secondary Outcomes

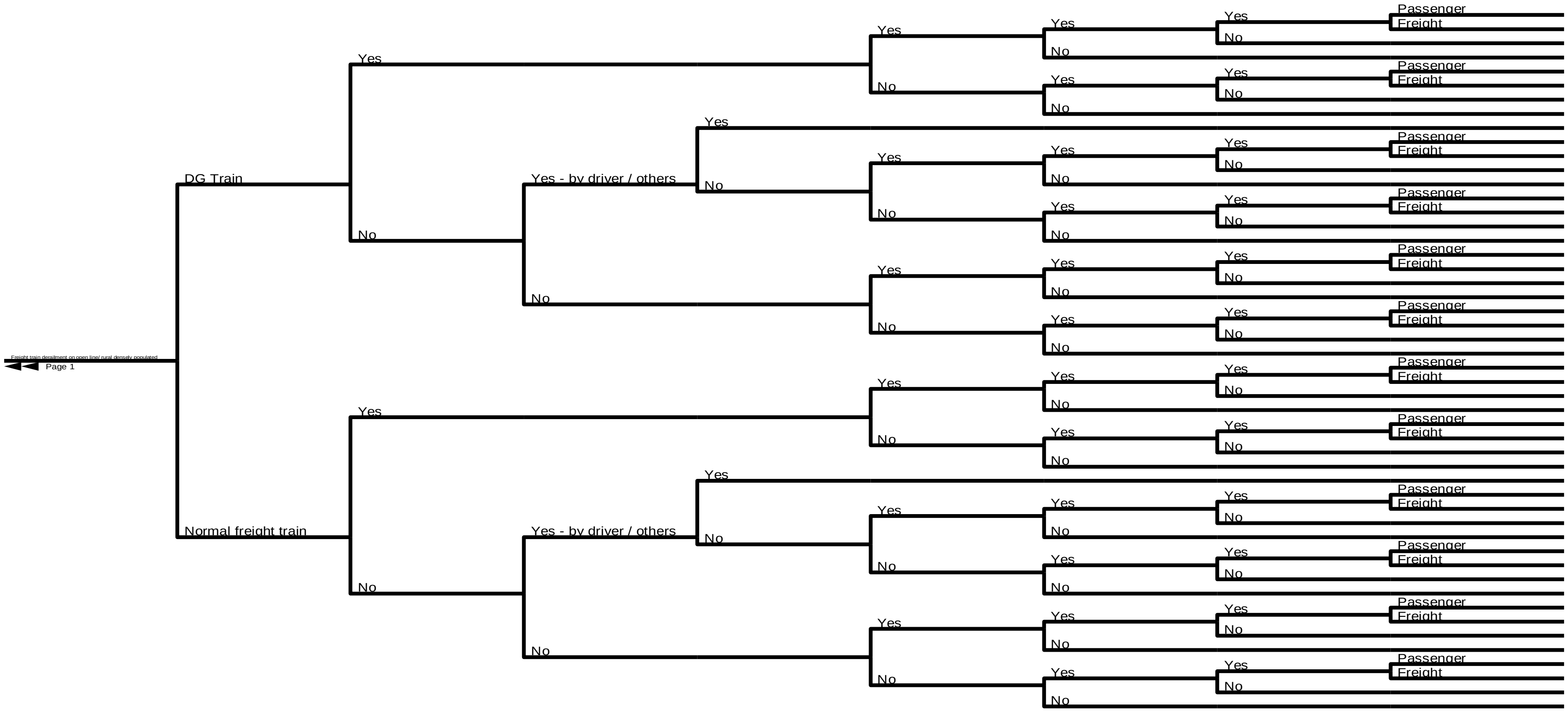
An important consideration further influencing the outcome and impacts of a freight train derailment are:

- If a wagon or wagon load fouls an adjacent line.
- If the freight train derailment is then compounded by a secondary event, namely a collision with an approaching passenger or second freight train.

We show these in a logical structure using an event tree.

[12] We note that it may be possible for an initially non-severe derailment to occur and for the train to continue and re-rail; we have not modelled these cases due to their rarity and problems with data capture for such events.

Figure 9 Freight Train Derailment Partial Event Tree



6.2 Event Tree Model Data

In total there are 6 event trees; one for countryside (meaning locations outside main population areas); station (meaning railway stations); urban (meaning locations with the potential for a high population density). Each has a high and low speed variant.

Data used to populate the scenario models are presented in Table 15 and Table 16.

Table 15 Data Table for Low Speed Derailment

Item	Variant	Data	Description	Data Source
1. Derailment location	Station	71%	71% of LS derailments occur in stations. The method used was to identify the speed and location of each derailment, allowing the appropriate percentages to be calculated.	DNV Accident Analysis [7, Annex 1].
	Urban	3%	29% of LS derailments occur at urban locations. To calculate this data we apportioned the 29% of LSD that occur outside station between urban and countryside. We made a conservative assumption 10% of the time these occur in densely populated urban areas. Hence ~ 3%. (Our modelling therefore assumes that 74% of freight train derailments occur in either stations or urban, i.e. heavily populated areas.)	DNV Accident Analysis [7, Annex 1]
	Countryside	26%	26% of LS derailments occur outside stations. Calculation as above.	DNV Accident Analysis [7, Annex 1]
2. DG train[13]?	None	66%	The proportion of trains carrying at least one DG wagon. The probability of the derailed wagon carrying dangerous goods is addressed in the impact modelling, and uses the same assumptions regarding trains running in complete and mixed configurations as applied by the Agency [1]	Agency Impact Analysis, [1]. A review of freight transport data indicated the original value to be valid.
3. Immediately severe?	None	26%	Proportion of LS freight train derailments that are immediately severe calculated by summing the number of LSD that were immediately severe. (Note to check this data item against the previous Agency work, we have summed the total number of derailments that were immediately severe (i.e. LSD and HSD). This reveals a combined total of 32% of derailments are immediately severe. This compares closely with the Agency figure of 33% for the same parameter.)	DNV Accident Analysis [7, Annex 1] (and compared with Agency Impact Analysis, [1]).

[13] A DG train is one which contains at least one wagon carrying DG. It is possible that a derailment of a DG train does not involve a DG wagon.

Item	Variant	Data	Description	Data Source
4. Is partial derailment detected?	None	70%	This data item is conditional on the outcome of 3 and is the percentage of partially derailed freight trains that are detected (before the consequences become severe).	Agency Impact Analysis, [1].
5. Is the train brought to a safe stop?	None	96%	This data item is conditional on the outcome of 4 and is the percentage of detected partially derailed freight trains that are brought to a safe stop. This differs from the previous Agency analysis, [1], which assumed all such outcomes would be safely managed. We derived this information by identifying cases where a initial derailment had been detected, but the outcome was still a severe derailment.	DNV Accident Analysis [7, Annex 1]
6. Contents / load spill?	None	30%	This data item is conditional on the outcome of 5. There is limited to support an analysis based on accident data, so we have chosen to apply conservative assumptions to this field, as follows: • Probability of wagon being empty – 50% (this is a contributing factor to freight train derailments, where empty wagons can often increase the likelihood of a derailment). • Where not empty, we have assumed a DG release 60% of the time for a LS severe derailment • Value applied = 60% * 50% = 30%	Conservative assumption, supported by DNV Accident Analysis [7, Annex 1] (items 6, 7 and 8)

Item	Variant	Data	Description	Data Source
7. Foul adjacent line?	None	38%	This data item is conditional on the outcome of 6. There is limited to support an analysis based on accident data, so we have chosen to apply conservative assumptions to this field, as follows: • Probability of derailment on lines where there is other traffic; 50%. (Some derailments are on single line or lines where there is little traffic.) • Derailment infringes envelope of trains running on adjacent line: 75%. Value applied = 75% * 50% = 38% A small number of accidents of this type are included in our accident database, with a smaller number that lead to any consequences of significance.	
8. Secondary collision?	None	1%	This data item is conditional on the outcome of 7. Factors that are relevant here are traffic volume, communication systems, time of day, freight routing etc. We have applied a factor of 1% based on an analysis of accident data. The combination of the factors described above when used in our model result in a predicted event of this type about once per year, which correlates with the accident data we have studied.	
9. Passenger train hits derailed freight wagon	None	50%	We have applied an even distribution between a passenger and freight train being involved in a secondary collision.	DNV Accident Analysis [7, Annex 1]

Table 16 Data Table for High Speed Derailment

Item	Variant	Data	Description	Data Source
1. Derailment location	Station	33%	33% of LS derailments occur in stations. The method used was to identify the speed and location of each derailment, allowing the appropriate percentages to be calculated.	DNV Accident Analysis [7, Annex 1]
	Urban	7%	67% of LS derailments occur outside stations. Our assumption is that 10% of the time these occur in densely populated areas. Calculation as LSD.	DNV Accident Analysis [7, Annex 1]
	Countryside	60%	67% of LS derailments occur outside stations. Our assumption is that 90% of the time these occur in countryside or sparsely populated areas. Calculation as LSD.	DNV Accident Analysis [7, Annex 1]
2. DG train?	None	66%	No change from LS table.	
3. Immediately severe?	None	49%	Proportion of HS freight train derailments that are immediately severe.	DNV Accident Analysis [7, Annex 1]
4. Is partial derailment detected?	None	70%	No change from LS table.	
5. Is the train brought to a safe stop?	None	96%	No change from LS table.	
6. Contents / load spill?	None	40%	This data item is conditional on the outcome of 5. There is limited to support an analysis based on accident data, so we have chosen to apply conservative assumptions to this field, as follows: • Probability of wagon being empty – 50% (this is a contributing factor to freight train derailments, where empty wagons can often increase the likelihood of a derailment). • Where not empty, we have assumed a DG release 80% of the time for a LS severe derailment • Value applied = 80% * 50% = 40%	
7. Foul adjacent line?	None	38%	No change from LS table.	
8. Secondary collision?	None	1%	No change from LS table.	

Item	Variant	Data	Description	Data Source
9. Passenger train hits derailed freight wagon	None	50%	No change from LS table.	

6.3 Consequence Model Usage, Summary and Outputs

6.3.1 Model Outputs

Interrogation of the event tree model reveals the end consequences. Considering the first branch shown in Figure 9 the outcome is:

- DG train derailment
- Immediately severe
- Loss of containment
- Fouls adjacent line
- Hit by train on adjacent line
- Train on adjacent line is a passenger train

In total there are over 100 potential outcomes (when allowing for different speed and location). However these simplify to a smaller sub-set of identical consequences, which are:

Table 17 Range of Possible Event Tree Outcomes

Consequence	Description
SD1	Severe derailment occurring immediately, contents spilling, fouling adjacent line and affecting passenger train on adjacent line
SD2	Severe derailment occurring immediately, contents spilling, fouling adjacent line and affecting freight train on adjacent line
SD3	Severe derailment occurring immediately, contents spilling, fouling adjacent line but no affect on adjacent line
SD4	Severe derailment occurring immediately, contents spilling but no affect on adjacent line
SD5	Severe derailment occurring immediately , fouling adjacent line and affecting passenger train on adjacent line
SD6	Severe derailment occurring immediately , fouling adjacent line and affecting freight train on adjacent line
SD7	Severe derailment occurring immediately , fouling adjacent line but no affect on adjacent line
SD8	Severe derailment occurring immediately but no contents spill or no affect on adjacent line
SD9	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), contents spilling, fouling adjacent line and affecting passenger train on adjacent line
SD10	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), contents spilling, fouling adjacent line and affecting freight train on adjacent line
SD11	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), contents spilling, fouling adjacent line but no affect on adjacent line
SD12	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), contents spilling, but no affect on adjacent line
SD13	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), no contents spilling, fouling adjacent line and affecting passenger train on adjacent line
SD14	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), no contents spilling, fouling adjacent line and affecting freight train on adjacent line
SD15	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), no contents spilling, fouling adjacent line but no affect on adjacent line
SD16	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected) but no contents spill or affect on adjacent line
NSD1	Number of non severe derailments per year. Must be without contents spill and no affect on adjacent line

6.3.2 Model Predictions

Based on the assumptions and data reported, and also that dangerous goods trains may contain only DG tank wagons, or combination of DG tanks / wagons and normal freight, our model predicts the following outcomes[14]:

- Immediately severe derailment involving a DG wagon; 19 out of 500 derailments ~ 4%.
- Not immediately severe derailment involving a DG wagon; about 11out of 500 derailments ~ 2%.
- Immediately severe derailment involving a normal freight wagon; about 165 out of 500 derailments ~ 33%.
- Not immediately severe derailment involving a normal freight wagon; about 93 out of 500 derailments ~ 19%.
- Derailments detected (by staff or others) and train brought to a safe stop; about 204 out of 500 ~ 41%.
- Derailments detected (by staff or others) but not brought to a safe stop; about 8 out of 500 ~ 2%.

The model is principally to be used, in conjunction with the frequency model, to test the potential effectiveness of the measures we have identified.

With regard to the consequence model described in this section, one particular measure is to be specifically tested, and that is measure number M-1. Measures in this category are wagon devices to detect derailment and either apply train brakes automatically (M-1a) or inform the driver of the suspected derailment (M-1b).

Considering these measures, the following model output parameters are important:

- Our risk model predicts 104 freight train derailments (comprising 93 normal freight wagon derailments and 11 derailments involving DG wagons) that are not immediately severe and are not detected. Wagon devices of type M-1 have the potential to bring these trains to a safe stop.
- The maximum potential benefit of such devices is therefore to prevent 104 derailments from becoming severe (assuming each and every wagon were to be fitted with devices of this type). However, we also know that some identified drawbacks must be considered for assessing the efficiency of this measure. These will be considered in the following study tasks.

Note these values differ slightly compared with the published report [7] as a result of minor data and modelling updates.

[14] These add to 101% because of rounding errors

7.0 Summary of Consequences (and Impacts)[15]

7.1 Impact Types

The event tree presented and described leads to the following potential impacts:

1. Infrastructure damage. Some degree of track damage will occur following a derailment. The extent of this depends on the geography and location of the derailment and also the severity and length of time taken for the train to stop.
2. Rolling Stock damage. Some degree of rolling stock damage will occur following a derailment. The extent of this depends on the geography and location of the derailment and also the severity and length of time taken for the train to stop.
3. Operational disruption. Some degree of operational disruption will occur following a derailment. The extent of this depends on the geography and location of the derailment and also the severity and length of time taken for the train to stop.
4. Injury or loss of life of the train driver as a direct result of the accident.
5. Loss of containment (for Dangerous Goods). This outcome has two components: the potential for loss of life extending beyond the train driver and possibly affecting the wider population); environmental contamination. We consider the case of freight trains that carry only dangerous goods and those where dangerous goods form only part of the cargo.
6. Secondary event, involving a second train colliding with the derailed train. (From our own analysis [7, Annex 1, accident numbers SE-4, SE-6 and DE-29 apply] there is evidence of such events occurring).

For categories 1 to 5 discussed above, the monetised impacts as used by the Agency [1] are to be re-used. Additional impacts are to be assessed for item 6 above.

There are other consequence affecting factors that have not been specifically modelled. These include, but are not limited to:

1. Rolling down an embankment and involving the general public.
2. Derailing in such a way as to infringe non-rail traffic (principally road traffic).
3. Derailments in tunnels.

We have not modelled these because there are no data to suggest derailments at these locations are any more common than open-line derailments. Also, the consequences may not necessarily be more severe. For example a dangerous goods derailment in a tunnel is likely to be contained and not directly affect members of the public, unless the tunnel is hit by another train which is very unlikely. It may be prudent for specific locations such as these to be further considered by a future study.

These are excluded from the present study on the basis of their rarity and therefore low weighted impacts compared with other more likely accident scenarios.

[15] For the purposes of this report we define consequences as the range of outcomes of the freight train derailment accident whereas impacts are the associated quantified or qualified level of loss associated with the consequence.

7.2 Impact Modelling

7.2.1 Dangerous Goods Consequence Models

When a derailment of a DG train occurs, there can be a number of outcomes including loss of life should a DG leak occur. The calculation of the consequence from a DG incident is explained below.

The calculation starts from the total number of DG derailments involving a contents spill. The contents spill can affect persons in the vicinity of the derailment, with the quantity of people potentially affected defined by the location of the incident. In this regard previous Agency work [1] specified a population density taken as a mean average weighted by the railway network length, with this set at 144 per km^2. Our models however have three possible incident locations: stations; urban; countryside.

We note that a factor of 3:1 is used [10] to represent the density at stations compared with urban locations. As a conservative assumption, we have used a density of 144 per km^2 for urban locations and a density of 432 per km^2 in stations. For countryside we used a density value of 80 per km^2. (If we assume that a freight train travels 10% of the time in stations and heavily populated areas, 25% of the time in urban areas, and 65% of the time in countryside areas, the weighted average population density equals approximately 144 per km^2.)

Next we considered the likelihood of various accident scenarios involving a specific class of DG carried. To enable us to do this, the percentage of DG class carried was obtained by examining the total annual railway transport of DG in millions of tonne kilometres, taken from EUROSTAT [11]. (This is represented in the last column of Table 18.)

A further consideration is the train formation, and whether a DG train is carrying DG exclusively, or whether it is of mixed configuration. For this Agency data [1] was used, modified for recent DG transport figures, and is incorporated into the calculations.

For each class of DG the probability of accidents occurring has been calculated, using data as shown in the tables below. Pool fire has been excluded as the considered impact distance is 2 x 10 meters and it is assumed that the nearest population is 30 metres from the track.

Table 18 Considered Accident Scenario by Class of Dangerous Goods Vehicle

DG Class	**Toxic (%)**	**Solid Explosion**	**VCE (%)**	**BLEVE (%)**	**Fire (%)**	**Jet Fire (%)**	**% goods in class**
1							1.27
2	33		11	11		11	12.70
3	13				87		59.00
4.1, 4.2, 4.3	0				100		4.27
5.1	0				100		3.86
5.2	0		0		100		0.06
6.1, 6.2	84				16		2.77
7							0.23
8	6				11		7.70
9							8.14
All							**100**

The table above therefore shows the probability that a DG train derailment will involve a certain class of DG. For example incidents involving Class 2 DG a toxic release will result in 33% of occasions, [12]. Where the outcome is a potential fire, the probably of ignition is also applied using the factors in Table 19 below, [12].

Table 19 Probability of Ignition of a Flammable Release

DG Class	Toxic	Solid Explosion	VCE	BLEVE	Fire	Jet Fire
1						
2	0	0	0.7	0.7	0	0.7
3	0	0	0	0	0.2	0
4.1, 4.2, 4.3	0	0	0	0	0.5	0
5.1, 5.2	0	0	0	0	0.5	0
6.1, 6.2	0	0	0	0	0.2	0
7	0	0	*0*	*0*	*0*	*0*
8	0	0	0	0	0.2	0
9	0	0	0	0	0	0
All						

Hence, a VCE will occur in 11% * 70% of cases where a severe incident involves a Class 2 DG wagon.

The impact area in m^2 and the lethality parameters were taken from [13], as follows.

Table 20 Impact and Lethality Factors

DG Accident Scenario	Impact Area (m2)	Lethality (%)
Pool Fire	320	100
Vapor Cloud Explosion (VCE)	11300	100
Boiling Liquid Expanding in Vapor Explosion (BLEVE)	44000	100
VCE of Liquefied Propane Gas (LPG)	18000	100
Jet Fire og LPG	2400	100
Chlorine Release	540000	50
Amonia Release	20000	50
Class 4 Fires	1200	100
Less Significant	320	100

When a derailment of a dangerous goods vehicle occurs there will also be an associated environmental cost. The number of DG derailments involving a contents spill obtained from the event tree is multiplied by the environmental cost per event, for which we have used the Agency work [1]. Environmental damage has not been considered for normal freight derailments.

7.2.2 Normal Freight Human Fatalities and Injuries

When a normal freight vehicle derails there could also be a number of human fatalities or injuries if the freight train collides with a passenger train.

From our accident analysis [7, Annex 1] we note only one case where injuries have been recorded, and in this case the number of injuries recorded was 2.

The number of injuries from normal freight derailments is calculated one in 10 accidents. This is a conservative assumption as our accident database indicates something less than this.

These values are used, with an associated cost per injury, as previously used by the Agency [1].

Concerning fatalities, it is very rare for these to occur from the mechanical impact associated with a freight train derailment. In the accidents we have studied there have been none reported over a 10 year period. We note that the Agency [1] used an estimate of one per year, however this would seem pessimistic based on available data.

Eurostat (table rail_ac_catvictin) records zero 3rd party fatalities associated with train derailments (with the exception of Viareggio) in the period 2006 to 2009 and 6 railway employee fatalities in the same period (both for the EU-27) although Eurostat includes both passenger and freight train derailments. For freight train derailments there are fewer railway employees at risk (usually the driver only), and we also note that it is unusual for the locomotive to be directly involved.

These data lead us towards a fatality figure, resulting from the mechanical impact of a freight train derailment, as significantly less than one per year and for the purposes of our assessment we have selected a value of 0.2 fatalities per year.

7.2.3 Freight Train Derailment Railway System and Operational Disruption

When a freight train derailment occurs there will be additional impacts on the railway system and operations. The following parameters were used relating to the costs associated with these impacts, [1].

Table 21: Railway System and Operational Costs[16]

	Track Damage		Wagon Damage		Disruption Costs	
Scenario	Average Km	Cost (E/km)	# wagons	Cost/wagon (E/wagon)	Hours disruption	Cost/hour (E/hour)
Immediate severe, DG involvement	0.5	427746	7	23526	50	16040
Not immediate severe, DG involvement	5	160405	7	23526	50	16040
Immediate severe, no DG involvement	0.5	427746	7	12832	50	16040
Not immediate severe, no DG involvement	5	160405	7	12832	50	16040
Not severe derailment, safe stop	0.5	32081	2	5347	12	8020

7.3 Impact Model Usage, Summary and Outputs

We report above the development of our impact models. Using the model, with the parameters described, the following results are obtained (for the case of 500 derailments per year):

- Total cost of freight train derailments = Euro 505 million. (This may vary between Euro 195 million and Euro 701 million using minimum and maximum values defined in [1, section 8.2]).
- Average cost per freight train derailment = Euro 1.01 million. (Ranging between Euro 390,000 and Euro 1,402,000 using minimum and maximum values defined in [1, section 8.2].
- Number of fatalities = 3.9 (resulting mainly from incidents in which there is a release of DG).
- Major cost impact relates to operational disruption.

As a comparison, our database [7, Annex 1] has recorded 2 accidents with loss of life and these are associated with incidents in which there is a release of DG. These equate to a total loss of life of 34 over a 10 year period. This is consistent with our modelling.

The principal future use of our impact model is the calculation of benefits that may be achieved through the implementation of new measures.

[16] Updated for inflation using rates of 3.7%, 1% and 2.1% for 2008, 2009 and 2010 respectively.

8.0 Measures Analysis and the Top Ten

8.1 Assessment Categories

The measures we have identified as part of our Part A activities are assessed as described in Table 22 (for preventative measures) and Table 23 (for mitigation measures). For these we have applied the following general scheme to determine our assessment methodology:

- Measures which have previously been ***discarded or are out of scope*** are referenced in the table below with a reference to that part of our analysis where this was agreed.
- For measures that are not discarded, we have considered how best to assess them.
    - We have used ***qualitative basis*** for assessment if the following applies:
        - They generally offer only small benefit in comparison with other measures, and / or;
        - They form part of a suite of measures that can be integrated together (for example a number of measures identified associated with rolling stock maintenance which can be integrated into a single measure), and / or;
        - There is insufficient data to enable a more detailed assessment and therefore there would be significant uncertainty in the results.
- Otherwise, measures are assessed on a ***quantified basis***.

Table 22 Assessment Method for Preventative Measures

Measure Number	Description	Time Category	Efficiency Assessment?
P-1	Check rail in sharp curves (radius less than 250 metres)	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 8.2.2.1
P-2	Track and flange lubrication (installed on track)	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 8.2.2.2
P-3 to P-5	Measure number no longer used.		These measures are related to collision events, where derailment is a secondary consequence. They have not been considered further
P-6	Geo radars	Medium	This measure was considered to have a commercial benefit rather than a direct derailment reduction benefit and has not been considered further.
P-7	Rolling stock mounted equipment for monitoring of rail profile conditions.	Medium	This measure was considered to have a commercial benefit rather than a direct derailment reduction benefit and has not been considered further.
P-8	Track circuit	Medium	This measure is primarily for train detection purposes and has not been considered further.
P-9	Interlocking of points operation while track is occupied.	Medium	This is a relatively low frequency / low severity contributor to freight train derailments. We have undertaken a qualitative assessment for this measure in Section 8.6.1.1
P-10 P-12	Hot axle box (hot bearing) detectors. Hot wheel and hot brake detectors.	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 8.2.2.3 These devices are assessed together as they are often part of the same detection system.
P-11	Acoustic bearing monitoring equipment	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 8.2.2.4
P-13	Wheel load and wheel impact load detectors	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 8.2.2.5

Measure Number	Description	Time Category	Efficiency Assessment?
P-14	Dragging object and derailment detectors	Medium	Dragging objects are a low contributor to freight train derailment. Derailment detectors are assessed at M1. Not considered further.
P-15	Bogie performance monitoring / Bogie lateral instability detection (bogie hunting)	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 8.2.2.6
P-16	Wheel profile measurement system / Wheel profile monitoring unit	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 8.2.2.7
P-17	Measure number no longer used.		These measures related to collision events, where derailment is a secondary consequence. They have not been considered further
P-18	Sufficient availability of maintenance resources (for Infrastructure maintenance)	Short	We have established parameters to enable a quantified assessment. This is reported in Section 8.2.4.2
P-19	Clearance of obstructions from flange groove (particularly at level crossings)	Short	We have established parameters to enable a quantified assessment. This is reported in Section 8.2.4.1
P-20	Ultrasonic rail inspection	Short	Rail brakes/ruptures are relatively low frequency contributors to freight train derailments. We have undertaken a qualitative assessment / discussion for this measure in Section 8.6.1.2
P-21	Track geometry measurement of all tracks	Short	Addressed with P-18 above.
P-22	EU-wide intervention/action limits for track twist	Medium	We have undertaken a qualitative assessment for these measures in Section 8.6.3.1
P-23	EU-wide intervention/action limits for track gauge variations	Medium	
P-24	EU-wide intervention/action limits for cant variations	Medium	
P-25	EU-wide intervention/action limits for height variations and cyclic tops	Medium	
P-26	Flange lubrication - locomotives	Medium	This measure is primarily for wear reduction purposes and has not been considered further.
P-27	Replace composite wheels with monoblock wheels	Medium	Insufficient data to enable the measure to be quantified.
P-28	Replace metal roller cages in axle bearings by polyamide roller cages.	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 8.2.3.1
P-29	Replace existing axles for stronger axles or axles with improved material properties with regard to crack initiation and crack propagation	Medium	Currently the subject of an on-going work programme (EURAXLES). Not assessed by this project.

Measure Number	Description	Time Category	Efficiency Assessment?
P-30	Increase the use of central couplers between wagons in fixed whole train operation	Long	Probably limited to bulk material block train on set routes. Cost of this measure significant compared to benefit. Not assessed by this project.
P-31	Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis.	Medium	Potential benefit considered relatively small compared to the cost of implementation. Significant commercial issues. Not assessed by this project.
P-32	Install disc brakes instead of wheel tread brakes for new wagons.	Medium	The primary objective for this measure is likely to be in relation to the Noise TSI. Whilst it may have secondary benefits in terms of reduced heat activation of wheels, potentially reducing wheel failure rates, it is not considered there is a strong enough correlation between this measure and a reduced derailment rate to justify its consideration as a freight train derailment measure. Also, other measures are in place, or could be put in place, which would be more effective against this potential derailment hazard.
P-33	Rolling stock design for track twists (for new wagons)	Long	The time for this measure to be implemented is governed by the renewal rate of wagons. Not likely to be possible before the long term, and hence not considered by this project.
P-34	Secure underframe brake gear from falling down	Medium	Brake gear or other wagon underframe gear that can fall down and cause derailment is in many countries prevented by the use of safety slings. Although a wider application of this measure may have potential benefit, we note that this a relatively low frequency contributor to freight train derailments. We have undertaken a qualitative assessment for this measure in Section 8.6.1.3
P-35	Regular greasing and checks of rolling stock buffers.	Short	This is assessed on a qualitative basis in conjunction with measure F-2 in Section 8.6.3.2
P-36	Wheel set integrity inspection (ultrasonic) programs.	Short	This is assessed on a qualitative basis in conjunction with measure F-2 in Section 8.6.3.2
P-37	Derating of allowable axle loads	Short	Currently the subject of an on-going work programme of the Joint Sector Service group. Not assessed by this project.
P-38	EVIC (European Visual Inspection Catalogue)-based inspection of freight train rolling stock axles	Short	Currently the subject of an on-going work programme through EVIC. Not assessed by this project.
P-39	Double check and signing of safety-classified maintenance operations	Short	This is assessed on a qualitative basis in conjunction with measure F-2 in Section 8.6.3.2
P-40	Qualified and registered person responsible for loading	Medium	This is assessed on a qualitative basis in conjunction with measure F-2 in Section 8.6.2.1
P-41	Locomotive and first wagons of long freight trains in brake position G	Short	This is assessed on a qualitative basis in Section 8.6.2.2
P-42	Limitations on use of brake action in difficult track geometry	Short	This is assessed on a qualitative basis in Section 8.6.2.2
P-43	Dynamic brake test on the route	Medium	This is assessed on a qualitative basis in Section 8.6.2.3.
P-44	Saw tooth braking to limit heat exposure to wheels	Short	This measure is assumed to be applied where it is required and is not assessed by this project.

Measure Number	Description	Time Category	Efficiency Assessment?
P-45	Initiation of braking or speed reduction prior to passing signal showing reduced speed	Short	We consider this to be part of existing driver practice and therefore implemented where required and is not assessed by this project.
P-46	Not allowing traffic controllers and drivers to override detector alarms	Short	This is assessed on a qualitative basis in Section 8.6.2.4.
P-47	Wagons equipped with a balance to detect overload in visual inspection.	Medium	This is assessed on a qualitative basis in Section 8.6.2.5.
F-1	End of train device (brakes)	Medium	Not considered to have substantial benefit for existing freight train lengths. Not assessed by this project.
F-2	Awareness program and improved maintenance for Rolling Stock	Short	This is assessed on a qualitative basis in Section 8.6.3.2
F-3	Heat sensitive material to reveal hot axle box conditions	Short	Not considered further. However we note that this measure could have a role to play to aid in separating false alarms from genuine alarms.
F-4	Machine Vision Devices	Medium	We do not believe we can make an assessment of systems of this type when solely deployed as a freight train derailment prevention system. Systems of this type are built around a core module with options that may include: • 3D Profiling (for out-of-gauge loads) • Fire detection functions • Pantograph defects detection • Wheel load measurement • Thermographic mapping In the context of a holistic accident prevention system, this technology may prove cost-effective. However, the functionality in relation to derailment prevention (wheel load, hot axle box detection etc) is already addressed. Systems of this type may detect potential derailment causes that are not covered by the systems studied to date – such as open hatches or covers that may become detached and pose a derailment risk – however it is inconceivable that a network of machine vision devices consisting of a core module and profile measurement module would be deployed for this purpose. We have not considered this further.
F-5	Telematics	Medium	This measure does not have a direct impact on derailment rate. Not assessed by this project.
F-6	Anti-lock devices	Medium	Quantified assessment
F-7	Sliding wheel detectors.	Medium	Quantified assessment
F-8	Handbrake interlock.	Medium	We consider this to be similar F-6 and F-7. This measure is not assessed.

Table 23 Assessment Method for Mitigation Measures

Measure Number	Description	Time Category	Efficiency Assessment Method
M-1a		Medium	Quantified assessment
M-1b		Medium	Quantified assessment
M-2	Equip tank wagons with impact shielding to protect against penetration		No. This is outside the scope of work covered by this project.
M-3	Install emergency warning lights on locomotive to warn train on neighbouring track going in opposite direction of derailment		No. This is outside the scope of work covered by this project.
M-4	Attach mechanical guides to the bogie structure or on wagon at an appropriate position so that is more likely that the derailed wagon is kept on the track and does not overturn.		No. This is outside the scope of work covered by this project.
M-5	Install safety rails (guard rails) at bridges and in tunnels		No. This is outside the scope of work covered by this project.
M-6	Install battering rams in front of safety critical pillar supports of roof structures and overbridges in order to prevent derailed rolling stock damaging such safety critical structures		No. This is outside the scope of work covered by this project.
M-7	Installation of dragging object and derailment detectors		No. This is outside the scope of work covered by this project.
M-8	Installation of deviation points leading to a safe derailment place in strongly descending tracks from marshalling yards and train formation stations		No. This is outside the scope of work covered by this project.
M-9	Radio or cell phone communication installations like GSM-R in order to transfer emergency stop orders to trains		No. This is outside the scope of work covered by this project.
M-10	Separate passenger and freight traffic to separate lines to a larger degree (which is also EU-policy)		No. This is outside the scope of work covered by this project.
M-11	Restrictions on freight traffic in general or hazardous materials transport in special through certain busy passenger terminals and/or underground stations to restrict traffic and limit the consequences of a derailment.		No. This is outside the scope of work covered by this project.
M-12	Develop and apply a checklist for dangerous goods transport as the Swiss checklist for dangerous goods transport by freight trains		No. This is outside the scope of work covered by this project.
F-9	Harmless infrastructure		No. This is outside the scope of work covered by this project.

8.2 Quantified Assessment Parameters and the Cost Model

8.2.1 General Assumptions and Clarifications

The following assumptions apply to the measures discussed below:

1. Some technical measures discussed in this section may benefit from trending. This trending can increase the effectiveness of such measures. These types of measures work on single inspection / pass-by, but their effectiveness is generally lower in this set-up. The trending function requires each wagon to be fitted with some form of telematics or wagon "tagging". The costs of such technology are not included in the assessment of derailment prevention measures.
2. The application scopes we discuss below are indicative based on suppliers' recommendations and other information. In practice, each IM or RU would need to consider an application scope that best achieves the objectives.
3. We note that some countries have invested heavily in some of the measures, whilst others may have chosen different options. We have not considered a per-country application scope taking this into account. Our analysis is therefore to be taken as a European average picture.
4. We consider each measure in isolation on its individual merits in terms of preventing or mitigating freight train derailments. Combinational measures are not considered. We have provided some commentary on combinational issues at Section 8.7.2.
5. Non-safety benefits (such as reduced maintenance costs, increased asset lifetime) are not considered.
6. Track length in the EU-27 is approximately 340,000 km (extracted from Eurostat, "Railway transport – Length of Tracks" and from DNV consultation), 85% of which is open for freight traffic (estimated from DNV consultation). Freight traffic therefore operates on approximately 289,000 km of track.
7. We have assumed an additional 10% for side-tracks in stations and yards, hence 34,000 km (all of which we assume can be operated by freight traffic).
8. We are aware that recent developments directed towards specific derailment causes (such as hot axle box derailments) will reduce the future benefit available, compared with the historical average. We discuss this in the relevant sections below.

8.2.2 Infrastructure Measures

8.2.2.1 Measure P-1: Check Rails

8.2.2.1.1 Measure Objective

Check rails are installed to guide the wheels in rigid crossings and point crossings. Check rails may also be installed in sharp curves to prevent derailments as it will hinder flange climbing on the outer rail in sharp curves. In some countries check rails may also be used to give additional safety against derailment when the track is passing safety critical installations such as overhead bridge supports. It is the application in sharp curves we consider here.

8.2.2.1.2 Measure Installation Scope

For this measure to be effective check rails would be installed in curves of radius less than 250 metres on all routes where freight may be carried (where not currently fitted). Information regarding the quantity of such locations within the European rail community is not available to the project team, and would require each IM to survey their network to determine suitable locations. In the absence of this information we have made the following assumptions:

- Applicable total track length for this measure is assumed to be (289,000 + 34,000) = 323,000 km.
- Our knowledge of track layout in Norway (as a reference example) indicates that in the region of 1% to 2% of the network open for freight traffic is made up of curves of this type. However, Norway has a "curvy" network and the average in the EU-27 is likely to be less than this. Further, some curves are fitted with check-rails, although not a significant number. Taking these factors into consideration we have chosen a reference value of 0.5% for track length satisfying our criteria. Applying these factors, we use a value of 323,000 km * 0.5% = 1,615 km.
- A more limited application scope may be possible. This may be for high usage freight routes on curvy lines or other "at-risk" sections, where alternative approaches (such as track lubrication or cant adjustment) are not feasible. However, detail on the extent of the EU-27 network that satisfies this requirement is not known and therefore not assessed.

8.2.2.1.3 Measure Effectiveness

In terms of a maximum potential benefit we reported 25 avoided derailments [7] to be possible and achievable with a comprehensive application scope (similar to that described above), if the measure could be 100% effective.

In [2] we assigned this measure an effectiveness of 90% which we would consider to be an appropriate reference value.

8.2.2.2 Measure P-2: Track Lubrication

8.2.2.2.1 Measure Objective

Lubrication of the flange and track contact point is an important measure in reducing the friction between rail and wheel flange and hence reduce the risk of derailment in difficult track geometries, i.e. in narrow curves or track sections with high cant and/or high twist. The reduced lateral track force in narrow curves should cause less wear, less noise and less risk of derailment.

8.2.2.2.2 Measure Installation Scope

In many countries traction unit based flange lubrication is an applied measure addressing this problem for regularly used routes. The major benefit from track lubrication units is in countries where flange lubrication measures are not frequently used, and for parts of the network that are not regularly operated (e.g. side-tracks which are common derailment locations).

Knowledge of each IMs network and the proliferation of side-tracks and their usage pattern is not available to the project team. In the absence of this information we have made the following assumptions:

- Side-tracks are installed approximately every 15 km of track length.
- 50% of side-tracks are infrequently used (and may have dry rails) or are otherwise at a lower level of repair than main-line routes.
- One or two lubrication units are required per side-track, depending on conditions. We have used an average of 1.5 per side-track.
- The required number of units is estimated at (289,000 / 15) * 1.5 * 50% = 14,450.

8.2.2.2.3 Measure Effectiveness

The effectiveness for this measure is somewhat difficult to estimate. In this respect we are not aware of any study that has been performed that quantifies lubrication effectiveness as a derailment mitigation option (we have contacted many suppliers on this subject, and they are also not aware of such studies). However, it is frequently referenced as a "good measure" and often recommended in accident reports as a measure that should be applied.

We have made a working assumption that it may be up to 50% effective in cases where dry rail has been a contributory derailment cause. This is applied to the maximum number of potentially avoided derailments for this measure, which we reported to be 25 [7].

8.2.2.3 Measure P-10 and P-12: Hot Axle Box / Hot Wheel and Brake Detectors (HABD/HWD)

8.2.2.3.1 Measure Objective

Hot axle boxes leading to axle journal seizures and ruptures are amongst the most frequent cause of freight train derailments, and also have a tendency to occur at high speeds, [7]. In response to this many IMs have taken steps to install hot axle box detectors, with recent activity to increase the coverage and replace older designs with newer technical solutions. Further, some countries that currently have no such devices are embarking on an implementation strategy [14]. In this context we estimated in our market assessment [2] approximately 1,500 units currently in use; a number which we believe to be increasing.

8.2.2.3.2 Measure Installation Scope

In terms of current installations, of the 1500 units we estimated to be in use, some will be "double units" covering adjacent lines. For the basis of our assessment we have assumed 50% to be double units, therefore:

- Coverage = 289,000[17] km / (1,500 * 1.5 * 85%[18]) = 151 km between installations.
- Coverage of one per 50 km (a typical installation density, although we do note that hot axle box derailments can occur less than 50 km from the last operational hot axle box detector) would require approximately 5,780 units installed in total, therefore a further 3,530 units.

8.2.2.3.3 Measure Effectiveness

The recent developments in terms of increased installation density and improved technology discussed in Section 8.2.2.3.1 is likely to make significant in-roads towards reducing derailments caused by hot axle boxes and related causes. (One IM has stated that they have reduced to almost zero the incidence of derailments caused by hot axle boxes / broken axles and broken wheels, partly as a result of implementing this technology – of course with suitable supporting arrangements such as the availability of side-tracks and a robust alarm management process.)

We therefore need to address the fact that solutions currently being implemented are likely to return benefits in future years, regardless of any additional action that may be taken. In this regard we have made the following working assumptions:

- The data used for our accident analysis is an average assessment based on previous years' accident figures. In this regard our accident data is "lagging" current figures and does not take into the developments discussed above. In particular the increasing use of HABD/HWD in recent years will have the effect of reducing the available benefit for

[17] We exclude side-tracks from the installation scope for these measures
[18] We have assumed that of the total HABD installations, they are equally distributed on mixed, freight only and passenger lines. Hence the 85% of them will be installed on freight carrying routes.

measures directed towards derailments from that cause. In this respect we have assumed our data is lagging by at least 1.5 years, and that by 2013 will be a further 1.5 years behind. To compensate for this we have applied the assumption (used in [7]) that a 6% year-on-year reduction of derailment rate and therefore the available benefit, should be applied[19]. Starting from our maximum risk reduction potential of 80 avoided derailments per year [7]; we arrive at a revised maximum potential benefit of 67 avoided derailments per year.

- We note from our accident analysis [7, Annex 1] that at least 10% of hot axle box derailments occur despite the incident train having previously passed a HABD/HWD. This is an underestimate of the true position since we only count cases where this has been explicitly stated. (In Germany, where the most HABD/HWD are installed, we observe the highest proportion of derailments due to hot axle boxes.) We assume 10% of such failures will continue to evade detection, even with a comprehensive application scope.
- Applying this we deduce that a revised maximum risk reduction potential is 60 avoided derailments.

8.2.2.4 Measure P-11: Acoustic Bearing Monitoring (Bearing Acoustic Monitoring; BAM)

8.2.2.4.1 Measure Objective

Acoustic bearing detectors are, like HABD, used to detect developing mechanical structural defects associated with wheel bearings. They are however based on the analysis of sound as wheel sets pass by. The major advantage over HABD is that acoustic bearing detectors are able to detect developing defects much earlier as such defects will result in increased noise. It is stated by one supplier that defects can be detected 10,000's of km before a failure occurs. Trending over time allows early identification of defects before they lead to failures.

8.2.2.4.2 Measure Installation Scope

We use the following assumptions:

- Suppliers' recommended 30 units per 50,000 km of track are installed. Hence a density of (289,000 / 50,000 * 30) = 173 units would be required. However, we note that this is mainly in relation to long haul routes in the USA and Australia. For short / medium haul routes (of say 100 km to 300 km) it is possible that a BAM would not be encountered very frequently / at all if installed at this density. (Although the significant advance warning stated for this measure does not require a freight train to pass a detector site very frequently.) We have calculated that one detector installation per 500 km or track would be necessary in Norway to cover approximately 95% of freight train operations, and consider this would be a suitable indicative installation density for European application, hence about 578 units. There are few installations existing in the EU (other than test locations), hence these would be new.

8.2.2.4.3 Measure Effectiveness

In terms of benefit and effectiveness:

- Maximum available benefit 63 avoided derailments per year [7] reduced by 6% per year as reported for HABD. This suggests a maximum achievable benefit of 53 avoided derailments per year.
- It is stated by one supplier that BAM are 90% effective in detecting the early on-set of bearing problems on a single pass-by, and that this increases to 95% when trended. It is

[19] We have applied the 6% factor to the derailment causes that we believe to be reducing; this does not apply to all derailment causes so it is not applied to all measures.

also stated that the technology can detect defects in brass or polyamide roller cages equally as reliably[20].

8.2.2.5 Measure P-13: Wheel Load and Wheel Load Impact Detectors (WLID) / Weighing In Motion (WIM)

8.2.2.5.1 Measure Objective

Devices of this type typically monitor rail vehicle wheels for rolling wheel surface defects such as flats and spalls, together with wheel out of roundness and vehicle weight imbalances. They may help to detect wheel defects and also identify conditions that may, if left un-rectified, lead to wheel-set failures.

8.2.2.5.2 Measure Installation Scope

Considering the information we have assembled:

- An installation density of approximately one unit per 1000 km is suggested, thereby indicating a fully covered installed base in the EU of (289,000 km / 1000 km) = 289 units. (Installation locations are likely to be where a freight train can be inspected and removed from service, or denied access to the network.) However, as we have reported for BAM, this is unlikely to provide full coverage for all freight traffic and we note that the Netherlands has an average installation density of about one unit per 170 track km (in the Netherlands this technology is used for track access charging in addition to derailment mitigation). We have assumed a targeted and planned installation density of one unit per 500 track km would provide a reasonably comprehensive coverage for most freight traffic, hence about 578 units.
- We estimated a total of 150 current installations [2], with 85% on freight traffic routes, hence 128 units. A further 450 units would therefore be required for a comprehensive coverage.

8.2.2.5.3 Measure Effectiveness

In terms of potential benefits and effectiveness, the following may be summarised:

- We indicated a maximum potential benefit of 120 avoided derailments. This is modified by the observed 6% year-on-year reported for HABD, hence 100 avoided derailments.
- We note that the Netherlands [14] is quoted as indicating a 90% reduction in hot axle box failures, as well as significant reductions in derailments by other causes (for example broken primary suspension reduced by almost 100%), following the application of this technology. Although the Netherlands uses relatively few HABD, it is considered likely that the combinational effect of these two technologies (as well as other factors) has resulted in this dramatic reduction in reducing hot axle box and other derailments. For the purpose of our modelling activity, we have assumed 75% effectiveness for this measure in isolation.

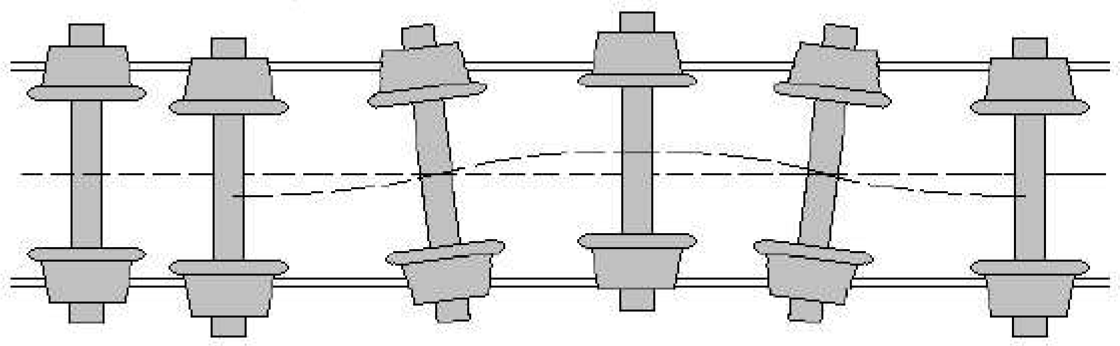
[20] These are supplier claims which we are unable to validate due to lack of EU experience.

8.2.2.6 P-15: Bogie Performance Monitoring / Bogie Lateral Instability Detection (bogie hunting)

8.2.2.6.1 Measure Objective

This wayside defect detection system is capable of detecting and identifying wagon bogies that exhibit poor steering performance, an example of which is shown below. Bogie hunting is likely to occur when the rail profile is worn outside of allowable conditions; a wheel profile detector is likely to offer similar functionality.

Figure 10 Lateral Instability



This system monitors safety performance in several dimensions such as: potential of flange climb derailment, gauge spreading, and rail over. Like BAM, devices of this type often rely on trending to enable defects to be identified and early maintenance action scheduled to correct the defect.

8.2.2.6.2 Measure Installation Scope

In terms of application:

- We have assumed that a similar coverage as BAM, hence a density of 578 units. There are few installations existing in the EU (other than test locations) therefore these would mostly be new installations.

8.2.2.6.3 Measure Effectiveness

In terms of benefit and effectiveness:

- We estimated a maximum available benefit of 47 avoided derailments per year [7]. This is not modified by our 6% reduction factor as derailments from this cause are not considered to be addressed by the recent programmes to reduce the frequency of hot axle box derailments.
- Little data exists in the countries that are within the scope of this study relating to the effectiveness of these measures, because they are not installed to any great extent. By virtue of the fact that they are installed in the USA, Australia and other geographies, we assume they are effective. We have used a 90% effectiveness rating for this measure.

8.2.2.7 P-16: Wheel Profile Monitoring System / Wheel Profile Monitoring Unit

8.2.2.7.1 Measure Objective

Damage to the wheel profile may be a contributing cause to derailments. Whereas wheel load impact detectors can detect some wheel profile problems, wheel profile measurement systems provide a more complete picture. They are also based on other technology: analysis of wayside digital camera images highlighting the profile using lasers or strobe light. A number of wheel profile parameters are captured, e.g. flange height, flange width, flange slope, tread hollow and rim thickness. Some measurement systems can operate with trains passing at high speeds (e.g. up to 140 km/h).

8.2.2.7.2 Measure Installation Scope

This type of unit would be installed where the widest coverage could be secured; this may include at major depots and selected freight routes across the network. It would not be required that freight trains / wagons were required to pass a detector site frequently, as defects evolve over time and are unlikely to be immediately catastrophic.

Considering the information we have assembled and our comparison of this technology with bogie hunting detectors:

- An installation density of one unit per 500 km, hence about 578 units.
- For the purpose of our assessment we estimate 30 current installations [2], with 85% on freight traffic routes, hence 26 units. A further 548 units would be required using this as a basis. (Installation locations are likely to be where a freight train can be inspected and removed from service, or denied access to the network.)

8.2.2.7.3 Measure Effectiveness

In terms of potential benefits and effectiveness, the following may be summarised:

- We indicated a maximum potential benefit of 23 avoided derailments. This is modified by the observed 6% year-on-year derailment reduction factor, hence 19 avoided derailments.
- We assume the effectiveness of this measure to be similar to other technical measures. An effectiveness of 90% is used.

8.2.2.8 F-7: Sliding Wheel Detectors

8.2.2.8.1 Measure Objective

The sliding wheel detector is a mechanical device that compares wheel rotation rates between wheel sets to detect locked wheels. It may detect issues such as handbrakes that are not released, jammed wagon brakes or seized axle box bearings.

8.2.2.8.2 Measure Installation Scope

The system is normally installed in depots and sidings on departure roads and possibly other strategic locations. Suppliers' recommendation for application in Great Britain (GB) would be for 100 units (and GB accounts for about 9% of European track length) hence about 1,100 units would be required to cover the European rail network. We are not aware of many that are currently installed; hence we consider these "new". We do consider this optimistic, and that it would probably not cover all freight origin points and strategic places en-route where locked wheels may be likely. We have increased our scope estimates by 20% to cover additional strategic points. Hence we use 1,320 units.

8.2.2.8.3 Measure Effectiveness

Our assessment of the measures potential effectiveness is as follows:

- We indicated a maximum potential benefit of around 27 avoided derailments. On further of this this measure we conclude that it cannot be as effective as, say measure P-6: Anti-Lock devices as it cannot detect locked wheels between detection sites. Hence to provide a realistic assessment of the potential effectiveness of this measure we have undertaken a detailed review of our accident database [7, Annex 1] to specifically identify freight train derailments that can be directly attributed to this cause (UK-1 and NL-8 are examples).

Through this research we consider that approximately 1% to 2% of freight train derailments have this as a cause and we have used 8 avoided derailments as our reference case.

- This measure is not applied in the EU and therefore we have no specific effectiveness data. However this is used in other countries, such as Australia. We assume that as it an existing and mature measure it is at least 90% effective.[21]

8.2.3 Rolling Stock Measures

8.2.3.1 Measure P-28: Replace Metal Roller Cages in Axle Bearings by Polyamide Roller Cages

8.2.3.1.1 Measure Objective

Polyamide roller cages are stated to offer safety improvements compared with brass roller cages, decreasing the incidence of overheating and axle box failures. Manufacturers' claims[22] include:

- Reduced friction and wear and reduced operating temperatures.
- Safe failure mode without seizing.
- Can operate for longer periods without lubrication (testing is stated to have shown that polymer cages can operate for more than 500 km when all lubrications is removed. This is well beyond that which steel based cages can safely operate), [15].
- Compared with machined brass cages they are substantially lighter, which minimizes dynamic adverse conditions in bearings. Two sliding elements steel - polyamide have better sliding properties as compared with steel - brass. In addition to that polyamide better damps vibrations and noise. Thanks to technologic abilities the cage design has been solved to permit optimum passage of lubricant to rolling elements. Another advantage of bearings is self-lubricating capacity of polyamide. In case of lubrication deficiency the wheel set seizure does not occur so instantly as in case of brass cage bearings, [16]

It is important to note that these are suppliers' claims. However in many derailment accident reports where a hot axle box has been the cause it is specified that the bearing had a brass roller cage; in none of the accidents has it been specified that there was a polyamide roller cage. We are aware that programmes to replace brass roller cages with polyamide roller cages have been introduced by several RUs, among those:

- CargoNet in Norway in 2000
- VR in Finland pre 2003.

The replacement appears to have been effective resulting in a reduced number of hot axle box derailments although sufficient data for quantification does not exist.

Similar programmes are applied by other RUs. Since the normal maintenance interval for freight wagon roller bearings are 12 years (for brass or polyamide to the best of our knowledge) the last brass roller cage in the CargoNet owned rolling stock fleet should be removed by 2012.

[21] To be effective the wheel must be locked and skid. It may not be effective in cases where the handbrake is only partly applied as the wheel may continue to rotate.
[22] We note many manufacturers' claim benefits from the use of these roller cages, and that it is also a common recommendation arising from accident reports to replace brass for polyamide roller cages. However, we have not seen any independent validation of such claims.

8.2.3.1.2 Measure Installation Scope

Currently a number of RUs are requiring the replacement of brass with polyamide roller cages on an opportunistic basis, to combat the significant problem of hot axle box derailments. We believe there to be little cost difference between brass and polyamide variants and hence this is a minimal cost option. We are however unable to assess this in any reasonable manner as there is no appreciable cost.

A second option would be to change all remaining brass roller cages with polyamide. We are unaware of the total number of bearings of each type in use, but we assume the following:

- 50% of the existing freight fleet are fitted with brass roller cages. There are about 720,000 freight wagons [7] with a mix of single axle and bogie wagons (equal mix assumed). This equates to upwards of 2,000,000 roller bearings requiring replacement.

8.2.3.1.3 Measure Effectiveness

- We estimated a maximum available benefit of 53 avoided derailments per year [7] as for HABD. This is modified by the observed 6% year-on-year derailment reduction factor, hence 44 avoided derailments.
- If we are able to take the suppliers' claims at face value, then the ability to operate for lengthy distances without lubrication and excessive heat build-up (up to 500 km) and also be more tolerant of vibrations is likely to be significant. On this basis we have assumed this measure to be 75% effective[23].

(Additional benefits could be for example requiring a lesser density of installation of HABD.)

8.2.3.2 F-6: Anti-lock Devices

8.2.3.2.1 Measure Objective

Devices of this type act to reduce locking of the wheels and associated wheel damage during braking on railway freight cars. In turn this may reduce maintenance costs of re-profiling wheel sets, increase safety with reduced risk of wheel cracking or major tread damage that could increase derailment risk, reduce impact forces to track and reduce noise.

8.2.3.2.2 Measure Installation Scope

The large retro-fit time (up to 12 days per wagon), coupled with the limited derailment safety benefit estimated for these types of product [3], would lead us to consider this measure will be applicable to new wagons only. Therefore to consider this measure we have modelled it as if it were fitted to the entire fleet but considering only the acquisition and on-going maintenance cost (not the fitting cost).

8.2.3.2.3 Measure Effectiveness

This measure addresses wheel failures and other derailment causes where these are caused by braking failures (including handbrakes not released, brakes remain stuck on after application etc.). We predicted up to 27 derailments from this cause [7]. This measure is not modified by our 6% reduction factor as derailments from this cause are not addressed by the recent programmes to reduce the frequency of hot axle box derailments.

The device has no measured effectiveness or reliability claims, since it is new to the market. We have assumed that it will be 75% effective in preventing derailments from the causes that it seeks to mitigate.

[23] We would consider it prudent for independent substantiation of suppliers' claims to be performed in advance of any recommendation.

8.2.3.3 M-1: Derailment Detection

8.2.3.3.1 Measure Objective

There are two devices of this type: those that act directly on the brake pipe invoking a immediate and automatic full application of the brake (M-1a); those that provide a clear indication to the train driver of a suspected derailment (M-1b) but without automatic brake application. The objective is to prevent a derailed axle causing further damage, and/or the initial derailment escalating in severity.

8.2.3.3.2 Measure Installation Scope

Two devices are fitted per wagon within the following scope:

- All freight wagons (approximately 720,000).
- All freight wagons carrying dangerous goods (DG) (approximately 100,000).
- A sub-set of DG wagons, as proposed by RID 2013 provision (approximately 17,000).

We consider these options in our analysis. We also consider that there are about 2,000 wagons fitted with devices of this type. These are largely fitted to DG tank wagons, and we assume that 75% are fitted to tank wagons carrying the most hazardous materials as covered by the proposed RID 2013 provision (hence 1,500).

8.2.3.3.3 Measure Effectiveness

We have studied the accident database we have assembled and are able to report the following[24]:

- There are five accidents that appear to have been initially non-severe, but the application of emergency brakes is stated to have been a contributory factor in the derailment escalating. We cannot know the outcome had emergency brakes not been applied. (Comparable with M-1a.)
- There are 62 accounts of cases where the application of emergency brakes (either through the brake pipe being severed or driver emergency braking) has occurred, and the train has been brought to a safe stop. We cannot know the outcome had emergency brakes not been applied; it is possible that the train would not have been brought to a safe stop.
- There are four cases where the driver has known or suspected a derailment but has not taken appropriate action leading to further wagons derailing. It is not known whether this further derailment led to an escalation of severity. (Comparable with M-1a.)

Given these data, it is not possible for us to conclude or differentiate between these two measures in terms of which may be the best option from a safety point of view. In the absence of information to separate the measures from an effectiveness perspective, the only parameter that we re-model (with reference to our event tree, [7]) is the detection probability. We assume that for wagons fitted with a device of this type (M-1a, M-1b) that 95% of derailments will be detected as soon as they occur.

[24] Not all accident report provide information to establish whether emergency braking was initiated, hence we are not able to include those in this analysis

8.2.4 Organisational Measures

8.2.4.1 Measure P-19: Clearance of Obstructions from Flange Groove (particularly at level crossings)

8.2.4.1.1 Measure Objective

Obstructions in the flange groove may lead to freight derailments, albeit few in number. Inspection and clearance of obstructions is a measure that may address this issue.

8.2.4.1.2 Measure Installation Scope

The European Level Crossing Forum report 125,000 level crossings in Europe. If we assume that 85% of these are on lines that freight traffic may use, then there are about 106,000 level crossings that fit within the scope of this study.

Some level crossings are more exposed to this hazard than others; for example urban locations where level crossings are surrounded by tarmac are perhaps less likely to get stones obstructing them, compared with rural locations. For the purposes of our assessment we have considered that most level crossings are in urban areas or are otherwise not significantly exposed to this hazard to the same extent. We have used an assumption that 25% of level crossings are exposed hence 26,500 level crossings would require additional inspection effort.

For this measure to be effective, inspections over and above the existing inspection interval would be necessary. In this regard we have assumed the following:

- That an inspection would be required after inclement weather. This would include wet weather / daytime thaw followed by freezing conditions. Strong winds that could move debris are another potential cause.
- Optimistically we have assumed that these weather conditions may occur 10 days per year, therefore additional inspections of 10 * 26,500 level crossings = 265,000 additional inspections.
- Each inspection takes 30 minutes.
- This is an on-going cost requirement.

8.2.4.1.3 Measure Effectiveness

We have assumed this measure will be 90% effective in removing all derailments attributable to this cause.

This measure is not modified by our 6% reduction factor as derailments from this cause are not addressed by the recent programmes to reduce the frequency of hot axle box derailments.

8.2.4.2 Infrastructure Track Geometry Measures

8.2.4.2.1 Measure Objective

Track geometry defects are one of the most common causes of freight train derailments. We have also noted that there is an increasing use of single axle wagons with a very long wheel base which makes the derailment risk in twisted track even larger and with an increased containerization as well as loading by bulk material by front wheel loader the control of skew loading is more of a challenge.

We consider this problem in relation to secondary lines predominately for freight operations, as well as side-track at stations:

We consider here the following:

- P-18: Sufficient availability of maintenance resources to maintain lines and tracks at stations and side tracks to minimum safety requirements.
- P-21: Track geometry measurement of all tracks.

Other issues such as

- P-22: EU-wide intervention/action limits for track twist.
- P-23: EU-wide intervention/action limits for track gauge variations.
- P-24: EU-wide intervention/action limits for cant variations.
- P-25: EU-wide intervention/action limits for height variations and cyclic tops.

are addressed elsewhere in our report.

8.2.4.2.2 Cost and Application Data

There is some difficulty making a quantified assessment of measures of this type, due to data shortages and also the insistence of many IMs that they both have sufficient resources and apply appropriate standards to all their assets. This is not always borne out by accident reports. Further there are national differences in accident rates and also criteria which pose a problem for a “European average study” such as this.

We have established from [17] an average railway maintenance cost of about €25,000 per track kilometre. Further, approximately 40% of this figure is for permanent way maintenance and about 50% for track work. Hence this equates to about €5,000 (€25,000 *40% * 50%) per track kilometre. We assume this is for track geometry testing and rectification work. This figure applies to main-track.

We assume secondary lines and side-track accounts for 34,000 km. We have further assumed that a partial inspection of these is already undertaken, perhaps at an expenditure of 50% of that applied to main-track. This has two consequences:

- An annual increased maintenance cost of €2,500 per secondary line / side-track kilometre would be required to maintain to a similar level to main-track.
- In addition to the cost above, it is likely that there would be an initial one-off spend required to upgrade secondary line / side-track to bring it up to specification. We have made an assumption here that in year one this would amount to double the annual maintenance cost, hence €5,000 per side-track kilometre.

8.2.4.2.3 Effectiveness Data

In our accident data we have identified that approximately 50% of derailments occur in stations / side-tracks, despite these locations accounting for 10+% or total track length. Using these approximate figures, we can postulate that:

- From the number of derailments predicted as a result of track geometry failures (129 [7]), it is theoretically possible that a 45% reduction could be achieved, to 58.
- This measure is not modified by our 6% reduction factor as derailments from this cause are not addressed by the recent programmes to reduce the frequency of hot axle box derailments.

8.3 The Cost Model and Parameters

8.3.1 Cost Model Summary

The cost model brings together all the facets that apply to the measures we have identified.

These are on the one hand costs associated with each measure and on the other hand the benefits that the measure may secure.

Costs of a measure include:

- The quantity (number of units, deployment rate, resource requirement etc.) for the measure.
- The costs per unit for the measure.
- Annual maintenance and upkeep other costs for measure.

Benefits include:

- The number of avoided derailments (or reduced number of severe derailments for "M" measures), each of which has benefits that include:
    - o Reduction in the number of fatalities and injuries associated with freight train derailments.
    - o Reduction in the quantity of damaged tracks, damaged wagons, operational disruption and environmental contamination.

It is the purpose of the cost model to weigh these factors such that the most efficient measures can be selected. To achieve this both the costs and benefits need to be monetised. The details of how this is achieved are provided in our report [7] although we recap these below.

The benefits of implementing a measure in terms of avoided derailments are monetised using the information shown below.

Table 24 Railway System and Operational Costs[25]

	Track Damage		Wagon Damage		Disruption Costs	
Scenario	Average Km	Cost (E/km)	# wagons	Cost/wagon (E/wagon)	Hours disruption	Cost/hour (E/hour)
Immediate severe, DG involvement	0.5	427746	7	23526	50	16040
Not immediate severe, DG involvement	5	160405	7	23526	50	16040
Immediate severe, no DG involvement	0.5	427746	7	12832	50	16040
Not immediate severe, no DG involvement	5	160405	7	12832	50	16040
Not severe derailment, safe stop	0.5	32081	2	5347	12	8020

In addition, the cost model assigns monetised benefits associated with the value of preventing a fatality or injury of €1,500,000 and €200,000 respectively.

Therefore, preventing an immediately severe DG derailment that leads to loss of three lives has a cost (at today's values) of:

- (3 * €1,500,000) + 0.5 * (€427,746) + 7 * (€23,256) + 50 * (€16,040) = €5,678,665.

An event of this type is predicted to occur at a rate that is calculated by our frequency assessment model. For example, if this is predicted to be once every ten years, then the annual cost is:

- 0.1 * €5,678,665 = €567,866.

[25] A severe derailment is defined as an event with a mechanical impact that may cause a leak of material from a DG tank / wagon, or for a contents spill of a normal freight wagon.

The costs of the measures themselves are unique to each measure, and we summarise the key cost components in Table 25 .

8.3.2 Economic Indicators

Of course a measure will have an investment cost that is made today (or at the time that the measure is implemented) and returns benefits over a period of time. In these cases it is practice to consider this in the economic assessment. This is normally achieved by the use of the following economic indicators:

1. **Net Present Value** – the difference between the present value of cash inflows and the present value of cash outflows.
2. **Benefit / Cost Ratio** – the ratio of benefits to costs (a ratio greater than 1 indicates that the benefit outweighs the cost).
3. **Internal Rate of Return** - can be defined as the break-even interest rate which equates the Net Present of a projects cash flow in and out.

Our assumptions / clarifications regarding the use of these indicators are:

- We apply a discount rate of 4%.
- We assume that the measure is fully implemented at Year 1 and will return benefits in the same year.
- We have applied today's costs and benefits regardless of when the measure is implemented. We believe this to be a reasonable assumption as costs and benefits are likely to be stable within the periods defined as short and medium term.
- We have assumed that any investment is made by the EU Railway actors, for the benefit of EU Railway actors. This means that the economic analysis will focus entirely on costs and benefits within the EU without consideration that some benefits may in fact be transferred to stakeholders outside EU, or that there may be an inequitable share of costs and benefits between actors.

Table 25 Cost and Benefits for Reference Case

Measure	Purchase / Installation Costs	Annual Maintenance Cost	Max Potential Benefit[26]	Measure Effectiveness / Other Considerations	Net benefit[27]
P-1: Check Rail	€500 / metre[28]. **Total installation cost for 1,615 km = €807.5 million**	Additional maintenance cost of €5 / metre [2]. **Annual additional maintenance cost €8 million**	25 avoided derailments	Assumed 90% effective where fitted [2]	**23 avoided derailments (6 HSD, 17 LSD)**
P-2: Track Lubrication	€3250 / installation[29]. **Total installation cost for 14,450 units = €47 million**	€3000 / installation (lubricant top-up) **Annual additional maintenance cost €43 million**	25 avoided derailments	Assumed 50% effective	**13 avoided derailments (10 LSD, 3 HSD)**
P-10 & P-12: HABD/HWD	€250k / installation **Total installation cost for 3,530 €882.5 million**	Approx. 30 hours per year (supplier info) **Annual additional maintenance cost €5.3 million**	60 avoided derailments	60 * 90% * 99% (99% being the availability figures for devices of this type, [2])	**53 avoided derailments (12 LSD, 41 HSD)**
P-11: BAM	€550k / installation **Total installation cost for 578 units = €318 million**	12 hours per year (supplier info) **Annual additional maintenance cost €347,000**	53 avoided derailments	53 * 90% * 98% % (98% being the availability figures for devices of this type, [2])	**47 avoided derailments (11 LSD, 36 HSD)**
P-13: Wheel Load / Impact Detectors	€400k / installation **Total installation cost for 450 units = €180 million**	12 hours per year (supplier info) **Annual additional maintenance cost €270,000**	100 avoided derailments	100 * 75% * 98% (98% being the availability figures for devices of this type, [2])	**74 avoided derailments (33 LSD, 41 HSD)**

[26] Refers to avoided derailments and related reduction of impacts
[27] Refers to avoided derailments and related reduction of impacts
[28] This is increased from the value used in our report [2]. Installation of check rails is likely to require change of sleepers or additional fixings for their attachment.
[29] This is a typical cost for a mechanical lubrication system installed and initially topped up with lubricant (supplier information)

Measure	Purchase / Installation Costs	Annual Maintenance Cost	Max Potential Benefit[26]	Measure Effectiveness / Other Considerations	Net benefit[27]
P-15: Bogie Hunting Detectors	€385k / installation **Total installation cost for 578 units = €222.5 million**	15 hours per year (supplier info) **Annual additional maintenance cost €433,500**	Max: 47 avoided derailments	47 * 90% * 99% (99% being the availability figures for devices of this type, [2])	**42 avoided derailments (30 LSD, 12 HSD)**
P-16: Wheel Profile Monitoring	€300k / installation **Total installation cost for 548 units = €164 million**	140 hours per year (supplier info). However, the regular pass-by check will be on opportunistic basis (100 hours). 40 hours of specific maintenance assumed. **Annual additional maintenance cost €1 million**	Max: 23 avoided derailments	23 * 90% * 95% (95% being the availability figures for devices of this type, [2])	**20 avoided derailments (14 LSD, 6 HSD)**
P-18 & P-21 Track Geometry	**€170 million to upgrade 34,000 km side-track and secondary lines**	**Annual additional maintenance cost €85 million**			**58 avoided derailments (35 LSD, 23 HSD)**
P-19: Clearance of Flange Groove	**€6.7 million to perform 132,500 hours per year inspections (circa €50 / hour)**	**€6.7 million to perform 132,500 hours per year inspections (circa €50 / hour)**	5 avoided derailments	5 * 90%	**4.5 avoided derailments (0.5 LSD, 4 HSD)**
P-28: Polyamide Roller Cages	Assumed 1 hour per bearing at cost of €75 (including purchase) **Total installation cost to replace 2 million brass roller cages = €150 million**	None	44 avoided derailments	44 * 75%	**33 avoided derailments (7 LSD, 26 HSD)**
F-6: Anti-lock Devices	€5,000 per wagon set **Total installation cost for 720,000 units (all freight wagons) = €3600 million**	30 mins / wagon per year **Annual additional maintenance cost €18 million**	27 avoided derailments	27 * 75%	**20 avoided derailments (8 LSD, 12 HSD)**

Measure	Purchase / Installation Costs	Annual Maintenance Cost	Max Potential Benefit[26]	Measure Effectiveness / Other Considerations	Net benefit[27]
F-7: Sliding Wheel Detectors	€40,000 per installation **Total installation cost for 1,320 units = €53 million**	Negligible, but has a life limited item that is replaced at 3 years (€250 assumed) **Three yearly additional maintenance cost €330,000**	8 avoided derailments	8 * 90% *99% (99% being the availability figures for devices of this type)	**7 avoided derailments (3 LSD, 4 HSD)**
M1- Derailment Detection	€2000 per wagon **All Freight: Total installation cost for 718,000 wagons = €1436 million** **All DG: Total installation cost for 98,000 wagons = €196 million** **RID scope: Total installation cost for 15,500 wagons = €31 million**	Negligible, but has 6 year maintenance requirement (1 hour per wagon assumed) **All freight (6 year) : €36 million** **All DG (6 year) : €5 million** **RID Scope (6 year) : €775,000**	N/A	95% effective in detecting a derailment	**All freight: 76 derailments prevented from becoming severe** **All DG: 10 derailments prevented from becoming severe** **RID scope: 2 derailments prevented from becoming severe**

8.4 Assessment Results – Reference Case

8.4.1 Quantitative Results Presentation

For the parameters established in this report, we show the results for our reference case.

Table 26 Quantitative Analysis (Sorted by Measure Number)

	Net Present Values			Benefit / Cost Ratio			Internal Rate of Return		
Measure	**10 years**	**20 years**	**40 years**	**10 Years**	**20 Years**	**40 Years**	**10 years**	**20 years**	**40 years**
P1-Check Rail	-701	-635	-559	0.2	0.3	0.4	-31%	-14%	-6%
P2-Track Lubrication	-276	-459	-667	0.3	0.3	0.3	N/A	N/A	N/A
P10&12-HABD/HWD	-507	-257	27	0.5	0.7	1.0	-16%	-4%	0%
P11-BAM	47	294	572	1.1	1.9	2.8	3%	10%	11%
P13-WLID/WIM	379	756	1,183	3.1	5.1	7.4	51%	52%	52%
P15 Bogie Hunting Detector	80	283	514	1.4	2.2	3.2	8%	14%	15%
P16-Wheel Profile	-27	65	170	0.8	1.4	1.9	-4%	5%	7%
P18-Track Geometry	-373	-568	-788	0.5	0.6	0.6	N/A	N/A	N/A
P19-Clearance Flange Groove	-20	-34	-49	0.6	0.6	0.6	N/A	N/A	N/A
P28-Roller Cages	109	284	482	1.7	2.9	4.2	16%	21%	21%
F6-Anti Lock Device	-3,581	-3,581	-3,580	0.0	0.1	0.1	N/A	N/A	N/A
F7-Sliding Wheel Detector	-0	35	75	1.0	1.6	2.4	0%	7%	9%
M1a-Derail Det All Freight	-385	303	1,094	0.7	1.2	1.7	-7%	3%	5%
M1a-Derail Det All DG	-44	56	170	0.8	1.3	1.8	-6%	3%	6%
M1a-Derail Det RID	-2	17	39	0.9	1.5	2.2	-2%	6%	8%

Table 27 Quantitative Analysis (Sorted by Benefit / Cost ratio)[30]

		Net Present Values			Benefit / Cost Ratio			Internal Rate of Return		
Rank	**Measure**	**10 years**	**20 years**	**40 years**	**10 Years**	**20 Years**	**40 Years**	**10 years**	**20 years**	**40 years**
1	P13-WLID/WIM	379	756	1,183	3.1	**5.1**	7.4	51%	52%	52%
2	P28-Roller Cages	109	284	482	1.7	**2.9**	4.2	16%	21%	21%
3	P15 Bogie Hunting Detector	80	283	514	1.4	**2.2**	3.2	8%	14%	15%
4	P11-BAM	47	294	572	1.1	**1.9**	2.8	3%	10%	11%
5	F7-Sliding Wheel Detector	-0	35	75	1.0	**1.6**	2.4	0%	7%	9%
6	M1a-Derail Det RID	-2	17	39	0.9	**1.5**	2.2	-2%	6%	8%
7	P16-Wheel Profile	-27	65	170	0.8	**1.4**	1.9	-4%	5%	7%
8	M1a-Derail Det All DG	-44	56	170	0.8	**1.3**	1.8	-6%	3%	6%
9	M1a-Derail Det All Freight	-385	303	1,094	0.7	**1.2**	1.7	-7%	3%	5%
10	P10&12-HABD/HWD	-507	-257	27	0.5	**0.7**	1.0	-16%	-4%	0%
11	P19-Clearance Flange Groove	-20	-34	-49	0.6	**0.6**	0.6	N/A	N/A	N/A
12	P18-Track Geometry	-373	-568	-788	0.5	**0.6**	0.6	N/A	N/A	N/A
13	P1-Check Rail	-701	-635	-559	0.2	**0.3**	0.4	-31%	-14%	-6%
14	P2-Track Lubrication	-276	-459	-667	0.3	**0.3**	0.3	N/A	N/A	N/A
15	F6-Anti Lock Device	-3,581	-3,581	-3,580	0.0	**0.1**	0.1	N/A	N/A	N/A

The top nine measures (Wheel Load Impact Detectors to Wheel Profile Detectors) show a positive NPV and therefore greater than unity benefit to cost ratio at Year 20, whilst the tenth best measure, Hot Axle Box / Hot Wheel Detectors is unable to show overall benefit at this point (although reached in Year 40).

[30] Note that IRR cannot compute measures where, for example, the cost exceeds the benefit beyond Year 1. We therefore rank our measures based on B/C ratio. We also use the results at year 20, as these are the likely lifecycles for each measure considered.

8.4.2 Qualitative Results Presentation

An alternative non-financial presentation is provided below.

Table 28 Qualitative Analysis (Sorted by Measure Number)

Measure	Fats	Track (km)	Wagons (number)	Opeartions (hrs)	Environmental events	Derails prevented
P1-Check Rail	0.16	35	109	751	3	23
P2-Track Lubrication	0.09	20	61	422	2	13
P10&12-HABD/HWD	0.47	70	270	1889	8	53
P11-BAM	0.41	63	240	1673	7	47
P13-WLID/WIM	0.59	104	366	2542	10	74
P15-Bogie Hunting Detector	0.29	63	199	1377	5	42
P16-Wheel Profile	0.14	30	95	657	2	20
P18-Track Geometry	0.36	85	280	1941	7	58
P19-Clearance Flange Groove	0.04	6	23	164	1	4.5
P28-Roller Cages	0.29	44	169	1180	6	33
F6-Anti Lock Device	0.17	28	99	693	3	20
F7-Sliding Wheel Detector	0.06	10	35	241	1	7
						Severe derailments saved
M1a-Derail Det All Freight	0.96	341	379	2881	17	76
M1a-Derail Det All DG	0.85	45	50	380	4	10
M1a-Derail Det RID	0.12	9	10	76	1	2

In this table it is of course not surprising to see that the measures with the best economic performance secure the largest benefit.

It is interesting to note however that “M” measures show the largest absolute benefit. This is because they are intended to prevent the escalation of consequences, and therefore target only the most serious outcomes.

To illustrate this point we consider measure M1 applied to all DG trains (M1a-Derail All Freight and P13- WLID/WIM detectors. We can see that M1a-Derail Det All Freight prevents 76 derailments from becoming severe whilst P13 prevents 74 derailments from occurring at all. On first consideration it may seem that preventing 74 derailments is the better outcome. However, of these 74, a number will be safely managed and not escalate in consequence, therefore only a proportion of these prevented derailments are severe. Further, since it is only severe derailments that lead to loss of life, preventing severe derailments has significant advantages in this respect.

8.4.3 Additional Measures and Discussion Points

8.4.3.1 Measure P28-(Polyamide) Roller Cages

An alternative opportunity exists for this measure, as introduced earlier in our report. That is the replacement of brass for polyamide roller cages at the next appropriate maintenance interval. We are not able to assess this in an economic sense as it has almost no cost.

The benefit will accrue over time, as a function of the maintenance intervals for wagons.

8.4.3.2 Measure M1-Derailment Detection

We have assessed only those measures that invoke an emergency braking (M-1a), not those that provide an alarm to the train driver (M-1b). The latter would require the train driver to take appropriate action although it is difficult to envisage an appropriate action that does not involve bringing the train to the prompt stop.

We have not identified any measures of type M-1b on the market, although we have to conclude that these would be more expensive that the "simple" M-1a measures. Additional technology would be required, possibly involving the provision of power, transmitting and receiving technology or some other form of alarm transfer. There is also likely to be a substantial training requirement to instruct the train driver how to react in an alarm situation.

Considering M-1b measures we therefore cannot conclude that these measures bring the same benefit as M-1a measures as new failure modes are introduced, including human error.

8.5 Sensitivity Analysis

8.5.1 Motivation

It is necessary for a study of this complexity to make certain assumptions regarding modelling parameters; this work is no different in that respect.

Whilst we have endeavoured to research and validate our assumptions, it is prudent to test the key assumptions to determine if the results are robust when subject to reasonable variance.

This is the purpose of our sensitivity analysis.

8.5.2 Method and Results

We considered two cases:

1. A minimising set of parameters; these present what we consider to the reasonable "worst case" in minimising the interests of each measure. These concentrate on:
    a. The assessed reasonable minimum effectiveness of the measure (leading to a reduced number of derailments avoided / detected and hence reduced benefit).
    b. The assessed reasonable increased application scope for the measure (leading to an increased quantity of that measure and hence an increased cost).
2. A maximising set of parameters; these present what we consider to the reasonable "best case" in maximising the interests of each measure.
    a. The assessed reasonable maximum effectiveness of the measure (leading to an increased number of derailments avoided / detected and hence increased benefit).
    b. The assessed reasonable reduced application scope for the measure (leading to a reduced quantity of that measure and hence a reduced cost).

We have limited our attention to application scope and effectiveness. Our set of minimising and maximising parameters is presented at [18, Appendix I] and the results below.

Table 29 Quantitative Analysis (Sorted by Benefit / Cost ratio) – Minimising Parameters

		Net Present Values			Benefit / Cost Ratio			Internal Rate of Return		
Rank	Measure	10 years	20 years	40 years	10 Years	20 Years	40 Years	10 years	20 years	40 years
1	P13-WLID/WIM	171	511	896	1.5	**2.5**	3.6	12%	17%	17%
2	P28-Roller Cages	-60	56	188	0.7	**1.2**	1.8	-7%	3%	5%
3	P15 Bogie Hunting Detector	-121	47	237	0.7	**1.1**	1.6	-8%	2%	4%
4	P11-BAM	-188	42	301	0.6	**1.1**	1.6	-9%	1%	4%
5	M1a-Derail Det All Freight	-601	-59	567	0.6	**1.0**	1.4	-11%	-1%	3%
6	M1a-Derail Det RID	-16	-6	5	0.5	**0.8**	1.1	-14%	-3%	1%
7	M1a-Derail Det All DG	-103	-42	27	0.5	**0.8**	1.1	-14%	-3%	1%
8	F7-Sliding Wheel Detector	-42	-17	11	0.5	**0.8**	1.1	-15%	-3%	1%
9	P10&12-HABD/HWD	-530	-295	-30	0.4	**0.7**	1.0	-17%	-4%	0%
10	P16-Wheel Profile	-170	-97	-15	0.4	**0.7**	1.0	-17%	-5%	0%
11	P18-Track Geometry	-453	-697	-972	0.5	**0.5**	0.5	N/A	N/A	N/A
12	P1-Check Rail	-1,597	-1,597	-1,595	0.1	**0.1**	0.2	N/A	N/A	N/A
13	P2-Track Lubrication	-446	-743	-1,080	0.1	**0.1**	0.1	N/A	N/A	N/A
	P19-Clearance Flange Groove	Not modelled								
	F6-Anti Lock Device	Not modelled								

Table 30 Quantitative Analysis (Sorted by Benefit / Cost ratio) – Maximising Parameters

		Net Present Values			Benefit / Cost Ratio			Internal Rate of Return		
Rank	Measure	10 years	20 years	40 years	10 Years	20 Years	40 Years	10 years	20 years	40 years
1	P13-WLID/WIM	409	806	1,257	3.2	**5.4**	7.8	56%	57%	57%
2	P28-Roller Cages	190	386	608	2.9	**4.9**	7.1	45%	47%	47%
3	P15-Bogie Hunting Detector	93	307	548	1.4	**2.3**	3.4	10%	15%	16%
4	M1a-Derail Det RID	12.45	41.34	74.30	1.39	**2.3**	3.23	0.09	0.15	0.15
5	P11-BAM	78	346	649	1.2	**2.1**	3.0	6%	12%	13%
6	F7-Sliding Wheel Detector	7	47	92	1.1	**1.9**	2.7	3%	10%	11%
7	M1a-Derail Det All DG	-15	105	242	1	**1.5**	2	-0	0	0
8	P16-Wheel Profile	-19	79	189	0.9	**1.4**	2.0	-3%	5%	7%
9	M1a-Derail Det All Freight	-212	593	1,516	0.9	**1.4**	2.0	-4%	5%	7%
10	P10&12-HABD/HWD	-484	-218	83	0.5	**0.8**	1.1	-15%	-3%	1%
11	P18-Track Geometry	-293	-439	-605	0.6	**0.6**	0.6	N/A	N/A	N/A
12	P1-Check Rail	-267	-178	-76	0.4	**0.6**	0.8	-20%	-6%	-1%
13	P2-Track Lubrication	-110	-182	-264	0.6	**0.6**	0.6	N/A	N/A	N/A
14	P19-Clearance Flange Groove	Not modelled								
15	F6-Anti Lock Device	Not modelled								

We have not modelled F6-Anti lock device as it considered clear from our reference case that it cannot be cost-effective. Further, we have eliminated P19-Clerance of Flange Groove as we believe our reference case already shows this measure in its best possible light and it still remains outside the top ten when compared with other measures (and this is a measure that we do not consider the Agency would be minded to make a specific recommendation on as it should be part of each IM's SMS).

We note here that although there is some re-ordering of priority our list of top ten measures remains unchanged.

8.5.3 Summary and Results Discussion

We were surprised to note measure F-7 appearing towards the top of the ranking (reference and sensitivity), however we do acknowledge that in our consultation exercise at least one IM did state this to be a known problem. Although the quantity of avoided derailments is relatively low, the cost of the measure is also relatively low, with low maintenance and upkeep costs.

Also measure P-28 has been assessed on the basis of fitting polyamide roller cages with immediate effect. We have also discussed an alternative option which is for the replacement of brass for polyamide roller cages at the next scheduled maintenance interval for axles / axle boxes. This is almost a zero cost option, although the benefits would take longer to materialise, and be a function of the maintenance cycle for freight wagons.

Measure P-11 would involve a radical departure from the existing means of addressing hot axle box derailments, which are controlled in the EU through other means. If these other means can be successful in reducing this as a derailment cause then the benefit of BAM will diminish also.

8.6 Qualitative Assessment

8.6.1 Technical Measures

8.6.1.1 Measure P-9: Interlocking Of Points Operation While Track Occupied

Our analysis [7, Annex 1] of accidents associated with points movement under a train indicates a small number of derailments from this cause mostly resulting from a lack of train detection / interlocking protection. These accidents usually occur at station entrances and exits. We estimated [7] 11 per annum, mostly low speed. (We have not considered shunting operations derailments, of which there are many.) Due to the relatively low number of derailments, and the relatively low consequence of such derailments, we have not researched data for a quantitative analysis.

Whilst this is the case, some locations could be addressed by a relatively low cost “fix”. In particular, if the point is electrically operated centrally from a signal box then the cost to implement a solution could be relatively small (we estimated a cost of €10,000 [2] for an additional track circuit (plus installation costs)). Also, we are able to assume that interlocking protection is very effective, as this is a high integrity system (although the possibility for human error exists).

We feel that is unlikely that the Agency would consider a specific recommendation for this measure on the basis of its low risk and also that such interlocking is not fitted in higher risk locations. Whilst we therefore do not offer this as a recommendation, it may prove cost-effective in mitigating a number of lower consequence freight (and passenger) train derailments and could form the basis of an advisory notice.

8.6.1.2 P-20: Ultrasonic Rail Inspection

Our analysis [7] of accidents associated with rail failures indicated up to 18 derailments per year annually potentially resulting from this cause. We also recognise that ultrasonic rail inspection is an effective technique to combat this problem.

However, whilst this is the case we note that this measure is extensively applied already. We therefore conclude that it is not the technical measure that requires strengthening; rather it is the frequency of its usage and also the analysis and implementation of findings that should be addressed which we consider an organisational issue.

8.6.1.3 Measure P-34: Secure Brake Gear Underframe

Our analysis [7] of accidents associated with braking components becoming loose and falling from a train indicated a small number of derailments potentially resulting from this cause (approximately 7 freight train derailments annually).

We consider that the cost of applying this measure to all freight wagons currently not equipped with a safety sling or appropriate containment system is likely to prove expensive as it will require an engineered solution bespoke to the wagon type. It is also possible that the measure may introduce its own risks, with the possibility that the safety sling itself becomes a derailment risk if not properly maintained.

We therefore have concluded that this measure would not be suitable for recommendation by the Agency.

8.6.2 Operational Measures

8.6.2.1 P-40: Qualified and Registered Person Responsible for Loading

Loading errors can contribute significantly to freight train derailments, usually in combination with other defects such as poor train handling or adverse track geometry. Control of such events is covered by national and local rules, which in some cases include the use of externally qualified loading personnel.

To strengthen this control through the EU, it could be considered to require the qualification and registration of loading personnel. However, although the problem of train loading is an issue of importance, we question how effective a measure like this may be. In particular:

- Freight train loading rules and controls are already in place, and allocated to persons through each RU's safety management system. An external qualification is unlikely, in our opinion, to have a significant impact in reducing the incidence of such events.
- The costs associated with designing and maintaining a qualification system is likely to be relative high as well as time consuming to implement.

We consider that better enforcement of existing controls is likely to be a more fruitful approach and therefore do not consider this measure further.

8.6.2.2 P-41: Locomotive and First Wagons of Long Freight Trains in Brake Position G; P-42: Limitations of Brake Action

We identified these as examples of existing measures that are currently applied in many countries, where required. There are potential drawbacks also with these measures in that they may reduce the braking effort available to the operator and therefore may contribute to derailments and other accidents or incidents.

On the basis that measures of this type are based on local operating conditions, it would not be appropriate or possible to propose an EU wide rule covering the intent. It is therefore a matter for national and company attention and we do not consider this further.

8.6.2.3 P-43: Dynamic Brake Test On-route

Some countries, such as Sweden, Finland and Norway support this functionality. However, we consider [3] that the potential in terms of derailment avoidance is relatively small and is unlikely to support making this a special provision.

It would be considered that a decision on this topic is best placed at the national level. We do not consider this further.

8.6.2.4 P-46 Not Allowing Traffic Controllers and Drivers to Override Detector Alarms

We have reported [7] a number of accidents that have occurred despite a warning being provided to the traffic controller and the incident train being allowed to continue. In this regard we consider that the use of the use of more modern integrated monitoring detection stations will go some way to eliminating this problem.

This is also conditioned by local operating constraints such as the location of detection stations and the availability of inspection locations.

All national “rule books” and operating instructions deal with operating in degraded conditions, and this we believe should continue to the case for alarm management.

8.6.2.5 P-47: Wagons Equipped with a Balance to Detect Overload in Visual Inspection

This is an interesting measure that has a role on a voluntary basis. It may provide partial protection against loading errors, in particular skew loading. Such a measure may be useful when a load is containerised and cannot easily be inspected.

Whilst we cannot consider that an EU regulation may be developed for this specific measure, it may be put forward as an advisory note for the voluntary consideration of wagon owners.

8.6.3 Organisational Measures

8.6.3.1 P22 to P-25: EU Intervention Limits

We have considered the issue of general maintenance for side-tracks at measures P-18 and P-21. As a separate issue we address the issue of intervention limits. This would apply to the main-line network.

It is clear that derailments, particularly those which are attributable to track twist, are a major concern. We estimated between 34 and 50 per annum; these include cases where track twist (for example) are within existing safety limits, but due to unfortunate freight train composition and loading (which may also be within relevant criteria) combine to cause a derailment. It may be the case that future possible changes in freight traffic, more containerisation and increased use of single axle wagons may require these parameters to be addressed just to maintain the status-quo. Further, for an interoperable and open railway, track parameters should be as consistent as possible so that freight train can pass safely through each country. A system of common and stricter safety limits and intervention limits would be a step forward.

Whilst we have estimated the potential benefit we cannot estimate the effort and expense that would be required to bring the EU railway up to a similar standard. We therefore are unable to perform a quantified analysis for this group of measures.

We also note that there would be some significant hurdles to cross regarding what a revised set of safety and intervention limits might be, the capture of these in a revised Infrastructure TSI for and then the implementation of these through the EU railway system.

We have therefore not considered this group of measures beyond this discussion.

8.6.3.2 F-2: Awareness Programme for Rolling Stock Maintenance

During our consultation exercise it was reported by IMs that some rolling stock operating on their networks was of a poor standard / poorly maintained. Also, we have identified a number of specific measures related to this issue, these being:

- P-35: Regular greasing and checks of rolling stock buffers.
- P-36: Wheel-set integrity inspection.
- P-39: Double check and signing of safety-classified maintenance operations.

If we can include hot axle box derailments and axle failures in the category of rolling stock maintenance related problems, then the benefit in terms of avoided derailments is very significant indeed. We are however unable to estimate the expense that may be required, in terms of increased maintenance, that would make significant in-roads into this problem.

On the basis of their being more than 100+ freight train derailments associated with wheel-set and axle failures, and with an average cost that may approach €1,000,000 per derailment [7] would suggest a substantial investment could be justified.

We may consider two options:

1. Initially the development of an awareness training programme, that sought to concentrate on main rolling stock maintenance derailment causes, and best practice (which could include measures P-38 in addition to those listed above). This could possibly be developed through the Agency, and rolled out to RUs and Entities in Charge of Maintenance (ECMs).
2. A second set of measures directed towards NSAs and concerned with Supervision of this aspect.

8.7 Other Issues

8.7.1 Identified Drawbacks

We have not so far considered potential drawbacks associated with our quantified and qualitative assessments of measures.

8.7.1.1 Provoking Derailments

We consider that measures P1-Check Rail and M1-Derailment Detection (types that apply full emergency train braking) have a common drawback. That is that they each may provoke derailments (albeit not very frequently).

For example an accident in Finland on 09 March 2009 had as a cause "***ice packed in the flange way between the crossing frog and the check rail in a turnout***". Poor alignment and maintenance of check rails may also contribute to derailments.

Similarly, train compression under heavy braking is also a known cause of derailments and hence a false alarm of some M1 devices may lead to this outcome. In this respect we note that CSM Regulation, Annex I, point 2.5.4 states:

For technical systems where a functional failure has credible direct potential for a catastrophic consequence, the associated risk does not have to be reduced further if the rate of that failure is less than or equal to 10^{-9} per operating hour.

It is possible that these measures may require to be demonstrated to meet this stipulation prior to any further recommendation being made.

8.7.1.2 False Alarms

False alarms are a potential issue with the majority of technical measures discussed in this report although some may have more direct impacts than others.

Measures based on trending or to detect early defects are less likely to have a service affecting consequence. We consider technical measures ***P11-BAM; P13-WLID; P15-Bogie Hunting; P16-Wheel Profile*** fall into this category. Alarms or warnings are likely to be dealt with at a convenient time without undue impact on the operational railway.

Measure ***P10/12-HABD/HWD and F7-Sliding Wheel Detectors*** are, in our opinion, more likely to have operational impacts as they may need more immediate attention which could involve bringing the incident train to an immediate stop (although in the case of the latter this is likely to be in at a location where an inspection is relatively straightforward and not service affecting).

8.7.1.3 Market Competition / Advantage

Measure F-7-Sliding Wheel Detectors are as far as we are able to establish a technology (in the form that we have considered) that is provided by only a small number of suppliers.

8.7.2 Potential Combinations

A number of measures address the same issues (which is not surprising since there are a relatively small number of high likelihood derailment causes).

Detection of hot axle box conditions is covered by ***P10/12-HABD/HWD; P11-BAM; P13-WLID*** (indirectly through the detection of leading indicators). Measure ***P28-Roller Cages*** also addresses the same problem.

The measures are not mutually exclusive however, and could be applied in combination. For example ***P11-BAM*** could be applied to long distance freight routes to provide optimum coverage at minimum cost (compared to other measures that require a much denser population of detection sites). This could be supplemented by the use of measure ***P10/12-HABD/HWD*** for shorter freight routes and strategic points of the network at critical locations.

Further, to the best of our knowledge, measure ***P28-(Polyamide) Roller Cages*** does not impinge on the effectiveness of existing detection systems, although this may need to be tested to confirm this manufacturer's claim. Further, it could be postulated that polyamide roller cages offer improved performance under emergency running and may allow an extension of the distance between detection sites thus allowing a lower density level for measure ***P10/12-HABD/HWD.***

9.0 Conclusions and Recommendations

9.1 Important Remarks

It is important to clarify that this report looks at the ***potential for improvement***, and is not an absolute assessment of the efficiency of all measures that are applied today. Therefore it follows that if a measure is applied extensively already there is little room for improvement through the further application of that measure. For this reason some measures that are extensively applied already are not considered in this work. Their omission should not be considered as suggesting such measures are not efficient.

In this context the measures listed in this section can be seen as efficient in addressing the potential reduction in risks associated with freight train derailments and providing the detailed background against which public policy can be formulated.

The assessment of measures does not consider the way or the order in which these interventions should be pursued, for example it is not considered whether these interventions should be introduced in a mandatory or voluntary way or whether the measure should be introduced as an EU harmonised measure or only within certain member states or only certain companies.

9.2 Efficiency Assessment of Measures

9.2.1 Technical Preventative Measures

We consider the following technical measures as being efficient (they have a positive or unity benefit / cost ratio in our reference case and all sensitivity studies):

- P13-Wheel Load Impact Detectors / Weighing In Motion
- P28-Replacement of Brass for Polyamide Roller Cages
- P15-Bogie Hunting Detectors
- P11-Bearing Acoustic Monitoring

Considering measure P28, we have considered an immediate replacement of brass for polyamide roller cages. We have also discussed an alternative option which is for the replacement of brass for polyamide roller cages at the next scheduled maintenance interval for axles / axle boxes. This is almost a zero cost option, although the benefits would take longer to materialise, and be a function of the maintenance cycle for freight wagons.

Potential drawbacks to the use of these measures (excluding measure P28) relate to the rate of false alarms. To some extent these can be overcome by the use of good alarm management processes. Further false alarms from those technical measures that are based on early defect detection are unlikely to have an immediate operational impact.

In addition the following two measures are efficient based on the parameters in our reference case:

- F7-Sliding Wheel Detectors
- P16-Wheel Profile Detectors

Potential drawbacks include false alarms as reported above. Finally, measure F7 is to the best of our knowledge a market with only a small number of suppliers. This may give rise to market advantage to existing suppliers of these systems if they were to form the basis of formal recommendation.

9.2.2 Technical Mitigation Measures

We consider the following mitigation measure as potentially efficient if the significant identified drawbacks could be solved:

- M1a-Derailment Detection (with automatic brake application) applied to All Freight Trains

This present assessment is fully in line with the previous assessment made by the Agency [1]. The significant drawback previously identified is confirmed by the present study and the related accident analysis. A false alarm of such a device may lead to train compression which is a contributory cause of freight train derailments (and also a significant operational disruption). In this respect we note that CSM Regulation, Annex I, point 2.5.4 states:

For technical systems where a functional failure has credible direct potential for a catastrophic consequence, the associated risk does not have to be reduced further if the rate of that failure is less than or equal to 10^{-9} per operating hour.

(Measure P1: Check rail has similar disadvantages, although this is not considered efficient by our assessment.)

Finally, we acknowledge an alternative type of derailment detection device which provides an alarm to the train driver when a derailment is suspected, but without an automatic brake application (type M1b). We are however not aware of these being available on the market (for freight application). We consider that an assessment of these devices, considering the human factors issues involved and their costs would be required before these could be formally assessed.

9.2.3 Organisational Measures

We note that the measures above are technical measures that are aimed at addressing, in some cases, organisational problems. Therefore we would add the following organisational and supervision items:

- F-2: Awareness Programme for Rolling Stock Maintenance. This measure may serve to address the problem of poor maintenance standards of rolling stock. This may include training that sought to concentrate on main rolling stock maintenance derailment causes and best practice. This measure may be followed by increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.
- P-18: Track Geometry (all tracks). Although the case for improvements in this area are not conclusively made from a quantified perspective, the problem of poor track geometry (in particular track twist), and the possible requirement to improve this aspect just to maintain current performance levels (see Section 8.6.3.1) should be considered. This is of course an area for each IMs own management system. However a specific measure in this regard must be concerned with increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.

The two measures above represent significant contributors to the derailment problem and organisational failures of individual IMs and RUs in fulfilling their obligations.

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MANAGING RISK

Det Norske Veritas

Assessment of freight train derailment risk reduction measures:

B1 – Derailment Risk Models

Report for European Railway Agency
Report No: BA000777/06
Rev: 02

27 June 2011

MANAGING RISK

Assessment of derailment risk reduction measures:
B1 – Derailment Risk Models
for

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Client ref:	ERA/2010/SAF/S-03	
Report No.:	BA000777/06	Rev 02, to address client comments
Indexing terms:		

Summary: This document provides a summary of status of the derailment risk models that have been developed for the quantification of freight train derailment costs and benefits analysis.

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MANAGING RISK

0.0 Executive Summary

0.1 Study Scope and Objectives

Det Norske Veritas (DNV) is completing a study on behalf of the European Railway Agency (the Agency), the objective of which is twofold:

1. Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation or on a voluntary basis within 5 to 10 years). For these measures, Part A work is also required to assess the market status for technical measures (defined as devices or systems) and establish objective performance data for the identified measures. The work in Part A also extends to identifying, as far as is possible, potential long term measures (not expected to be ready to implement within 10 years) as an input to other research projects currently underway.
2. Part B has the objective of analysing the measures identified in Part A with a view to establishing those that are the most efficient. Part B addresses such measures which are available at the short and medium terms.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland. In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

This report concerns the Part B task associated with the ***construction of detailed fault and event trees describing freight train derailments and showing the action of the safety functions on derailment risks***[1]***.***

0.2 Study Results, Conclusions and Next Steps

This document is intended to show the progress of the work completed in Part B-1; the development of outline fault and event trees, and the processes used to generate these model structures. Principally, the activity has involved:

1. The review of a significant number of freight train derailment accidents to establish the causes and consequence of these events.
2. Fitting the measure previously identified in Part A onto the model structures to indicate the areas in which these measures may provide a benefit.

These activities have led to the following model development activities, which are reported in the remainder of this document:

- Barrier models which show where the measures identified in Part A interact with freight train derailment causes and consequences
- Fault tree models which show, as far as is feasible from the data available, the combinations of causes that may lead to a derailment

[1] The technical scope excludes intentional acts and derailments during civil works. Marshalling operation incidents are also excluded as the impacts arising from such events are very limited. Collisions leading to derailment are also excluded from the study scope; however collisions that occur pursuant to a derailment are included.

- Event trees which show, as far as is feasible from the data available, the development of a derailment accident into its possible outcomes.

The work reported here will be taken forward leading to a quantified working risk model in which the potential benefits of the introduction of new measures, or the extension of scope of existing measures, can be quantified using cost-benefit approaches.

Contents

1.0 Introduction

1.1 Background

In 2009 the European Railway Agency (the Agency) issued a recommendation (ERA/REC/01-2009/SAF) on a specific proposal, made by the RID Committee of Experts, for a new harmonised rule aimed at reducing the consequences of freight train derailments, potentially involving dangerous goods. The recommendation concerned the potential use of a specific Derailment Detection Devices (DDD, the EDT-101) a device which automatically applies the brakes on a freight train when a derailment of a wagon equipped with that device is suspected.

Although the Agency's recommendation was that the EDT-101 DDD should not be adopted in the RID, the joint meeting of RISC and Inland TDG EU regulatory committees agreed that considering the low potential benefit expected with EDT-101 type devices, as well as some other problems related to the operation of trains equipped with these types of detectors, more efficient prevention measures should be further explored before deciding on imposing, by law, measures based on derailment detection.

Therefore recognising that freight train derailments remain a safety and operational concern, and following a request made by the above mentioned EU Committees, the Agency has commissioned further work the objective of which is to carry out an exhaustive analysis of all prevention and mitigation measures which could reduce the risks related to freight train derailments.

Det Norske Veritas (DNV) was selected to deliver this work, the results of which are presented in this and related documents.

1.2 Overall Project Scope and Objectives

The study is divided into two distinct research stages: Parts A and B.

Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation within 5 to 10 years). This is to be achieved through the following schedule of activities:

- Task A.1 - identification of existing operational and technical measures.
- Task A.2 - description of the markets and technologies covered by the devices/systems in use or which may be used at the short or medium term.
- Task A.3 - description of the rules (inc. specific devices/systems used) in generic functional and performance terms.
- Task A.4 - advice on innovative longer term measures (unlikely to be available within 10 years) which might be considered in a future R&D project.

Part B has the objective of analysing the measures identified in Part A with a view to identifying those that are the most efficient. Part B is scoped to include all prevention measures but is limited to mitigation measures based on derailment detection.

Part B is to be achieved through the following schedule of activities:

- Task B.1 – construction of detailed fault and event trees[2] describing freight train derailments and showing which derailment cause or impact the identified safety functions act on.
- Task B.2 - semi-quantitative assessment of benefits and drawbacks of existing safety rules, and of new or improved measures at short and medium terms, using data on actual/targeted performance as well as conservative assumptions.
- Task B.3 - top ten ranking of potentially efficient new safety measures or improvements at short and medium terms, including practical and legal implementation aspects.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland. In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

[2] The technical scope excludes intentional acts and derailments during civil works. Marshalling operation incidents are also excluded as the impacts arising from such events are very limited. Collisions leading to derailment are also excluded from the study scope; however collisions that occur pursuant to a derailment are included.

2.0 Project Abbreviations Used

Term	Description
(the) Agency	European Railway Agency
CSI	Common Safety Indicator
CSM	Common Safety Method
CST	Common Safety Target
DDD	Derailment Detection Device EDT-101
DNV	Det Norske Veritas
EVIC	European Visual Inspection Catalogue
IM	Infrastructure Manager
JSSG	Joint Sector Support Group
Long Term	Measures that are unlikely to able to be introduced before 10 years
Medium Term	Measures that could be introduced within 5 to 10 years
NDT	Non Destructive Testing
NSA	National Safety Authority
RAM	Reliability, Availability and Maintainability
RID	Regulations Concerning the International Carriage of Dangerous Goods by Rail
RIV	Regolamento Internazionale Veicoli)
RU	Railway Undertaking
Short Term	Measures that could be introduced before 1st of January 2013
SMS	Safety Management System
Target countries	EU-27 countries plus the 3 candidate countries, Norway and Switzerland
TDG	Transport of Dangerous Good Regulations
TSI	Technical Specification for Interoperability
UIC	International Union of Railways

3.0 Methodology and Preparatory Work

3.1 Summary

A fuller specification for task B.1, [1], is provided below:

The task B.1 shall describe the effects of 'generic' safety functions covered by the safety measures identified in part A of the study within detailed fault and event trees. Derailments should be the central events. In principle the safety functions should constitute (entirely or in part) the preventing barriers in the causal chain of derailment occurrences or should act as mitigating barriers of potential derailment impacts. The development of the detailed fault and event trees should be a combination of the following analyses:

1. *theoretical analysis of derailment risks, including a bibliography survey, and including impact categories previously used in ERA/REP/03-2009/SAF,*
2. *categorization of causes reported from past incidents and accidents following relevant guidelines for accidents investigation,*
3. *definition of relevant branches covering the description of identified Safety functions. In principle large part of these branches should already be identified with the two previous points,*
4. *apportionment of derailment causes and impacts supported by data[3] from railway operating companies and railway infrastructure managers as well as by expert judgments and/or conservative assumptions.*

Besides direct faults or events, the most relevant combinations of faults or of events leading to derailment occurrences or to specific categories of impacts should be described and discussed.

As a result, the scenario tree should include all the safety functions contained in the safety measures identified in part A of the study as well as branches not covered by safety measures yet.

Our methodology for gathering the information required by bullets 1 and 2 is covered in the following sections:

- Section 3.2; Fundamental Requirement of a Railway System, and
- Section 3.3; Accident Analysis and Surveys

Our methodology for structuring the gathered information into a logical arrangement, as required by bullets 3 and 4, is covered in the following sections:

- Section 4.4: Fault and Event Tree models, and
- Section 4.5; Barrier models.

[3] In the context of this project step, we define "data" as information that enables derailment causes and impacts to be identified and correctly modelled. It does not mean data in the numeric / quantified sense.

3.2 Fundamental Requirements of a Railway System[4]

To address the requirement for a *"theoretical analysis of derailment risks, including a bibliography survey, and including impact categories previously used in ERA/REP/03-2009/SA,* we analysed, [2], the fundamental requirements of a freight railway transport system.

Our analysis of this aspect was informed by the following:

- Internal (DNV) expert knowledge and internet research.
- An emerging accident analysis (see below).
- Previous work on this subject as performed by the Agency [4], and others.

In addition, as part of this work a large consultation exercise with Infrastructure Managers (IMs), Railway Undertakings (RUs) and other actors, as reported in [2], was undertaken. Principally this contributed to the establishment of safety measures, although it has informed and strengthened our understanding of the derailment problem.

We concluded that the fundamental requirement of a railway system consists of:

- A fixed infrastructure comprising train formation yards, track, power catenaries, signalling and telematics system for communication.
- A number of transport units consisting of traction equipment and load carrying units (rolling stock) normally coupled into trains of a certain length.
- Operational personnel in an organisational structure that ensures qualified personnel as well as appropriate operational procedures and information management for handling the trains in a safe manner.

It follows that the essence of a safe railway operation is to manage and ensure the following:

1. Structural and functional integrity of the infrastructure and its subsystems.
2. Structural and functional integrity of the rolling stock.
3 Control of the infrastructure – train interface in terms of wheel / rail guidance.
4. Train operation and management necessary for a safe and effective operation.
5. Support and maintenance, monitoring, supervision and development of safety with the relevant organization and responsibilities.

In our work [2], we discussed in detail the causes of freight train derailments; these being as a result of failures of one (or more than one) of these elements. In the interests of brevity, we have not repeated that work here.

3.3 Accident Analysis and Accident Summaries

To address the requirement for a *"categorization of causes reported from past incidents and accidents following relevant guidelines for accidents investigation, we* analysed [3] 201 freight train derailment accident reports and from these we have established the primary, secondary and additional combinational accident causes and consequences.

In addition, and as a supplement to our accident analysis, we have also studied a further 400+ accident summaries reported to the Agency as part of their work [4] making a total in excess of 600. The majority of accidents studied have been recent (i.e. occurring 2000 onwards) so that the results can be considered current.

[4] We provide a much more comprehensive analysis of the derailment problem at [2].

3.4 Structuring the Collected Information

To address the requirement for a *"definition of relevant branches covering the description of identified Safety functions…"* and *"apportionment of derailment causes and impacts supported by data from railway operating companies and railway infrastructure managers as well as by expert judgments and/or conservative assumptions,* we have developed fault and event trees and "barrier" models. These draw together the work from Part A, and the work reported above, into a model structure as discussed below.

3.4.1 Fault and Event Tree Models

We present the developed fault and event trees in Section 4.4. The models developed are based on standard fault and event tree techniques (which it is assumed the reader is familiar with).

To prepare the models we have used information collected during Part A work, supported by our accident analysis [3]. This information allows the structure of the model to be developed, as well as providing information regarding the relatively likelihood of causes and impacts.

The fault and event trees developed do not show specific safety functions (or measures) in their structure. This is so because in our report [5] we provided a list of close to 60 measures that are now or could in the future be applied to reduce either the likelihood or consequence of a freight train derailment. To depict such measures on a fault tree would require a new model construct to be developed; this would introduce a logical AND gate into every part of the model where each preventative measure applied. Similarly to show mitigation measure on an event tree would normally require a new branch to be introduced, which may double the amount of subsequent branches. This would lead to overly complicated fault and event tree structures, difficult to read and understand (and also not in keeping with the manner in which we shall quantify the analysis).

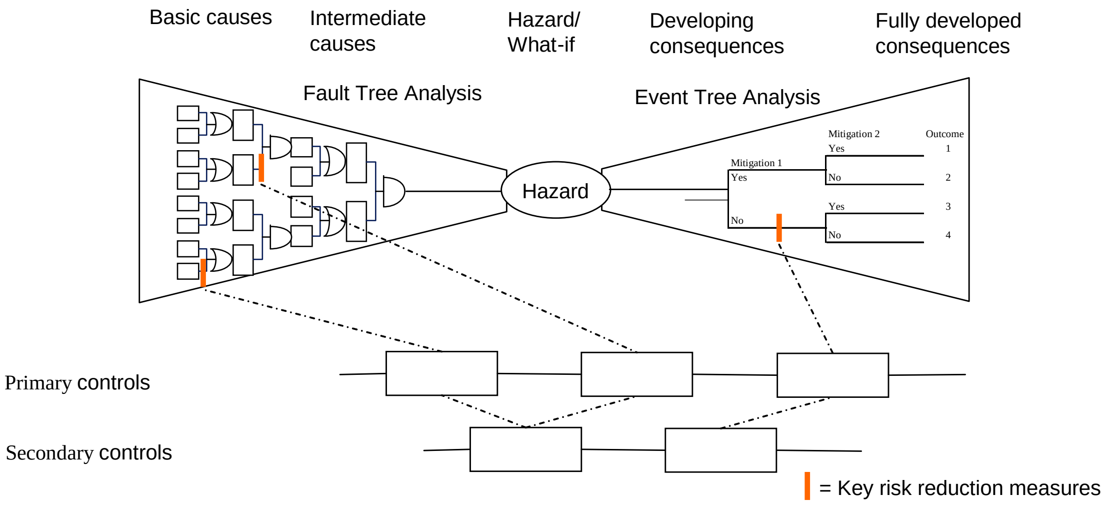
We have therefore opted to also use "barrier models" to show the overlay of safety measures on the fault and event tree models, and the methodology for these is discussed below.

3.4.2 Barrier Models

The barrier model structure is very similar to a traditional fault and event tree "bow-tie" model.

Considering the diagram below a barrier is shown physically at the location where it applies. This allows the barrier to be shown in the correct place logically within the model, whilst avoiding the need to introduce new model structures and complexity.

Figure 1: Bow-tie Model Structure



Barriers can be in many forms, and can include technical measures, or management system / procedural measures as applicable.

The developed barrier models are shown for the freight train derailment problem in Section 4.5.

4.0 Results

4.1 Analysis of Derailment Consequences

4.1.1 Factors Affecting Derailment Consequences

In terms of consequences of a freight train derailment a number of factors apply. These include but are not limited to:

- The presence of controls to reduce (mitigate) the consequences. These may include: technical measures such as physical protection of tank wagons, operational measures such as speed restrictions, and "harmless infrastructure" (i.e. absence of sharp objects), etc[5].
- The type of freight being carried.
- Route selection to separate passenger and freight traffic or to avoid stations and places with large numbers of people and other sensitive locations, etc.
- Layout and geography of the infrastructure and surrounding environment.

"Luck" and circumstance on the day may also contribute to one accident having few consequences, whereas a very similar accident can result in very significant losses.

Our primary mechanism for understanding the consequences associated with freight train derailments and the scenarios that lead to these consequences has been work completed by the Agency [4], supplemented by a comprehensive analysis of previous accidents [3]. The following sections describe the thought processes that have led to the construction of the event trees used for this analysis (presented at Figure 3).

4.1.2 Location of Derailment and Train Type

Our first observation when studying accident reports [3] was the predominance of freight train derailments that occur in stations. In fact about 50% of accidents we have studied occur at these locations. This is an important parameter to consider because stations are potentially densely populated areas which of course has a bearing on freight train derailment impacts. We therefore started our analysis by considering location, and have considered the following:

- Stations
- Rural densely populated areas
- Countryside

At this point of our analysis we identified that the next factor to influence the impacts was the type of freight train that has been derailed, specifically if it involved dangerous goods. This is linked directly to the preceding discussion because the derailment of a dangerous goods train in a station has potentially more severe impacts than elsewhere (see also Section 4.1.6).

4.1.3 Type of Derailment

Our next consideration relates to the type of derailment, and whether it is immediately severe (defined as a derailment with a mechanical impact that may cause a dangerous goods leak or cargo spill) or not. An immediately severe derailment will normally involve a wagon overturning, or being unable to move therefore confining the incident to the derailment location.

[5] Note that this project is only required to assess mitigation measures related to the detection of a derailment – other mitigation measures are not considered further by this work.

In this case, there is a high likelihood that the contents will be lost, which in the case of dangerous goods may have immediate consequences to people and the environment. This is modelled within our event tree as:

- Contents spill / load lost.

As an alternative, the derailment may not be immediately severe. In this case the train may continue if the driver (or other observer) has not identified the situation. Should the train continue (without detection of the initial derailment) we have assumed that a severe derailment[6] will occur at some time in the future. Conversely, if the initial non-severe derailment is detected then the driver has an opportunity to bring the train to a safe stop.

We have discussed here the branches on our event trees as follows:

- Derailment immediately severe?
- Is partial derailment detected?
- Partially derailed train brought to a safe stop?

The discussions presented above deal with the direct outcomes of the initial derailment. The final part of our analysis considers the possibility of secondary outcomes and impacts.

4.1.4 Secondary Outcomes

An important consideration further influencing the outcome and impacts of a freight train derailment are:

- If a wagon or wagon load fouls an adjacent line.
- If the freight train derailment is then compounded by a secondary event, namely a collision with an approaching passenger or second freight train.

4.1.5 Summary of Consequences (and Impacts)[7]

The event tree presented and described leads to the following potential impacts:

1. Infrastructure damage. Some degree of track damage will occur following a derailment. The extent of this depends on the geography and location of the derailment and also the severity and length of time taken for the train to stop.
2. Rolling Stock damage. Some degree of rolling stock damage will occur following a derailment. The extent of this depends on the geography and location of the derailment and also the severity and length of time taken for the train to stop.
3. Operational disruption. Some degree of operational disruption will occur following a derailment. The extent of this depends on the geography and location of the derailment and also the severity and length of time taken for the train to stop.
4. Injury or loss of life of the train driver as a direct result of the accident.
5. Loss of containment (for Dangerous Goods). This outcome has two components: the potential for loss of life extending beyond the train driver and possibly affecting the wider

[6] We note that it may be possible for an initially non-severe derailment to occur and for the train to continue and re-rail; we have not modelled these cases due to their rarity and problems with data capture for such events.

[7] For the purposes of this report we define consequences as the range of outcomes of the freight train derailment accident whereas impacts are the associated quantified or qualified level of loss associated with the consequence.

population); environmental contamination. We consider the case of freight trains that carry only dangerous goods and those where dangerous goods form only part of the cargo.

6. Secondary event, involving a second train colliding with the derailed train. (From our own analysis [3, accident numbers SE-4, SE-6 and DE-29 apply] there is evidence of such events occurring).

For categories 1 to 5 discussed above, the monetarised impacts as used by the Agency [4] are to be re-used. Additional impacts are to be assessed for item 6 above.

4.1.6 Other Consequence Affecting Factors

There are other consequence affecting factors that have not been specifically modelled. These include, but are not limited to:

1. Rolling down an embankment and involving the general public.
2. Derailing in such a way as to infringe non-rail traffic (principally road traffic).
3. Derailments in tunnels.

We have not modelled these specifically however because there are no data to suggest derailments at these locations are any more common than open-line derailments.

Also, the consequences may not necessarily be more severe. For example a dangerous goods derailment in a tunnel is likely to be contained and not directly affect members of the public, unless the tunnel is hit by another train which is very unlikely. It may be prudent for specific locations such as these to be further considered by a future study.

These are excluded from the present study on the basis of their rarity and therefore low weighted impacts compared with other more likely accident scenarios.

4.2 Analysis of Derailment Causes

4.2.1 Factors Affecting Derailment Causes

Unlike derailment consequences, where the range of outcomes is relatively clear cut, there are a number of issues that make developing a fault tree for derailment causes more challenging. The primary issue is that there is not always a direct cause – effect relationship. This particularly applies to operational and track geometry failures where such events may reduce or eliminate the safety margin, but do not always lead to a derailment.

Notwithstanding these issues, the main mechanism for understanding what may cause a freight train derailment has been the accident analysis and supporting summaries [3, 4]. This analysis tells us that a freight train derailment may occur in the presence of a failure[8] (or combination of failures and/or defects[9]) of the fundamental railway system requirements described above, in Section 3.2. Further it is apparent that some derailment causes are influenced by speed and as a general rule track geometry derailments normally occur at low (less than 40km/h) speed, with the exception of heat buckles. Wagon based failures on the other hand, such as wheelset failures, are more common at higher speeds. Where such a relationship has been established, this factor is built into the frequency analysis, leading to outputs for freight train derailments that occur at both low speeds and high speeds.

In the sections below, we present the results of our analysis into failures that may lead to a freight train derailment.

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[8] We define a failure as a condition that leads to the system not being fit for purpose and outside allowable tolerances

[9] We define a defect as a condition that leads to the system being outside its optimal operating condition, but within working tolerances

4.2.2 Infrastructure Derailment Causes

Derailments caused by infrastructure failures and defects are classified as follows:

1. Failed substructure, comprising:
    a. Subsidence
    b. Earth slide / tunnel collapse (leading to derailment, not collision)
    c. Substructure wash-out due to flooding etc
    d. Bridge failure (leading to derailment)
2. Structural failure of the track superstructure, comprising:
    a. Rail failures
    b. Joint bar & plug rail failures
    c. Switch component structural failure
    d. Failure of rail support and fastening
    e. Track superstructure unsupported by substructure
    f. Other track and superstructure failure
3. Track geometry failure, comprising:
    a. Excessive track twist
    b. Track height/cant failure
    c. Lateral track failure
    d. Track buckles (heat-curves)
    e. Excessive track width
    f. Other or unspecified track geometry causes
4. Other infrastructure failures

For referencing purposes, these derailment causes are classified using this numbering structure; for example derailment causes associated with substructure are classified I_1"n", where "n" represents the specific sub-cause. This nomenclature is used within the fault trees reported in Section 4.4.

4.2.3 Rolling Stock Derailment Causes

Derailments caused by rolling stock failures and defects are classified as follows:

1. Wheelset failures (wheels and axles), comprising:
    a. Axle ruptures:
        i. Hot axle box and axle journal rupture
        ii. Axle shaft rupture
        iii. Axle rupture, location not known
    b. Wheel failure:
        i. Rupture of monoblock wheel
        ii. Failure of composite wheel with rim and tyre

iii. Excessive flange or wheel tread wear (wrong wheel profile)

2. Bogie and suspension failures, comprising:
    a. Failure of bogie structure and supports
    b. Spring & suspension failure
    c. Other
3. Twisted or broken wagon structure/frame
4. Wagon with too high twist stiffness in relation to length
5. Brake component failure
6. Other or unknown rolling stock derailment cause

For referencing purposes, these derailment causes are classified using this numbering structure; for example derailment causes associated with wheelset failures are classified RS_1A"n", where "n" represents the specific sub-cause. This nomenclature is used within the fault trees reported in Section 4.4.

4.2.4 Operational (including Train Control) Derailment Causes

Derailments caused by operational failures and defects are classified as follows:

1. Train composition failures, comprising:
    a. Unfavourable train composition (empties before loaded wagons)
    b. Other
2. Improper loading of wagon, comprising:
    a. Overloading
    b. Skew loading
        i. Wagon wrongly loaded
        ii. Wagon partly unloaded
    c. Insufficient fastening of load
    d. Other incorrect loading
3. Train check and brake testing, comprising:
    a. Un-suitable brake performance for route characteristics
    b. Brakes not properly checked or tested
    c. Brakes not correct set with respect to load or speed of brake application
4. Wrong setting of points/turnouts, comprising:
    a. Wrong setting in relation to movement authority
    b. Point switched to new position while point is occupied by train
5. Mishandling of train en route, comprising:
    a. Overspeeding:
        i. Too high speed through turnout in deviated position
        ii. Too high speed elsewhere

    b. Other mishandling of train

6. Brake shoe or other object left under train

7. Other operational failures

For referencing purposes, these derailment causes are classified using this numbering structure; for example derailment causes associated with improper loading/skew loading of wagons are classified O_2B"n", where "n" represents the specific sub-cause. This nomenclature is used within the fault trees reported in Section 4.4.

4.2.5 Combinational Derailment Causes

In addition to single failures that are reported to be the primary cause of freight train derailments, combinations of defects may also work together in certain circumstances to lead to the same outcome. These defects may be outside of normal operating parameters, but not sufficiently so to require their immediate repair.

As an example, the following freight train derailment occurred on 12 December 2006 at Dombås station, Norway[10]:

"Train 5709 on route from Oslo (Alnabru) to Trondheim derailed with one axle when entering track 3 at Dombås station via turnout no 1. The train weight was 908 tonnes with a train length of 466 m, all exclusive of locomotives. At the exit of the station another couple of axles had derailed. A total of 4 axles derailed altogether. The derailed axles belonged to 2 short coupled autocar wagons with a long wheel base. The overall length of the wagon assembly was 25.76 metres.

The derailment cause is judged to be a combination of 2 factors:

1. A track defect comprising a low left rail in front of turnout no 1 at the station.

2. Damage to spring suspension of the wagon, partly caused by a previous non-repaired failure. The wagon was also involved in the 26 July derailment between Dombås and Dovre.

The accident cause was a combination of faulty track and faulty rolling stock suspension.

Other common combinations (limited to second order events, i.e. those involving two causes) are referred to in the fault trees reported in Section 4.4. These are shown below.

[10] SHT/JB 2008/03

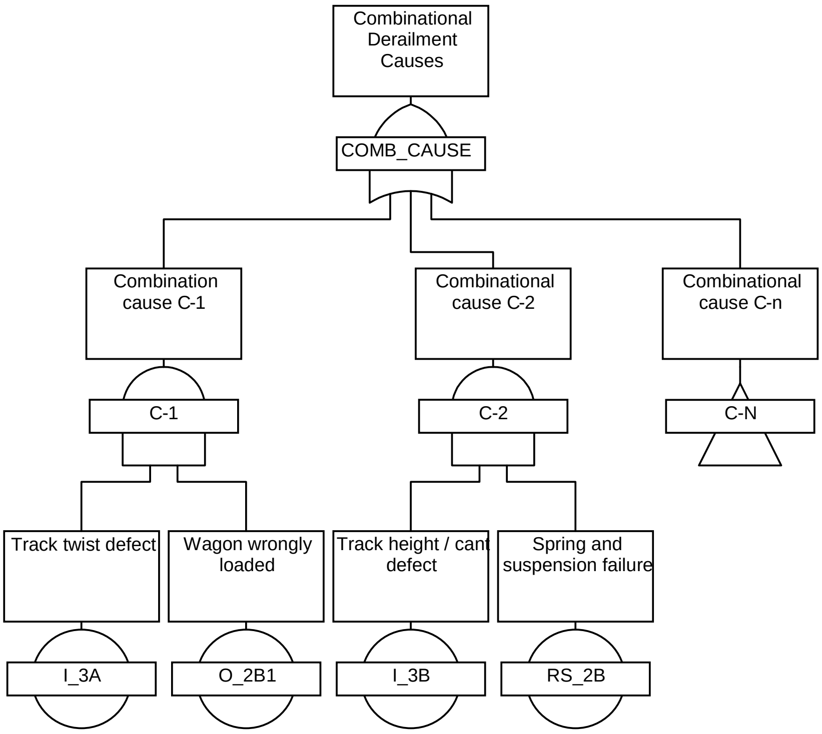
Table 1 Some of the Combinational Causes Modelled

Category		C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10	C-11	C-12	C-13	C-14	C-15	C-16	C-17
Infrastructure	Env									1								
	1.a.																	
	1.b.																	
	1.c.																	
	1.d.																	
	2.a.			1														
	2.b.			1														
	2.c.																	
	2.d.												1					
	2.e.															1		
	3.a.	1					1	1	1					1	1	1		
	3.b.		1															
	3.c.							1										
	3.d.																1	
	3.e.				1								1					
Rolling Stock	1.a.i).																	
	1.a.ii).																	
	1.a.iii)																	
	1.b.i)																	
	1.b.ii).																	
	1.b.iii)																1	1
	2.a.																	
	2.b.		1															
	3						1											
	4													1				
	5																	
Operations	1.a.											1						1
	2.a.										1							
	2.b.i)	1							1									
	2.b.ii)														1			
	2.c.										1							
	3.a.																	
	3.b.																	
	3.c.																	
	4.a.																	
	4.b.					1												
	5.a.i)																	
	5.a.ii)				1													
	5.b.					1				1		1						
	6																	

Note that the category reference uses the numbering system above (e.g. Infrastructure 2a is rail failure).

In terms of a fault tree structure, an example of how these are combined is presented below (for C-1 and C-2).

Figure 2: Example Structure for Combinational Causes C-1 and C-2



4.2.6 Other Causal Affecting Factors

There are other derailment causal affecting factors that have not been specifically modelled. These include, but are not limited to:

1. Failures of high integrity systems, such as signalling interlocking.
2. Derailment that are caused by certain external events, such as intentional acts.

These are either out of scope, or are considered rare compared with more frequent freight train derailment causes.

4.3 Organisational Issues Affecting Derailment Causes (and Consequences)

4.3.1 The European Railway Safety Directive

The European Railway Safety Directive (2004/49/EC) [6] supports the development of open and transparent access to the European rail market. The Directive, which was introduced in 2004, establishes a common regulatory framework designed to ensure that safety does not present a barrier to the establishment of a single market for railways, and includes organisational requirements, which include:

- The establishment of Common Safety Indicators (CSIs) which are high level indicators of significant risks to the mainline rail network (e.g. signals passed at danger and broken rails).
- The establishment of Common Safety Methods (CSMs) which are harmonized approaches to risk management, the exchange of safety relevant information and the evidence resulting from the application of a risk management process. These will include the Common Safety Method on Supervision and the Common Safety Method on Monitoring, although these are not in force yet.
- The establishment of Common Safety Targets (CSTs) which define the minimum safety levels and safety performance that must at least be reached by the system as a whole in each Member State, expressed as national reference values for individual risks to passengers, employees, level crossing users, 'others' and unauthorized persons on the railway.
- The requirement for Safety Authorizations and Certificates which requires the Member States' National Safety Authority (NSA) to grant safety authorizations to Infrastructure Managers and safety certificates to Railway Undertakings (e.g. train operating companies). The purpose of safety authorizations/certificates is to provide evidence that railway operators have established suitable Safety Management Systems (SMS) and are operating in accordance with them. In this regard the Common Safety Method on Conformity Assessment sets out legally the harmonised way in which all NSAs should approach assessments prior to the award of safety certificates and safety authorisations and establishes principles they need to apply to supervision after the award of the safety certificate or safety authorisation.
- The Investigation of Accidents.
- Provisions for Audits, Inspections, Supervision and Controls.

The degree to which these are applied has an influence on the accident frequency (and in some cases potentially the consequences). The linkage between a failure of these controls and a freight train derailment may typically follow one of the sequences below:

Initiating event - **Failure to enforce maintenance controls:**

1. Maintenance not performed;

   → potentially leading to rolling stock or infrastructure out of tolerance

      → potentially leading to derailment

Initiating Event: **Lack of engagement of senior management:**

2. Potentially leading to poor safety culture / de-motivated staff;

   → potentially leading to failure to apply documented controls or to "cut corners"

      → potentially leading to derailment

To this extent failures of this type may be root causes that lead to a freight train derailment.

4.3.2 Assessment of Organisational Failures

The assessment of such issues is a challenging task, for the following reasons:

- Whilst accident investigations and summaries normally present intermediate causes (e.g. “derailment due to excessive track twist”, etc), these often do not identify root causes. (For example, an organisational cause may be the lack of adequate resources, of a method to prioritise maintenance activities.)
- There is no generally accepted method that we are aware of to assess the impact that an SMS of differing levels of maturity may have on the performance of an organisation.
- There is often no direct cause – effect relationship between an organisational failure and, in this case, a freight train derailment.

However, we can conclude the following:

- Where a derailment has occurred due to e.g. excessive track twist, this is generally an organisational failure because it represents a situation when agreed parameters have not been applied (further in some cases this situation is known about by the IM).
- Other organisational failures may include failure to deal with information in an appropriate manner. Examples that fall into this category include failure to deal with hot axle box or other warnings that may be raised.
- Most failures associated with locomotives and wagons fall into the organisational category, as they normally represent failures to comply with standards and regulations, lack of training etc.
- Indeed, there are only a small number of failures that could be classed as non organisational; these may include sudden environmental events, and some failures that may be difficult to identify (for example those that require in-depth investigation and inspection and cannot be cost effectively performed on a regular basis).

Considering these factors, we shall assess organisational failures on a qualitative basis within our final part B activities.

4.4 Fault and Event Tree Models

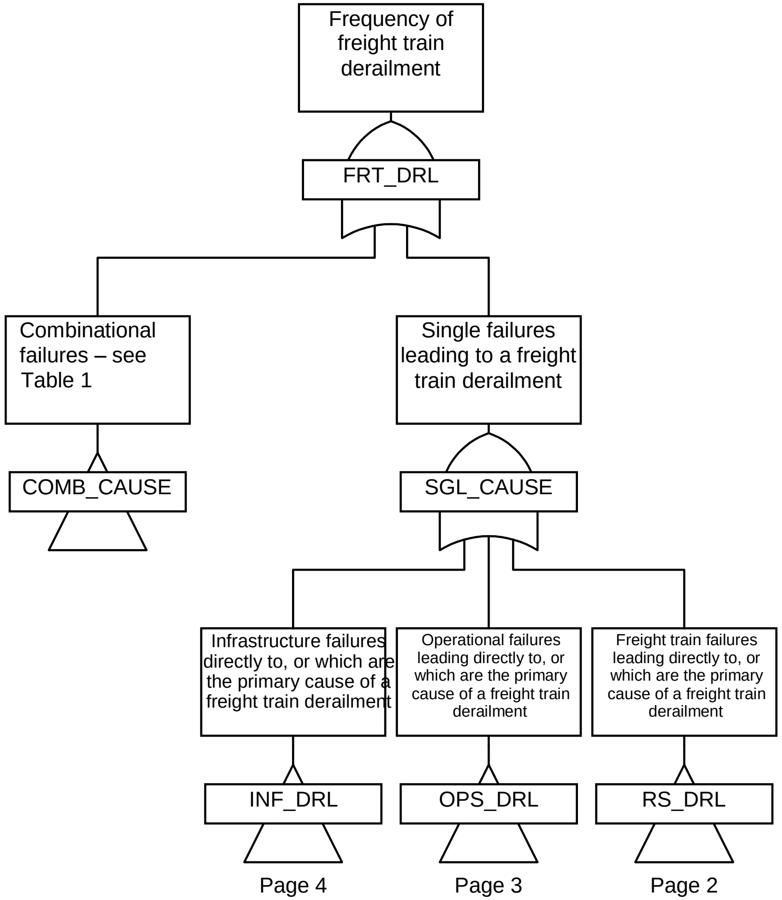
We have developed fault and event trees to provide a fuller picture of the freight train derailment problem. We point out the following in relation to the use of this technique (or of any other predictive technique):

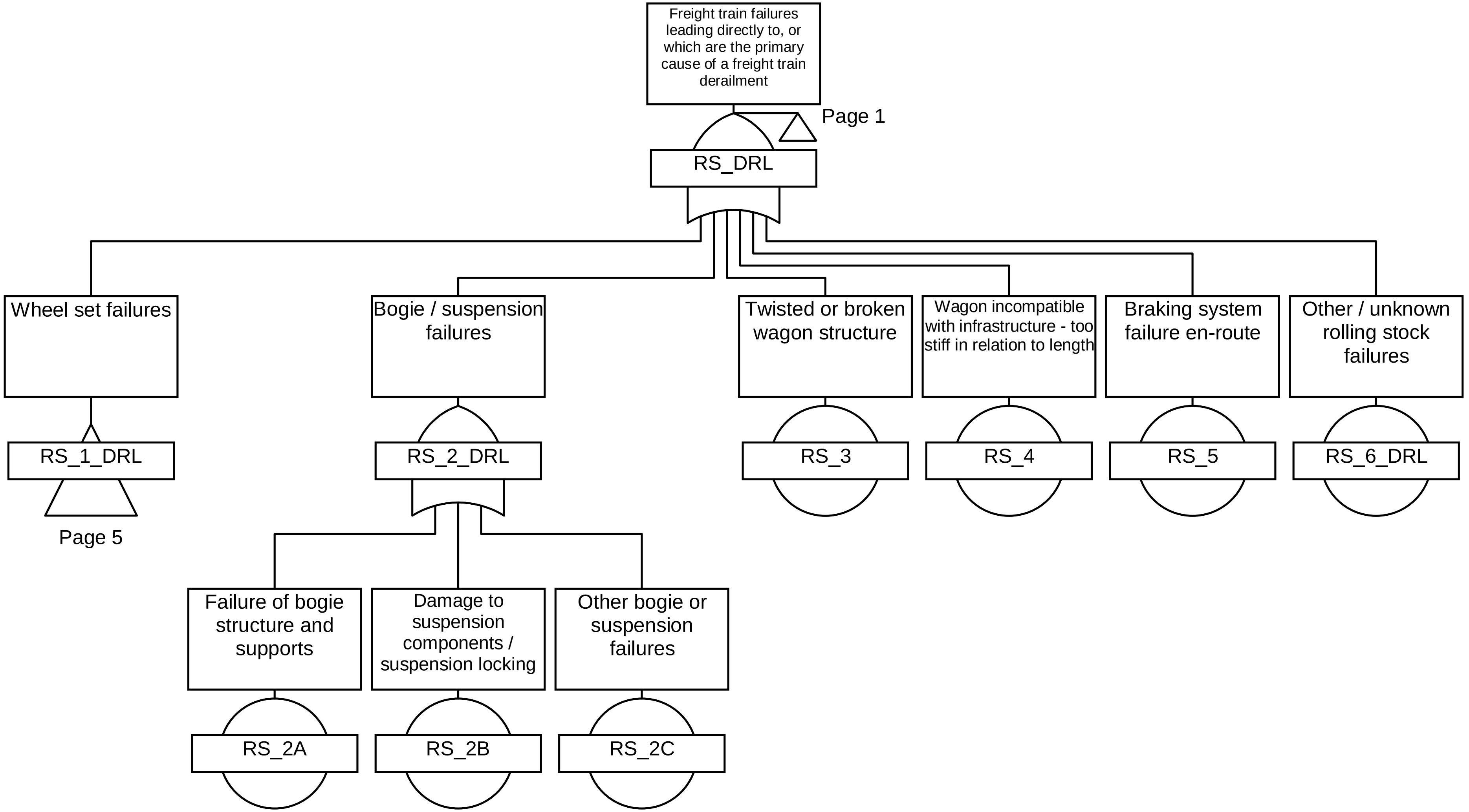
1. The use of event trees to represent consequences is, we consider, relatively straightforward and robust as the range of outcomes is predictable.
2. For fault trees however there are some challenges and limitations that need to be considered:
    a. Available data (from accident reports, which is the main data source for our models) is inconsistent in its approach to identifying causes. In some cases root causes are specified, whilst in other intermediate causes are identified.
    b. Fault and event trees assume a direct cause / effect relationship (or for the analyst to build into the model the appropriate factors to represent this relationship).

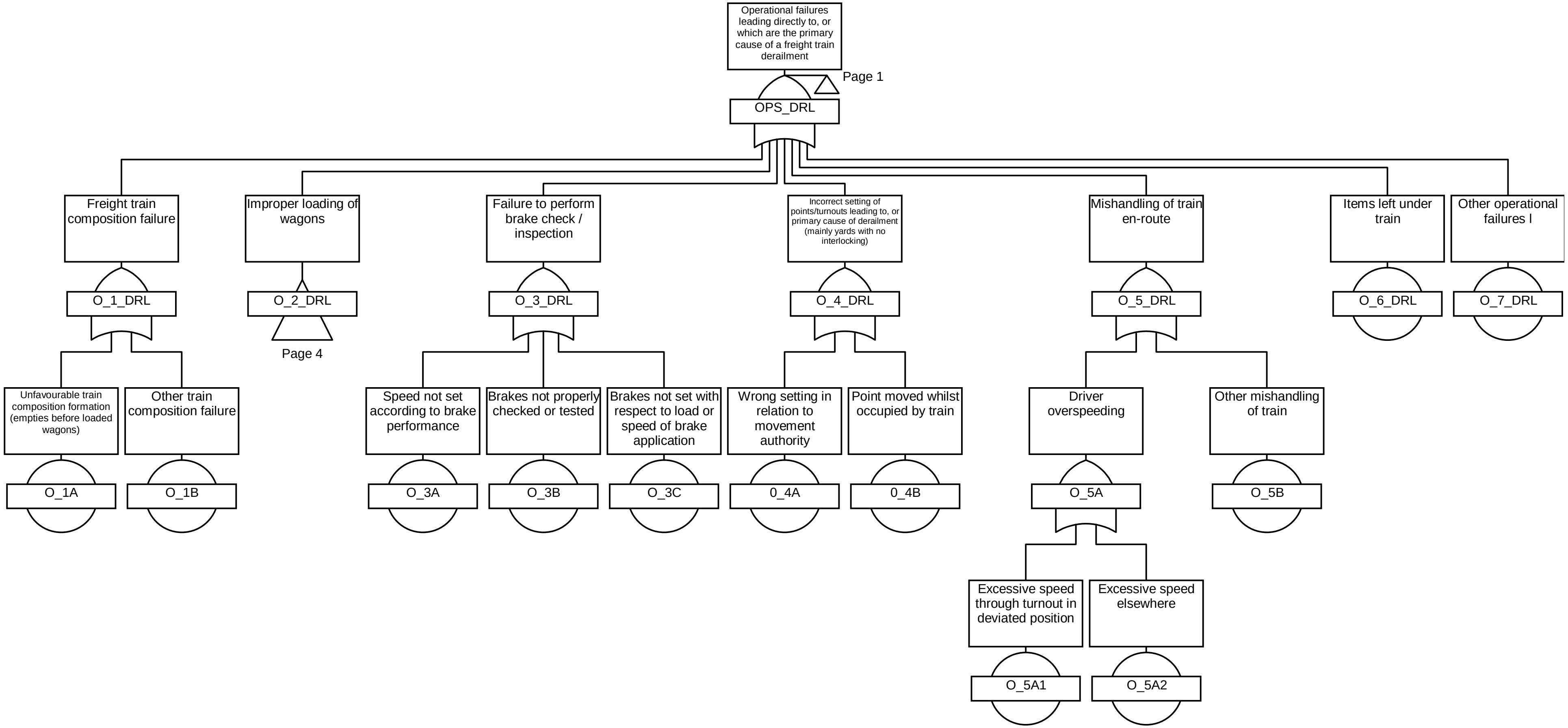
Considering these factors, the fault and event trees models presented below are developed to a level that is supported by robust data, and/or which can be supported with the use of conservative assumptions.

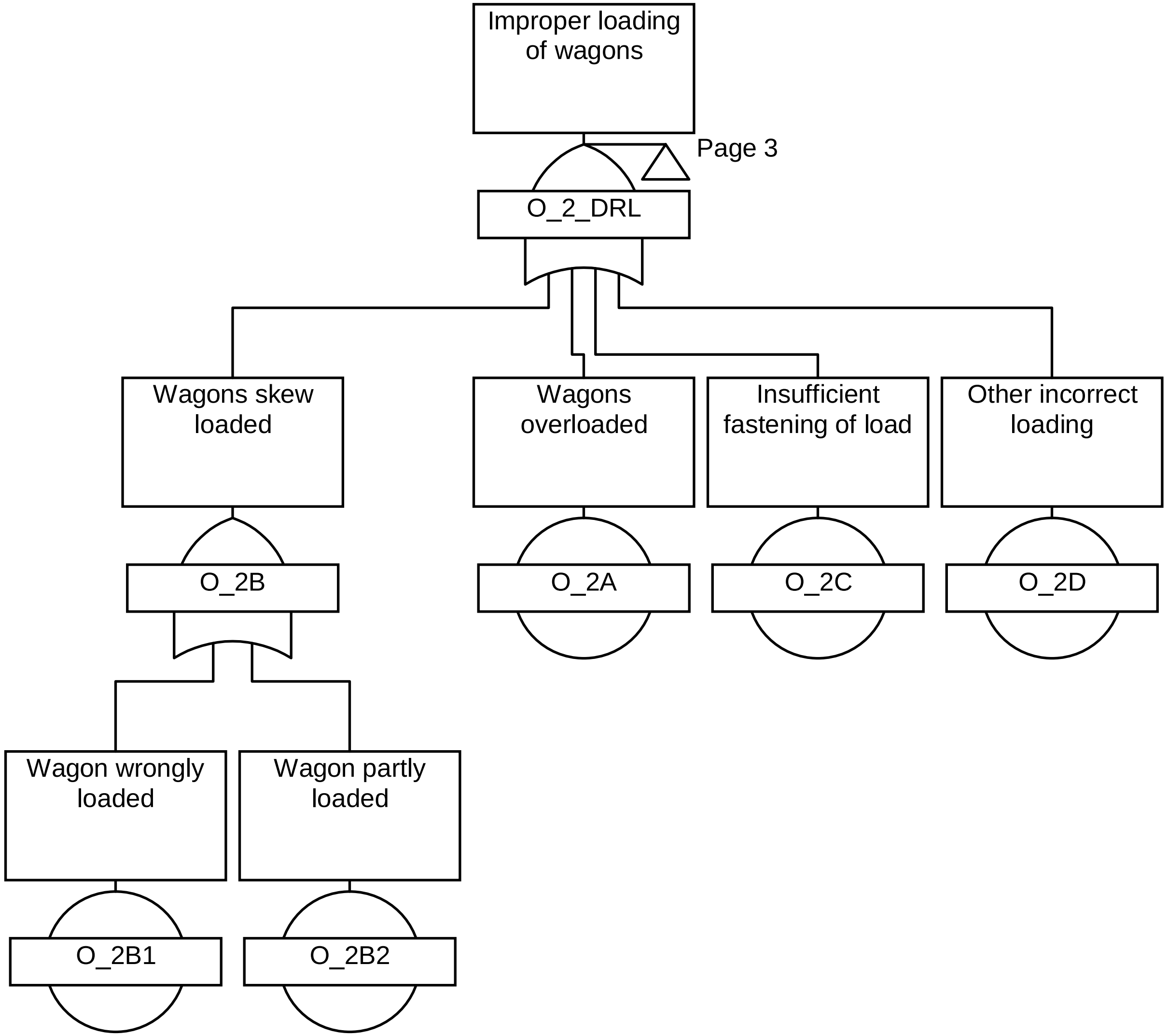
Figure 3: Fault and Event Tree Model

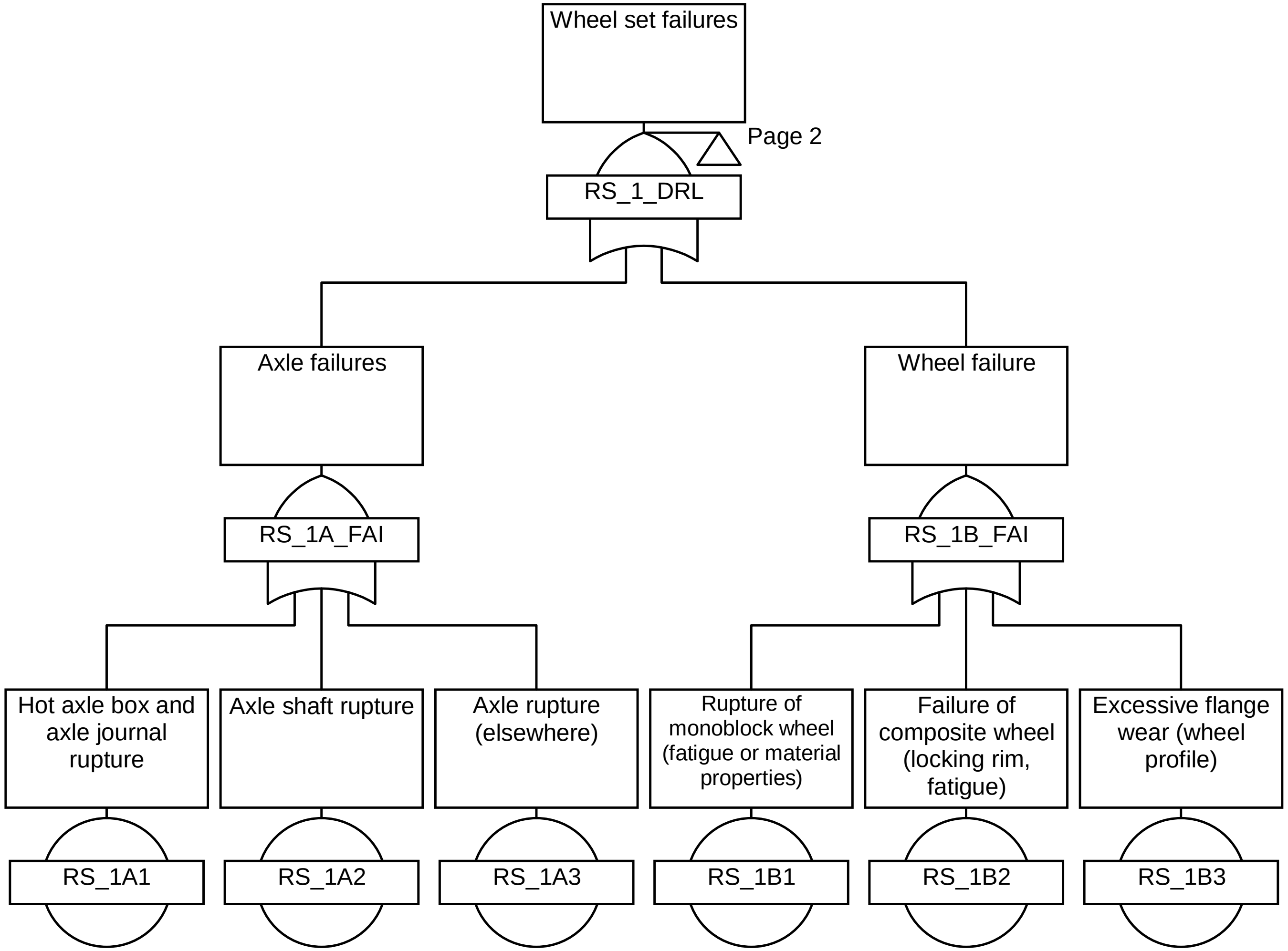
Note that there are two fault trees, one for low speed and one for high speed. Only one is shown (the only difference being that different data is used for each).

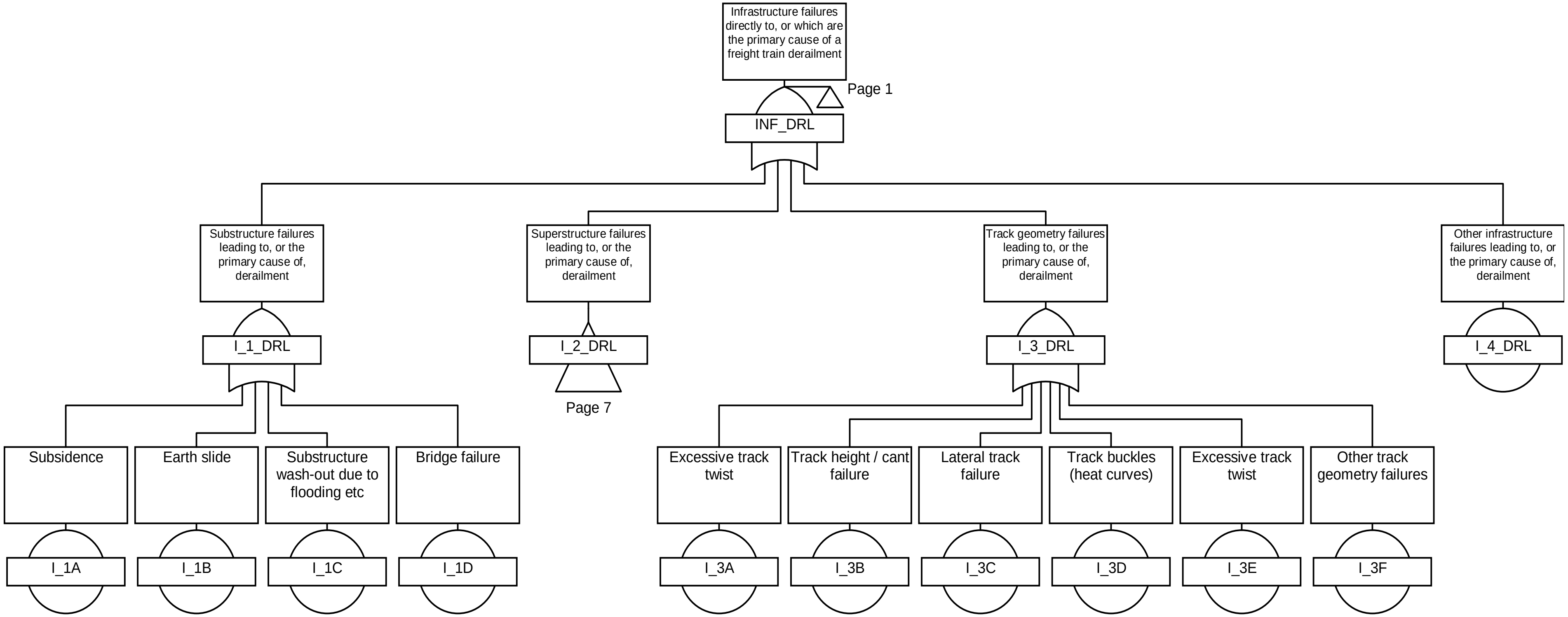


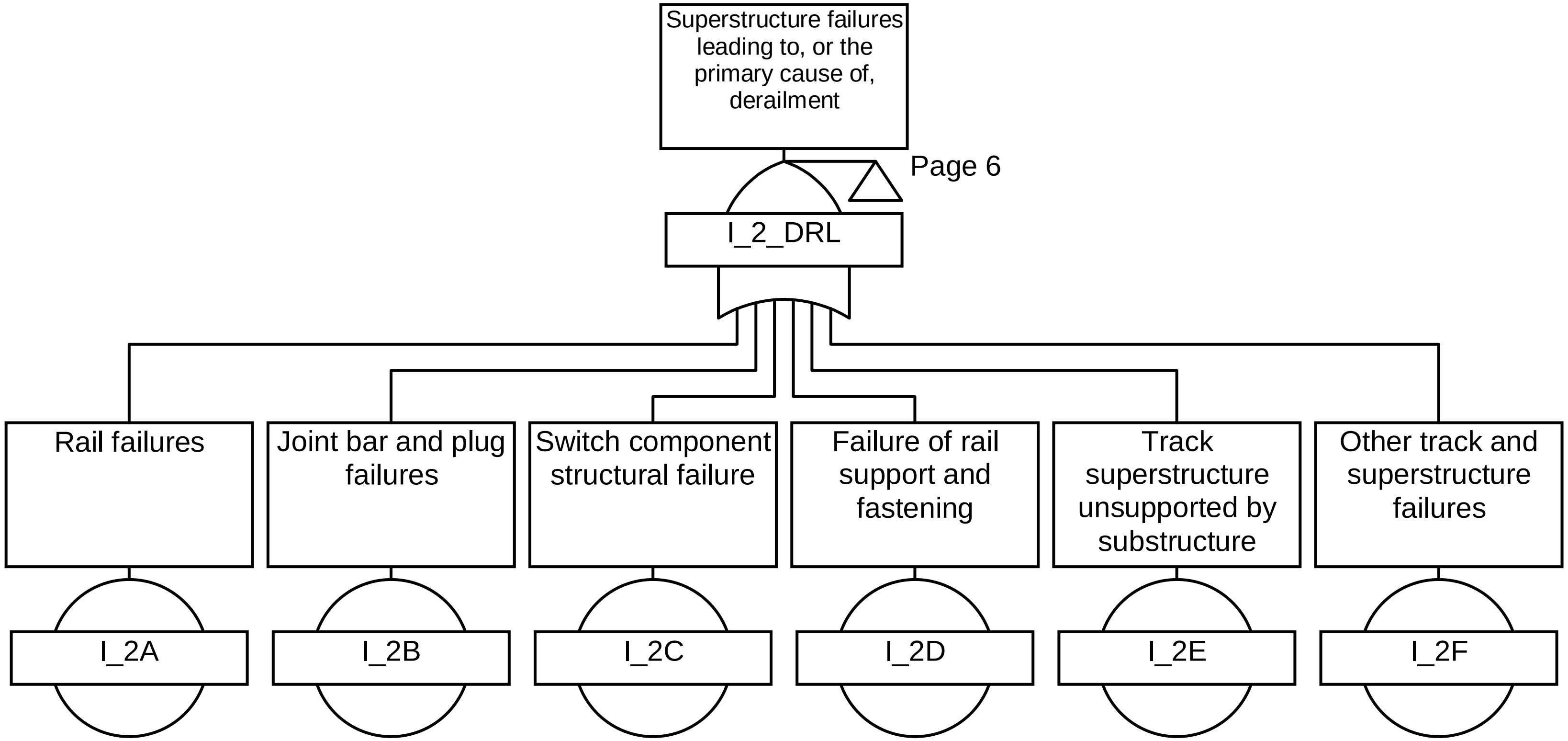

Freight train failures leading directly to, or which are the primary cause of a freight train derailment
Page 1
RS_DRL
Wheel set failures
RS_1_DRL
Page 5
Bogie / suspension failures
RS_2_DRL
Failure of bogie structure and supports
RS_2A
Damage to suspension components / suspension locking
RS_2B
Other bogie or suspension failures
RS_2C
Twisted or broken wagon structure
RS_3
Wagon incompatible with infrastructure - too stiff in relation to length
RS_4
Braking system failure en-route
RS_5
Other / unknown rolling stock failures
RS_6_DRL


Operational failures leading directly to, or which are the primary cause of a freight train derailment
Page 1
OPS_DRL
Freight train composition failure
O_1_DRL
Unfavourable train composition formation (empties before loaded wagons)
O_1A
Other train composition failure
O_1B
Improper loading of wagons
O_2_DRL
Page 4
Failure to perform brake check / inspection
O_3_DRL
Speed not set according to brake performance
O_3A
Brakes not properly checked or tested
O_3B
Brakes not set with respect to load or speed of brake application
O_3C
Incorrect setting of points/turnouts leading to, or primary cause of derailment (mainly yards with no interlocking)
O_4_DRL
Wrong setting in relation to movement authority
0_4A
Point moved whilst occupied by train
0_4B
Mishandling of train en-route
O_5_DRL
Driver overspeeding
O_5A
Excessive speed through turnout in deviated position
O_5A1
Excessive speed elsewhere
O_5A2
Other mishandling of train
O_5B
Items left under train
O_6_DRL
Other operational failures I
O_7_DRL


Improper loading of wagons
Page 3
O_2_DRL
Wagons skew loaded
Wagons overloaded
Insufficient fastening of load
Other incorrect loading
O_2B
O_2A
O_2C
O_2D
Wagon wrongly loaded
Wagon partly loaded
O_2B1
O_2B2

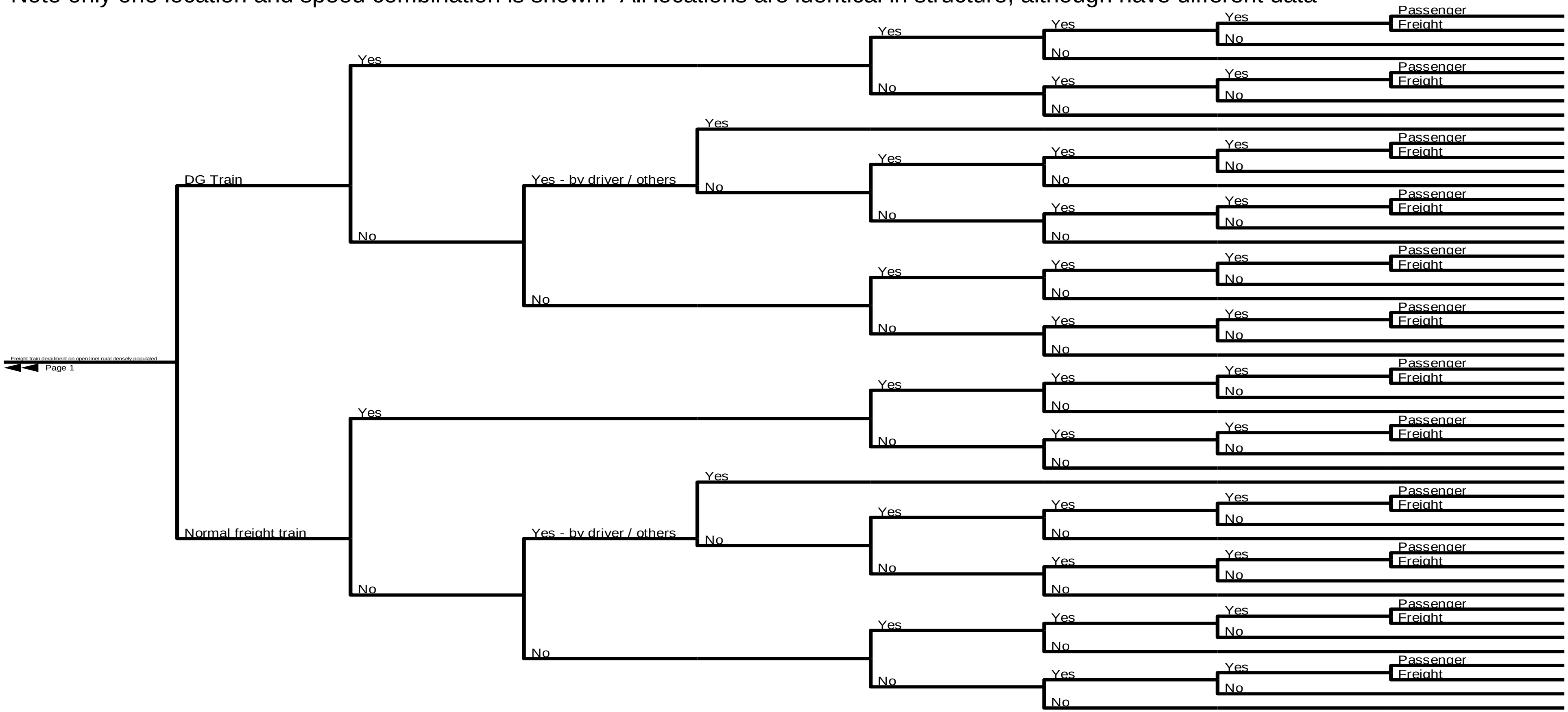

Wheel set failures
Page 2
RS_1_DRL
Axle failures
Wheel failure
RS_1A_FAI
RS_1B_FAI
Hot axle box and axle journal rupture
Axle shaft rupture
Axle rupture (elsewhere)
Rupture of monoblock wheel (fatigue or material properties)
Failure of composite wheel (locking rim, fatigue)
Excessive flange wear (wheel profile)
RS_1A1
RS_1A2
RS_1A3
RS_1B1
RS_1B2
RS_1B3


Infrastructure failures directly to, or which are the primary cause of a freight train derailment
Page 1
INF_DRL
Substructure failures leading to, or the primary cause of, derailment
I_1_DRL
Superstructure failures leading to, or the primary cause of, derailment
I_2_DRL
Page 7
Track geometry failures leading to, or the primary cause of, derailment
I_3_DRL
Other infrastructure failures leading to, or the primary cause of, derailment
I_4_DRL
Subsidence
I_1A
Earth slide
I_1B
Substructure wash-out due to flooding etc
I_1C
Bridge failure
I_1D
Excessive track twist
I_3A
Track height / cant failure
I_3B
Lateral track failure
I_3C
Track buckles (heat curves)
I_3D
Excessive track twist
I_3E
Other track geometry failures
I_3F


Superstructure failures leading to, or the primary cause of, derailment
Page 6
I_2_DRL
Rail failures
Joint bar and plug failures
Switch component structural failure
Failure of rail support and fastening
Track superstructure unsupported by substructure
Other track and superstructure failures
I_2A
I_2B
I_2C
I_2D
I_2E
I_2F

Does derailment occur on open line?	DG or other freight train?	Derailment immediately severe?	Is partial derailment detected?	Partially derailed train brought to safe stop?	Contents spill / load lost?	Wagon or load fouls adjacent line?	Wagon or load hit by train on adjacent line?	Other train type affected is passenger train?

Note only one location and speed combination is shown. All locations are identical in structure, although have different data



4.5 Barrier Model

4.5.1 What is a Barrier Model?

In our report [5] we provided a list of close to 60 barriers (or measures) that are now or could in the future be applied to reduce either the likelihood or consequence of a freight train derailment.

However, to depict preventive barriers on a fault tree would normally require a new model construct to be developed; this would introduce a logical AND gate into every part of the model where the barrier applied leading to a complex and cumbersome model. We have therefore chosen to show the barriers on a “barrier model”.

4.5.2 Causal Measures Barrier Model

In our Functional and Performance report [5] we developed a relationship between safety functions and causal mitigation measures, as shown in Table 2.

We have translated this onto a barrier model as shown in Figure 4. The purpose of the barrier model is to show a simplified structure of the failures that may lead to a derailment, and the barriers that are (or could be) in place to reduce the likelihood of that cause leading to a derailment.

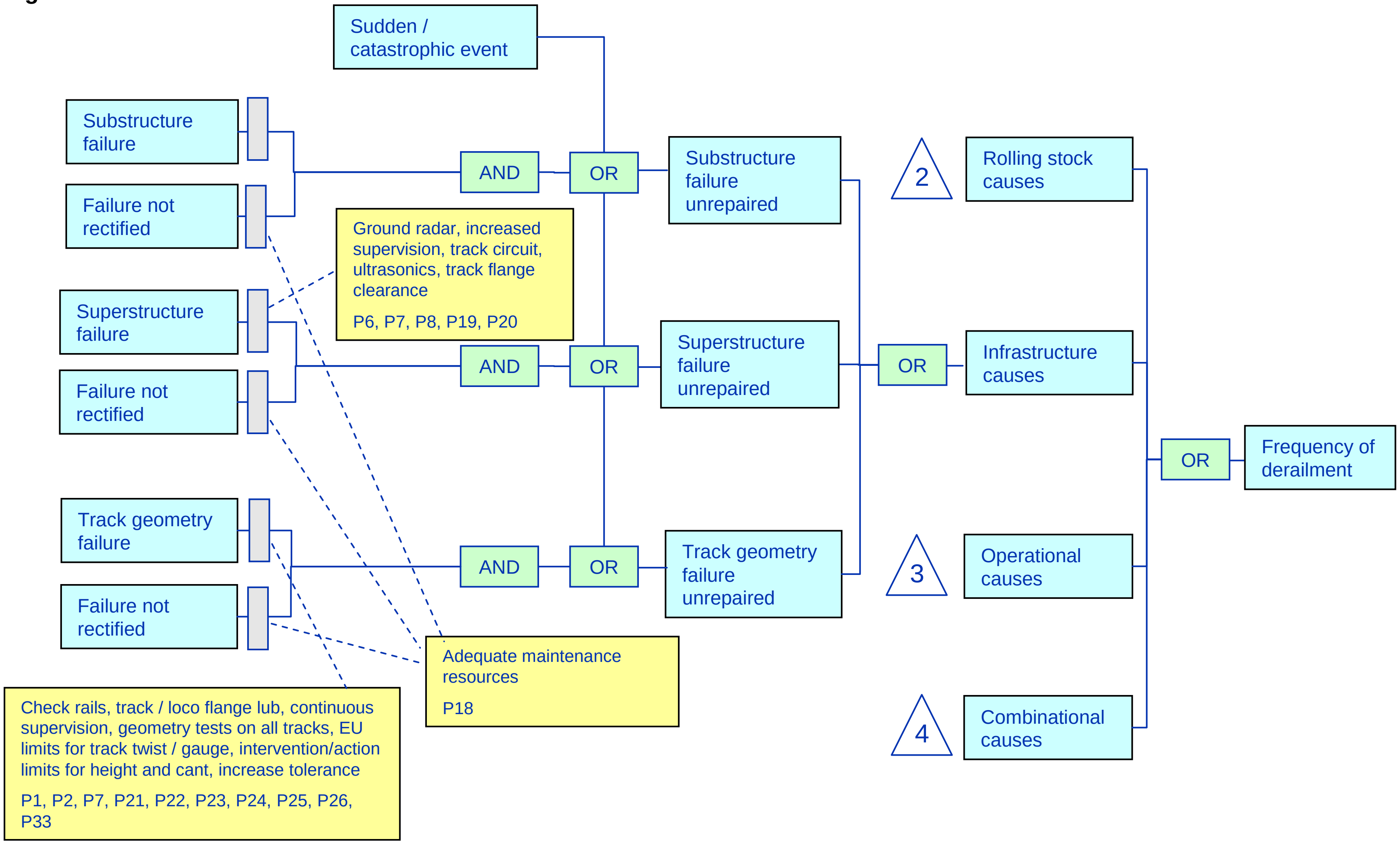
As an example the barrier model depicts on page 2 of Figure 4 the measures that apply to the detection of hot axle boxes.

Table 2 Link between Derailment Cause and Prevention Measure

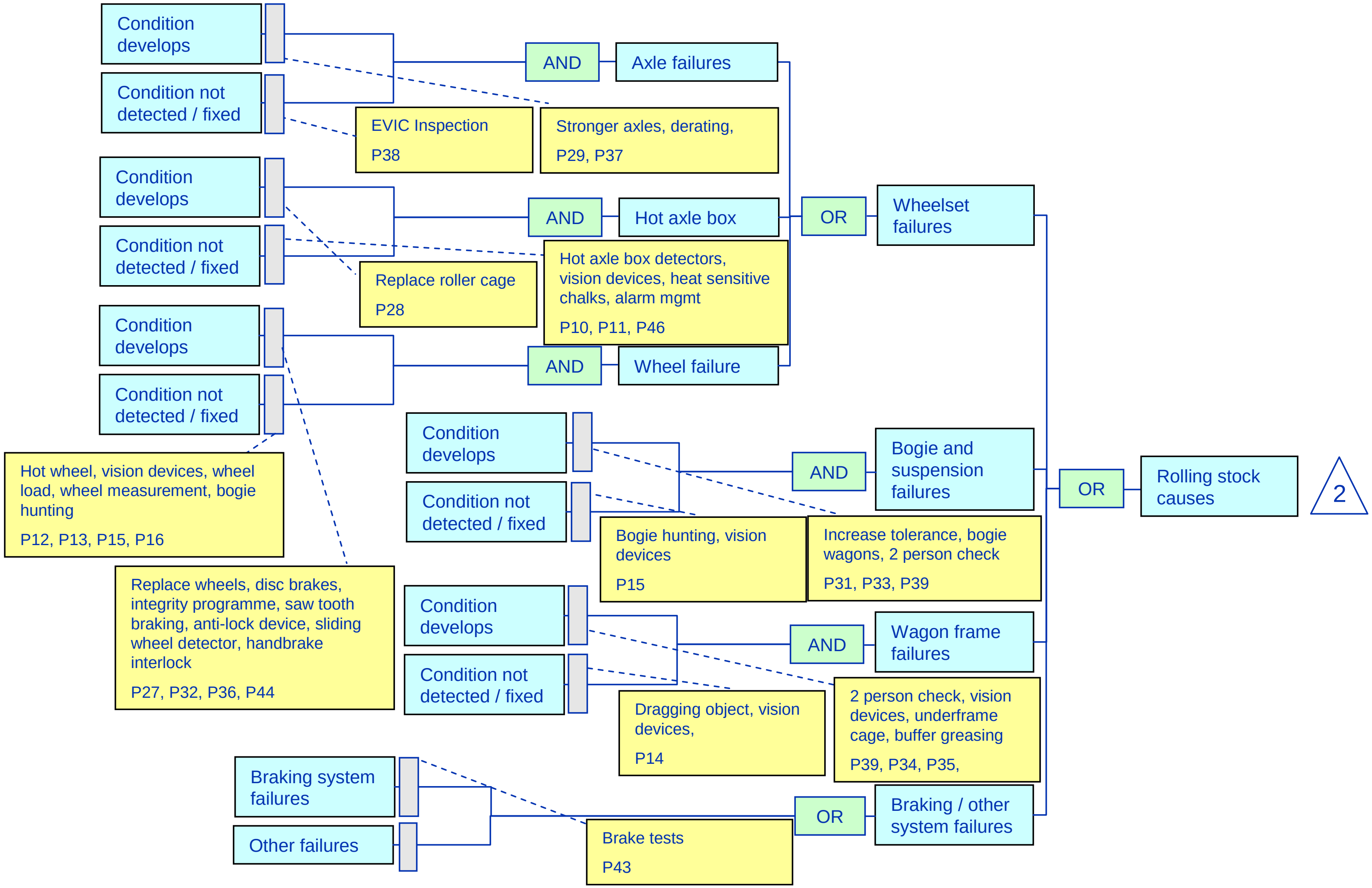
Derailment Cause	Safety Function	Measure	P#	Comment
Axle failure / seizure	Monitor axle bearing temperature	Hot axle box detectors	P-10	
		Acoustic bearing monitoring	P-11	
		Machine vision device	N/A	Potential future measure
		Use of thermo-sensitive materials to detect axle temperature condition	N/A	Potential future measure
	Prevent Axle Failure	Replace metal roller cages with alternative materials	P-28	
		Use of stronger axles	P-29	
		Derating of axle loads	P-37	
		Inspect axles of freight train rolling stock according to EVIC	P-38	
Track geometry defects / failures	Maintain track geometry within acceptable limits	Track geometry tests on all tracks	P-21	
		Establish EU-wide limits for track twist	P-22	
		Establish EU-wide limits for track gauge	P-23	
		Establish intervention/immediate action limits for track cant	P-24	
		Establish intervention/immediate action limits for track height	P-25	
		Continuous supervision of track conditions via rolling stock mounted equipment	P-7	
		Adequate maintenance resources for network	P-18	Derailment is one possible consequence
	Rolling stock to be more tolerant to geometry defects	Increase rolling stock tolerance to track twist defects	P-33	
	Detection of potential superstructure defects	Ground penetration radar	P-6	
Rail ruptures / failures	Detection of potential / existing rail ruptures	Continuous supervision of track conditions via rolling stock mounted equipment	P-7	
		Track circuit to detect rail ruptures	P-8	Derailment prevention is a secondary benefit
		Ultrasonic inspection of rail to detect onset of rupture conditions	P-20	Derailment is one possible consequence
Flange climb	Prevent flange climbing	Check rail in sharp curves	P-1	
		Track and flange lubrication (infrastructure)	P-2	Derailment prevention is a secondary benefit
		Bogie performance monitoring equipment	P-15	
		Flange lubrication of locomotives	P-26	Derailment prevention is a secondary benefit
Collision with obstructions	Prevent collision with obstruction	Rock scree and avalanche protection structures	P-3	Derailment is a secondary consequence
		Rock scree and avalanche detectors	P-4	Derailment is a secondary consequence
		Level crossing obstacle detectors	P-5	Derailment is a secondary consequence
		Clear track flange from obstructions	P-19	Derailment is the primary consequence

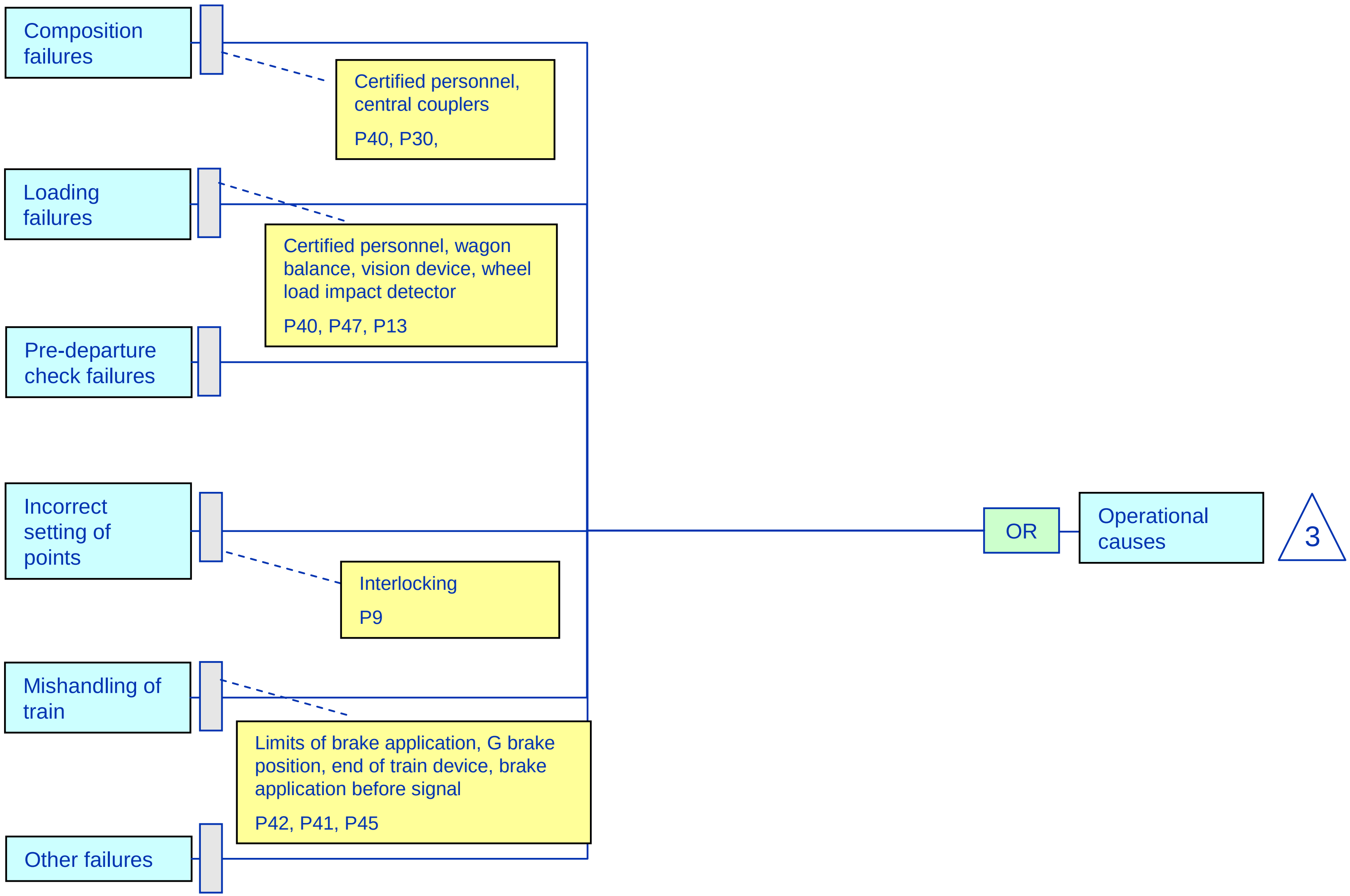
Derailment Cause	Safety Function	Measure	P#	Comment
Points movement under train	Prevent points movement under train	Interlocking to prevent points movement whilst track occupied	P-9	
Wheel structural or profile failure	Monitor wheel / brake temperature	Hot wheel / hot brake detectors	P-12	
		Machine vision device	N/A	Potential future measure
	Detect wheel defects	Wheel load / wheel load impact detector	P-13	
		Wheel profile measurement systems	P-16	
		Machine vision device	N/A	Potential future measure
	Prevent wheel failure	Replace composite wheels with monoblock wheels	P-27	
		Replace tread brakes for disc brakes (reduce heat activation)	P-32	Derailment prevention is a secondary benefit
		Wheel set integrity inspection programme	P-36	
		Saw tooth braking to limit heat exposure on wheels	P-44	
		Anti-lock device	N/A	Potential future measure
		Use of trackside sliding wheel detector	N/A	Potential future measure
		Install handbrake interlock to prevent train movement with handbrake applied	N/A	Potential future measure
Overloading / skew loading / improper loading	Detect improper loading conditions	Wheel load / wheel load impact detector	P-13	
		Loading gauge infringement detectors	P-17	Derailment is one possible consequence
		Machine vision device	N/A	Potential future measure
	Prevent improper loading conditions	Use of registered and certified loading personnel	P-40	
		Use of wagon balance to detect overload conditions	P-47	
Loose equipment	Detect / prevent dragging loose equipment	Dragging object detector	P-14	May also detect derailed axles
		Install under-frame cages to retain brake components	P-34	
		Regular greasing / check of buffers to prevent them falling off	P-35	
		Machine vision device	N/A	Potential future measure
Wagon/ rolling stock failures	Detect bogie hunting (steering) problems	Bogie performance monitoring equipment	P-15	
	Better riding quality	Increased use of bogie wagons	P-31	Derailment prevention is one possible benefit
	Prevent safety failures of rolling stock	Safety critical maintenance activities to be checked by two persons	P-39	
Train composition failures / buffer locking	Reduce compression forces and buffer locking	Use of central couplers	P-30	
		Locomotive and first wagon to be in brake position G	P-41	
		Operational limit on brake application in certain track geometry	P-42	
		End of train device	N/A	Potential future measure
Train braking failure	Detect onset of train brake defects	Perform dynamic brake testing during operation to detect defects	P-43	
Overspeeding	Prevent overspeeding	Initiate braking prior to passing signal to reduce overspeeding risk	P-45	
Failure to take correct action when alarm raised	Alarm management	Implement / improve alarm management instructions	P-46	

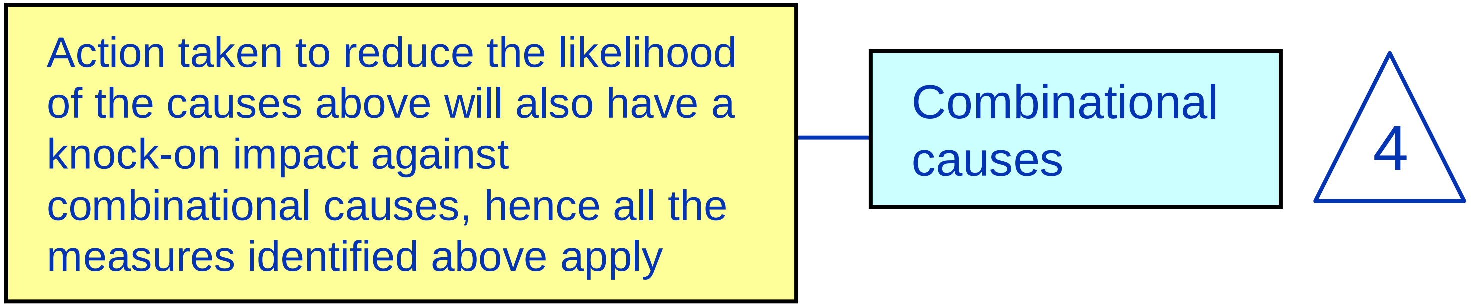
Figure 4: Causal Barrier Model



MANAGING RISK


Condition develops
Condition not detected / fixed
AND
Axle failures
EVIC Inspection
P38
Stronger axles, derating,
P29, P37
Condition develops
Condition not detected / fixed
AND
Hot axle box
OR
Wheelset failures
Replace roller cage
P28
Hot axle box detectors, vision devices, heat sensitive chalks, alarm mgmt
P10, P11, P46
Condition develops
Condition not detected / fixed
AND
Wheel failure
Hot wheel, vision devices, wheel load, wheel measurement, bogie hunting
P12, P13, P15, P16
Replace wheels, disc brakes, integrity programme, saw tooth braking, anti-lock device, sliding wheel detector, handbrake interlock
P27, P32, P36, P44
Condition develops
Condition not detected / fixed
AND
Bogie and suspension failures
Bogie hunting, vision devices
P15
Increase tolerance, bogie wagons, 2 person check
P31, P33, P39
OR
Rolling stock causes
2
Condition develops
Condition not detected / fixed
AND
Wagon frame failures
Dragging object, vision devices,
P14
2 person check, vision devices, underframe cage, buffer greasing
P39, P34, P35,
Braking system failures
Other failures
Brake tests
P43
OR
Braking / other system failures


Composition failures
Certified personnel, central couplers
P40, P30,
Loading failures
Certified personnel, wagon balance, vision device, wheel load impact detector
P40, P47, P13
Pre-departure check failures
Incorrect setting of points
Interlocking
P9
Mishandling of train
Limits of brake application, G brake position, end of train device, brake application before signal
P42, P41, P45
Other failures
OR
Operational causes
3


Action taken to reduce the likelihood of the causes above will also have a knock-on impact against combinational causes, hence all the measures identified above apply
Combinational causes
4

4.5.3 Mitigation Measures Barrier Model

We have not developed a barrier model for measures that affect derailment frequency. This is because the only consequence mitigation barriers being assessed by this project are those related to derailment detection, see Table 3. With reference to the event tree, these apply only in one location, under the node “Is partial derailment detected?”

Table 3 Link between Derailment Consequence Safety Function and Measure

Safety Function	Measure	M#
Reduce severity of derailment	Install DDD that apply brakes on detection of a derailment	M-1a
	Install a detection device which provides an alarm to the train driver when derailment is suspected	M-1b
	Install mechanical guides to keep derailed wagon upright	M-4
	Install guard rails to control derailed wagon movement at certain locations	M-5
	Use of checklist (to confirm correct train configuration)	M-12
	Install dragging object detectors to detect partially derailed wagons	M-7
Prevent loss of containment	Install tank shielding to prevent penetration	M-2
Prevent secondary collision / accident	Install warning lights on locomotives	M-3 / M-13
	Install battering rams to provide protection to other structures (bridges etc)	M-6
	Install deviation points to direct runaway trains to safe derailment place	M-8
	Provision of radio communications to provide advance warning to other trains	M-9
	Use of checklist (to require that communication / warning devices are operational)	M-12
	Separate passenger and freight traffic to reduce likelihood of secondary collision	M-10
	Restrictions placed on quantity and type of freight traffic in busy locations	M-11

5.0 Conclusions

This document is intended to show the progress of the work completed in Part B.1; the development of outline fault and event trees, and the processes used to generate these model structures. Principally, the activity has involved:

1. The review of a significant number of freight train accidents to establish the causes and consequence of these events.
2. Fitting the measure previously identified in Part A onto the model structures to indicate the areas in which these measures may provide a benefit.

The work reported here will be taken forward leading to a quantified working risk model in which the potential benefits of the introduction of new measures, or the extension of scope of existing measures, can be quantified using cost-benefit approaches.

6.0 References

1. Assessment of existing technical and operational measures against freight train derailments in the Community’s railways, Contract ERA/2010/SAF/OP/01.
2. Assessment of freight train derailment risk reduction measures: A1 – Existing measures, DNV BA000777/02, dated April 2011
3. DNV Accident Analysis, 08 June 2011
4. Impact Assessment on the use of Derailment Detector Devices in the EU Railway System, ERA/REP/03-2009/SAF dated May 2009
5. Assessment of freight train derailment risk reduction measures: A3 – Functional and Performance Assessment, DNV BA000777/04, dated April 2011
6. Railway Safety Directive; Directive 2004/49/EC of April 29th on safety of the Community’s railways. OJ L 220/16, dated 21.0.2004.

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Det Norske Veritas

Assessment of freight train derailment risk reduction measures:

B2 – Risk model and potential effectiveness of measures

Report for European Railway Agency
Report No: BA000777/07
Rev: 02

21 July 2011

MANAGING RISK

Assessment of derailment risk reduction measures:
B2 – Risk model and potential effectiveness of measures Rev 2
for

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Summary: This document provides a summary of the derailment risk models and their usage, together with a statement of the potential benefit that may be achieved from the measures identified by earlier stages of this project.

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0.0 Executive Summary

0.1 Study Scope and Objectives

Det Norske Veritas (DNV) is completing a study on behalf of the European Railway Agency (the Agency), the objective of which is twofold:

1. Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation or on a voluntary basis within 5 to 10 years). For these measures, Part A work is also required to assess the market status for technical measures (defined as devices or systems) and establish objective performance data for the identified measures. The work in Part A also extends to identifying, as far as is possible, potential long term measures (not expected to be ready to implement within 10 years) as an input to other research projects currently underway.
2. Part B has the objective of analysing the measures identified in Part A with a view to establishing those that are the most efficient. Part B addresses such measures which are available at the short and medium terms.

0.2 Study Results, Conclusions and Next Steps

This document is intended to show the progress of the work completed in Part B-2; ***semi-quantitative assessment of benefits and drawbacks of existing safety rules, and of new or improved measures at short and medium terms, using data on actual/targeted performance as well as conservative assumptions.***

Our activities in achieving this task have involved:

1. The quantification of risk models to quantify the problem of freight train derailments.
2. The development of impact models to establish the financial and other impacts associated with freight train derailments.
3. The use of these models to provide preliminary results relating to the identification of freight train derailment causes and the maximum risk reduction potential associated with the introduction of new measures, or the extended use of existing measures
4. A benchmarking activity to provide validity to our modelling approach.

The work reported here will be taken forward to a final project task leading to the identification of a top ten ranking of potentially efficient new safety measures or improvements at short and medium terms, including practical and legal implementation aspects.

Contents

List of Annexes: Annex 1DNV Freight Train Accident Analysis (under separate cover)

1.0 Introduction

1.1 Background

In 2009 the European Railway Agency (the Agency) issued a recommendation (ERA/REC/01-2009/SAF) on a specific proposal, made by the RID Committee of Experts, for a new harmonised rule aimed at reducing the consequences of freight train derailments, potentially involving dangerous goods (DGs). The recommendation concerned the potential use of a Derailment Detection Devices (DDD[1]). This device automatically applies the brakes on a freight train when a derailment of a wagon equipped with that device is suspected.

Although the Agency's recommendation was that the DDD should not be adopted in the RID, the joint meeting of RISC and Inland TDG EU regulatory committees agreed that considering the low potential benefit expected with DDD type devices, as well as some other problems related to the operation of trains equipped with these types of detectors, more efficient prevention measures should be further explored before deciding on imposing, by law, measures based on derailment detection.

Therefore recognising that freight train derailments remain a safety and operational concern, and following a request made by the above mentioned EU Committees, the Agency has commissioned further work the objective of which is to carry out an exhaustive analysis of all prevention and mitigation measures which could reduce the risks related to freight train derailments.

Det Norske Veritas (DNV) was selected to deliver this work, the results of which are presented in this and related documents.

1.2 Overall Project Scope and Objectives

The study is divided into two distinct research stages: Parts A and B.

Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation within 5 to 10 years). This is to be achieved through the following schedule of activities:

- Task A.1 - identification of existing operational and technical measures.
- Task A.2 - description of the markets and technologies covered by the devices/systems in use or which may be used at the short or medium term.
- Task A.3 - description of the rules (inc. specific devices/systems used) in generic functional and performance terms.
- Task A.4 - advice on innovative longer term measures (unlikely to be available within 10 years) which might be considered in a future R&D project.

Part B has the objective of analysing the measures identified in Part A with a view to identifying those that are the most efficient. Part B is scoped to include all prevention measures but is limited to mitigation measures based on derailment detection.

[1] DDD is an acronym used to refer to a type of detector which automatically activates train brakes when a derailment is detected. Device type EDT-101 is an example of such a device.

Part B is to be achieved through the following schedule of activities:

- Task B.1 – construction of detailed fault and event trees[2] describing freight train derailments and showing which derailment cause or impact the identified safety functions act on.
- Task B.2 - semi-quantitative assessment of benefits and drawbacks of existing safety rules, and of new or improved measures at short and medium terms, using data on actual/targeted performance as well as conservative assumptions.
- Task B.3 - top ten ranking of potentially efficient new safety measures or improvements at short and medium terms, including practical and legal implementation aspects.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland (hereafter called the target countries). In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

[2] The technical scope excludes intentional acts and derailments during civil works. Marshalling operation incidents are also excluded as the impacts arising from such events are very limited. Collisions leading to derailment are also excluded from the study scope; however collisions that occur pursuant to a derailment are included.

2.0 Project Abbreviations Used

Term	Description
(the) Agency	European Railway Agency
CSI	Common Safety Indicator
CSM	Common Safety Method
CST	Common Safety Target
DDD	Derailment Detection Device EDT 101
DG	Dangerous Goods
DNV	Det Norske Veritas
ECM	Entity in Charge of Maintenance
ERADIS	European Railway Agency Database of Interoperability and Safety
EVIC	European Visual Inspection Catalogue
HAB	Hot Axle Box
HS	High speed (>40km/h)
IM	Infrastructure Manager
Immediately Severe	A derailment with a mechanical impact that may cause a leak or material from a Dangerous Goods wagon.
JSSG	Joint Sector Support Group
Long Term	Measures that are unlikely to able to be introduced before 10 years
LS	Low speed (40km/h or less)
Medium Term	Measures that could be introduced within 5 to 10 years
NDT	Non Destructive Testing
NSA	National Safety Authority
RAM	Reliability, Availability and Maintainability
RID	Regulations Concerning the International Carriage of Dangerous Goods by Rail
RIV	Regolamento Internazionale Veicoli)
RU	Railway Undertaking
Short Term	Measures that could be introduced before 1st of January 2013
SI	Speed Independent
SMS	Safety Management System
Target countries	EU-27 countries plus the 3 candidate countries, Norway and Switzerland
TDG	Transport of Dangerous Good Regulations
TSI	Technical Specification for Interoperability
UIC	International Union of Railways

3.0 Methodology and Preparatory Work

3.1 Summary and Document Organisation

A fuller specification for task B.2, [1], is provided below:

> *"The task B.2 should use the fault and event trees developed in B.1, as well as the data collected in the Part A in order to carry out a semi-quantitative assessment of the current efficiency[3] of safety measures (based on semi-quantitative cost-benefit indicators, compatible with definitions set out in ERA/REP/03-2009/SAF) and of the maximum risk reduction potential.*
>
> *Then, the potential improvements of each measures (for example, reduction of related costs or improved reduction of risks) shall be assessed, taking account to the foreseen implementation scheme, including at least the nature and level of proposed rules: EU, National or Companies levels, and including the description of the most efficient application scope: for example all the freight fleet or a specific part of it.*
>
> *The potential of risk reduction for scenarios not covered yet by any safety measures (potential new measures) shall also be assessed and described."*

Our methodology for achieving these tasks has been to:

- Populate previously developed [2] risk and cost assessment models with representative data (Section 4.0).
- Benchmark models with the previous Agency study [3], (Section 7.0).
- Use the models to produce results relating to the existing freight train derailment situation, and then to establish the potential benefit that can be achieved against certain derailment causes (Sections 4.4, 5.2 and 6.3).

3.2 Preparatory Work – Accident Analysis

3.2.1 DNV Work

DNV has reviewed reports on derailment accidents in Europe[4] (and to a lesser extent the US and Canada for comparison). The information was retrieved through National Investigation Body reports, European Railway Agency Database of Interoperability and Safety (ERADIS) incident reports and notifications, previous Agency collected accident information to the extent cause information was given, and in a few instances, from other information sources.

It has been our objective to collect information from as many European countries as possible, although we note that the number of investigation reports available varies greatly between the European countries with little or no regard to the actual number of derailments in the various countries.

In selecting the accidents to be used we:

- Included accidents involving complete train movements, eliminating marshalling operation accidents on the basis of their low severity and impacts.
- Used accident reports where it was possible to identify the cause(s).
- Used accidents that were recent (generally post 2000).

[3] This report focuses attention on the potential effectiveness in terms of risk reduction. The efficiency, which includes cost-effectiveness, is to be reported in B.3

[4] The DNV researched accidents are presented in a separate document [4]

Table 1 gives an overview of the number of accidents analysed for each country as well as the network length and the volume of freight traffic performance in the same countries (based on 2008 figures).

Table 1: Accident Reports Studied

Country		**No of accidents included in analysis**	**Network line length** (km)	**Traffic volume** (1000 mill tonnkm)	**Traffic volume per unit of line length** (mill tonn/km)
Belgium	BE	2	3513	8,57	2,43
Bulgaria	BG	0	4144	4,69	1,13
Czech republic	CZ	3	9486	15,44	1,63
Denmark	DK	3	2641	1,87	0,71
Germany	DE	32	33 855	115,65	3,42
Estonia	EE	1	919	5,94	6,46
Ireland (Republic)	IE	1	1919	0,10	0,052
Greece	EL	0	2552	0,79	0,31
Spain	ES	10	15041	10,48	0,70
France	FR	9	29901	40,63	1,36
Italy	IT	1	16861	23,83	1,41
Latvia	LV	0	2263	19,58	8,65
Lithuania	LT	0	1765	14,75	8,37
Luxemburg	LU	0	275	0,28	1,02
Hungary	HU	15	7892	9,87	1,25
the Netherlands	NL	8	2896	6,98	2,41
Austria	AT	24	5664	21,92	3,87
Poland	PL	6	19627	52,04	2,65
Portugal	PT	1	2842	2,55	0,90
Romania	RO	6	10 777	15,24	1,414
Slovenia	SI	0	1 228	3,52	2,87
Slovakia	SK	8	3 622	9,30	2,57
Finland	FI	16	5 919	10,78	1,82
Sweden	SE	8	11 022	23,12	2,1
United Kingdom	UK	17	16 218	24,83	1,53
Norway	NO	17	4 114	3,62	0,88
Switzerland	CH	13	3 557	12,27	3,45
		201			

3.2.2 Agency Work

In addition, the Agency provided access to a number of accident summaries used for their previous work [3]. DNV studied these to eliminate duplicates, those which were not derailments and those which occurred during marshalling operations etc. On completion, the usable Agency provided data amounted to:

- 212 accident summaries from a range of European countries.
- 143 more detailed accident descriptions from France.

The total volume of information used was 201 (DNV collected data) + 212 (Agency collected data) + 143 (Agency collected data) = 556

We used these data as reported in the section below.

3.2.3 Compiling and Analysis of Data

3.2.3.1 Frequency Analysis

We studied all the 556 data sources to determine the quality of data regarding identification of causes. In this respect the 201 DNV collected accidents and the 143 French accidents reported via the Agency were considered of suitable detail to enable causes and their frequencies to be established (the causes are those appearing in Section 4.3).

Each of these 201 DNV collected derailment accidents was classified and their frequency of occurrence estimated as a percentage. Further, we analysed the 143[5] Agency collected French accidents to establish the same information and compared the distributions, which we found to be closely aligned. Hence the frequency analysis used the results from 344 derailment accidents.

These data are used to populate our frequency risk model, which is described at Section 4.1.

Where required conservative assumptions have been used to supplement data shortages.

3.2.3.2 Derailment Scenarios and Impacts

Concerning the scenario trees, we have used the available data as reported in Section 5.0. It has been our objective to make use of the previous Agency data where possible, updated if appropriate. In particular:

- For the scenario (event) tree reported in [2] we re-used Agency data where this was possible.
- We supplemented previous Agency data with our own data / updates where this was required. (Therefore making use of the additional 201 DNV researched accidents.)
- Impacts resulting from a freight train derailment were the subject of the Agency's previous comprehensive analysis, [3], updated as appropriate.

We provide data tables in Section 5.0 for reference.

[5] We have not included the French accidents in our report [4] because to include these may give the perception that the study results were unduly biased towards problems in France, and further they are provided to this study on a confidential basis.

4.0 Risk Model – Frequency Assessment

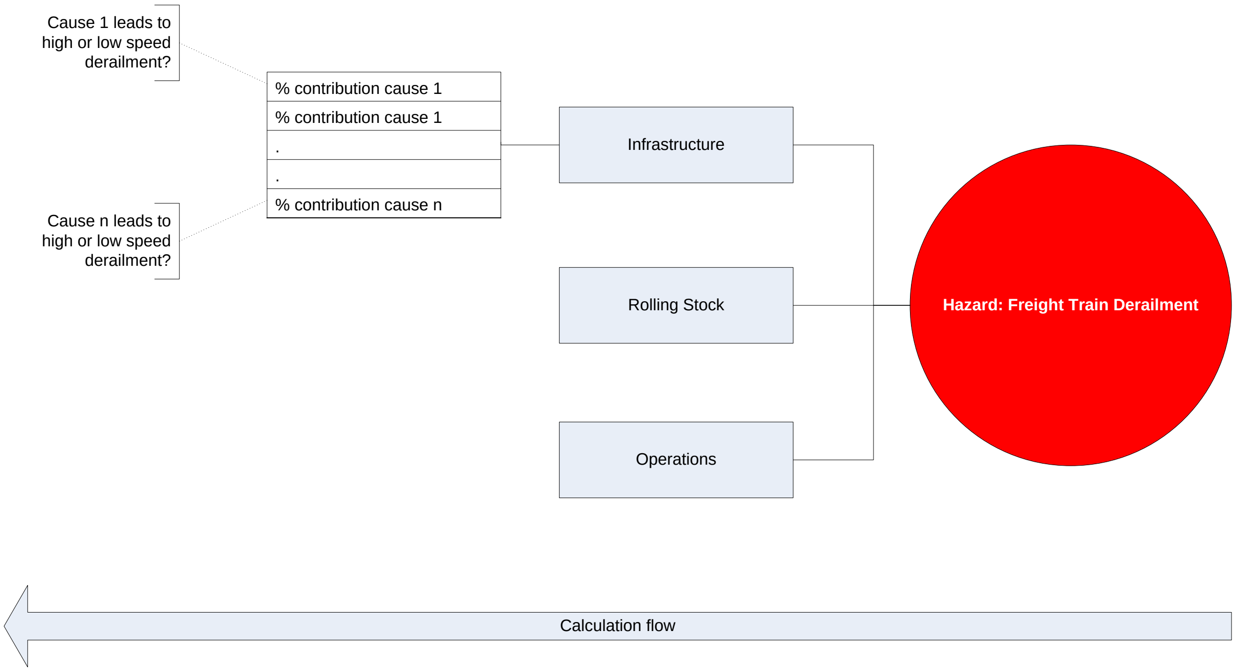
4.1 Overview and Approach

Our analysis uses an apportionment technique to predict the frequency of causal events that lead to a freight train derailment. The technique works as follows:

1. Establish the annual quantity of freight train derailments.
2. Establish the percentage contribution from each freight train derailment cause. This includes whether the cause is more likely to result in a high or low speed derailment[6].
3. Calculate the frequency contribution per cause as the product of 1 and 2.

We summarise our approach in the diagram below.

Figure 1: Establishing Freight Train Derailment Frequency Parameters



We consider first the quantity of freight train derailments.

4.2 Annual Number of Freight Train Derailments

The Agency work on this subject [3] presented an analysis based on an assumed quantity of freight train derailments. The starting point used was 500 significant train derailments per year. This information was used by the Agency as follows to calculate the annual number of freight train derailments [3]:

> *"The 500 significant derailments/year that were used in the study concern both passenger trains and freight trains. It is assumed in the study that about 60% of all derailments are freight train derailments. This gives an estimate of about 300 significant freight derailments per year. It was then further estimated (…) that about 50% of all open line derailments will be significant, to the point that they would be included in the*

[6] We define high speed as being in excess of 40km/h. This is in line with CPR-18E, Guidelines for Quantitative Risk Assessment [5]

EUROSTAT statistics[7]. This finally yields about open line 600 freight train derailments per year."

Since that date however a significant decrease in derailments is reported, as follows:

Table 2 Annual Numbers of Train Derailments

	2006	2007	2008	2009
Eurostat (EU-27)	549	452	***247***	***141***
Agency [6] (EU-27+NO+CT)	***477***	***346***	***319***	***177***

The reported numbers of derailments in 2009 (and 2008 to a lesser extent) should however be taken with caution, as indicated by green shaded cells. In 2007, the threshold for reporting accidents changed: the threshold of EUR 50,000 of damage increased to EUR 150,000 in line with the UIC recommendation. As a consequence, the number of derailments reported to Eurostat in 2008 and 2009 reduced considerably.

Similarly, a more stringent definition of a significant accident was introduced by the Railway Safety Directive (49/2004) and the Directive 149/2009 has been gradually put in place by several Member States since 2006, leading to the distortion of the picture depicted by the reported figures. In this regard, the Agency [6] state:

> *…the number of train derailments dropped significantly in 2009, to 177 reported events. The main reason is that in several countries shunting movements were previously reported under this category. Nevertheless, on average a derailment is reported every second day in the EU, causing significant traffic disruptions."*

Beside the changes in reporting requirements, it should be noted that the EU aggregate available at the Agency is strongly influenced by the high figures reported by Poland and France, accounting together for more than half of all derailments in the EU. These numbers are very high when compared with figures in countries with comparable train-km performance such as Germany, UK or Italy and suffers from important fluctuations over time. Reflecting the Agency's position Eurostat advised us that:

> *"More particularly, the EU aggregate is especially influenced by the Polish figures, accounting for 40-45% of the total number of derailments observed at EU level. Poland has reported a significant decrease over the 2007-2009 periods, and this had consequently a significant impact at total EU level."*

And Poland advised us that:

> *"…the improvement was illusionary. The explanation is the change of derailment categories (according to current regulations)."*

On balance, we support the Agency view that train derailments are reducing in number slightly, along with the number of all train accidents. For the purposes of our analysis we have used a conservative estimate of a 6% year on year reduction.

Using these data, and from a starting point of 600 freight train derailments per year in 2008 (as used by the Agency [3]), we estimate the 2011 equivalent train derailment value to be about **500 per year**.

This reduction in the annual quantity of freight train derailments will result in it becoming more difficult to identify future cost-effective solutions as the available benefit is reducing. However this will not affect the ranking of measures.

[7] Table: RAIL_AC_CATNMBR - Annual number of accidents by type of accident

4.3 Analysis of Causes and Likelihoods

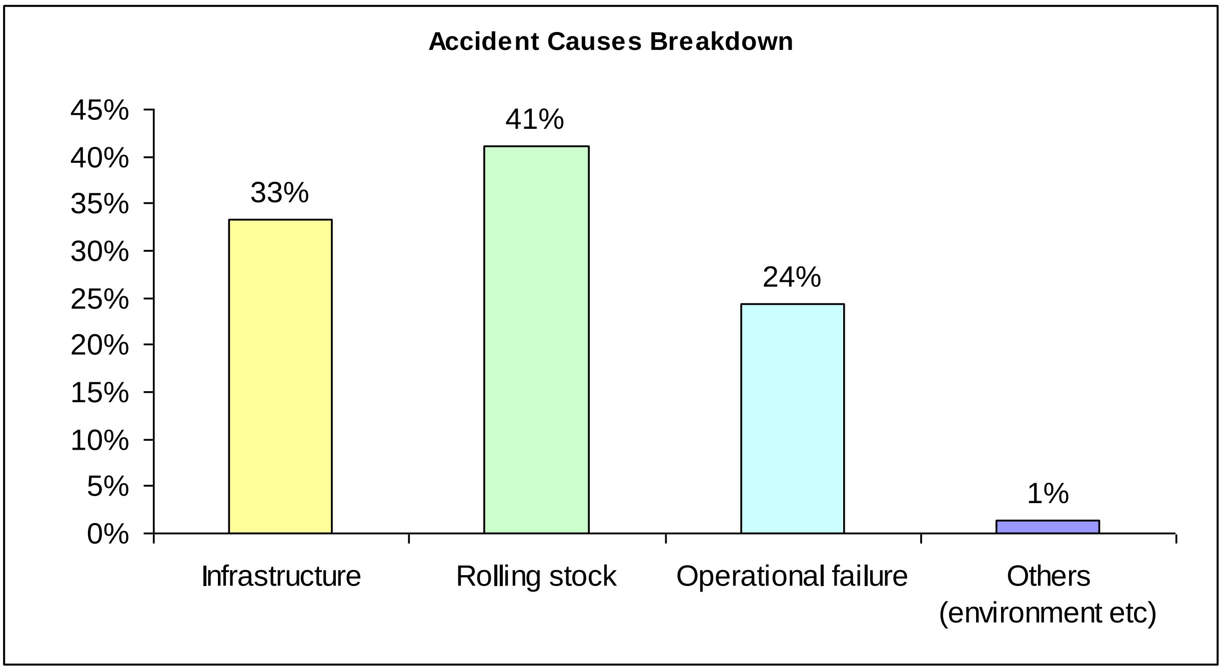
Freight train derailment accidents can result from a single failure[8] or a combination of defects[9]. The former may be something that is out of specification to the extent that it can be considered the only or dominant cause of the derailment (a broken axle may fit into this category). The latter may consist of combinations of equipments / systems that are outside their ideal operating tolerances, but not so much as to be solely responsible for a derailment (a combinational cause may be track geometry which is outside its intervention limit, but within its safety limit, AND a wagon which is skew loaded).

We consider these in turn.

4.3.1 Single Derailment Causes

Derailments which have been assessed as having a single or dominant cause we have estimated to account for 78% of derailments, [4]. Our analysis of single cause derailment accidents, by sub-system, is presented below (in the figure below, 41% of single cause failures result from sub-system rolling stock).

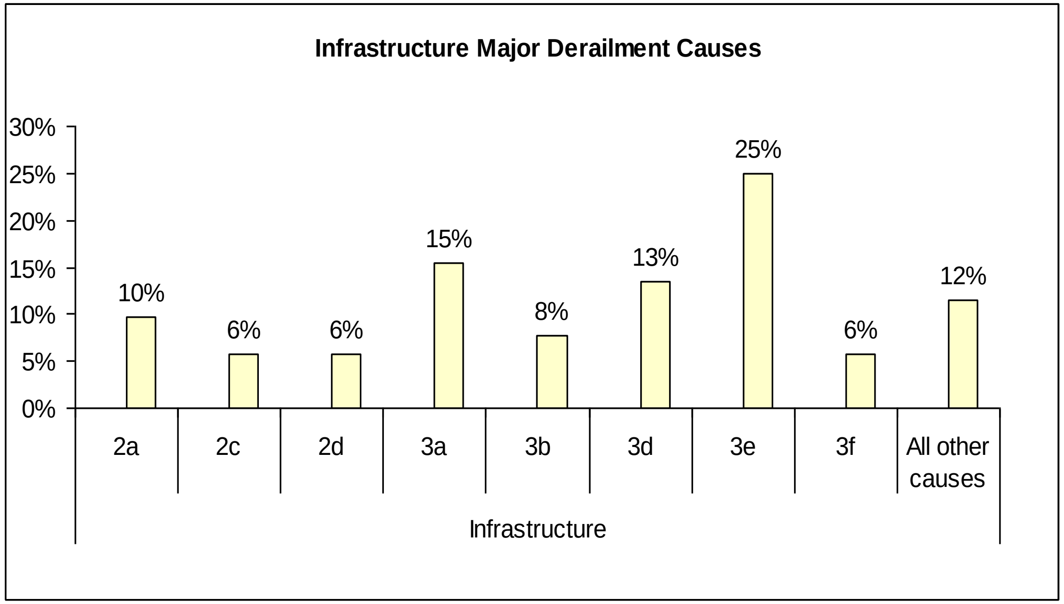
Figure 2: Freight Train Derailment by Sub-System (Single Causes)



We break these down further in the following two sections and we again present the information relative to the category the failures belong to. We only show those causes that more than 3% to derailments in the category.

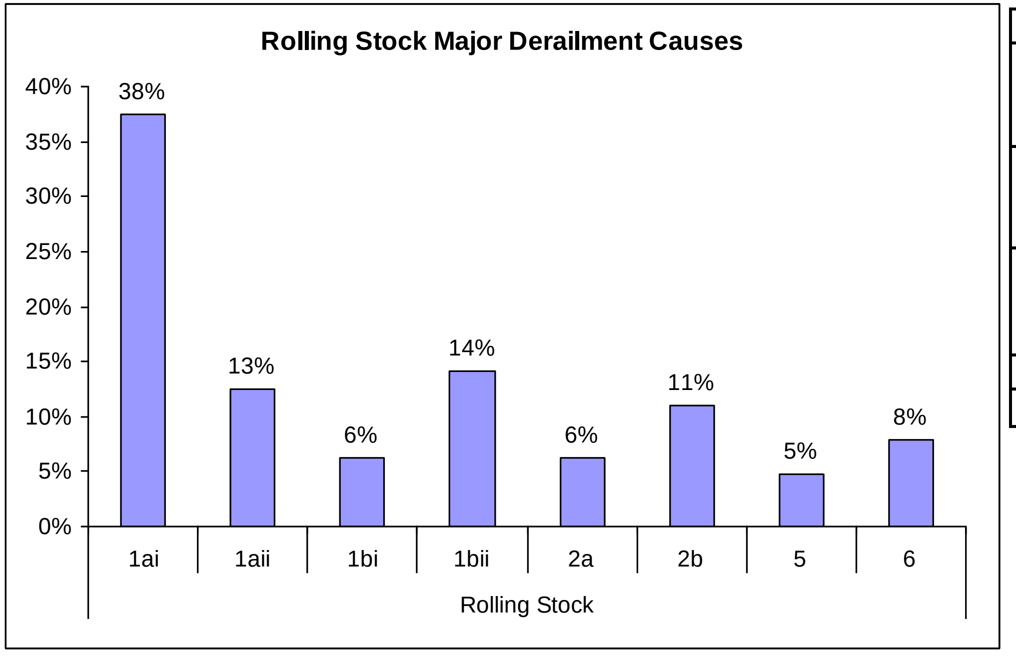
[8] We define a failure as a condition that leads to the system not being fit for purpose and outside allowable tolerances
[9] We define a defect as a condition that leads to the system being outside its optimal operating condition, but within working tolerances

Figure 3: Freight Train Derailment - Infrastructure



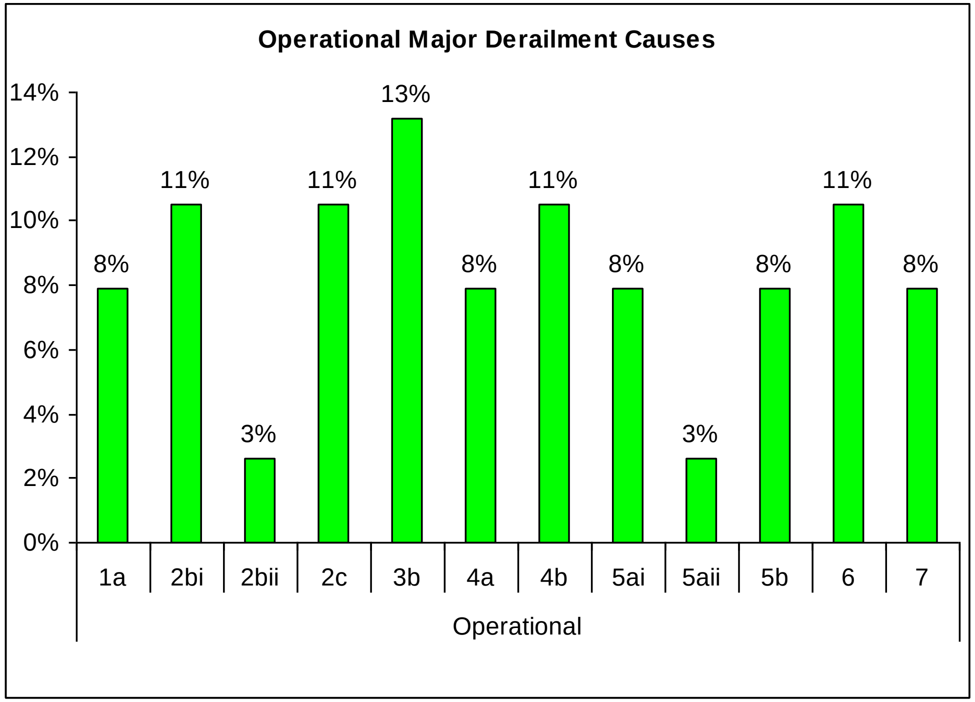
#	Description (only those contributing >3% shown in diagram)
2	Structural failure of the track superstructure, comprising:
a.	Rail failures
c.	Switch component structural failure
d.	Failure of rail support and fastening
3	Track geometry failure, comprising:
a.	Excessive track twist
b.	Track height/cant failure
d.	Track buckles (heat-curves)
e.	Excessive track width
f.	Other track geometry failures
Oth	All other causes

Figure 4: Freight Train Derailment – Rolling Stock



#	Description (only those contributing >3% shown in diagram)
1a	Wheelset failures (wheels and axles), comprising:
i.	Hot axle box and axle journal rupture
ii.	Axle shaft rupture
1b.	Wheel failure:
i.	Rupture of monoblock wheel
ii.	Failure of composite wheel with rim and tyre
2	Bogie and suspension failures, comprising:
a.	Failure of bogie structure and supports
b.	Spring & suspension failure
5	Brake component failure
6	Other or unknown rolling stock derailment cause

Figure 5: Freight Train Derailment – Operational



#		Description (only those contributing >3% shown in diagram)
1		Train composition failures, comprising:
	a.	Unfavourable train composition (empties before loaded wagons)
2		Improper loading of wagon, comprising:
	b.	Skew loading
	i.	Wagon wrongly loaded
	ii.	Wagon partly unloaded
	c.	Insufficient fastening of load
3		Train check and brake testing, comprising:
	b.	Brakes not properly checked or tested
4		Wrong setting of points/turnouts, comprising:
	a.	Wrong setting in relation to movement authority
	b.	Point switched to new position while point is occupied by train
5		Mishandling of train en route, comprising:
	a.	Overspeeding:
	i.	Too high speed through turnout in deviated position
	ii.	Too high speed elsewhere
	b.	Other mishandling of train
6		Brake shoe or other object left under train
7		Other operational failures

4.3.1.1 Link between Cause and Speed

Although it is not possible to provide a clear linkage between freight train derailment cause and speed of derailment, it is the case that some derailment causes occur more often at higher speed; this is partly due to the type of failure and partly due to the operational constraints that may be in place. For example, track geometry derailment causes may lend themselves to lower speed derailments. This is not necessarily because of the specific failure per-se (although in some cases operating at lower speed may make a derailment more likely), but possibly because the track geometry defect / failure is known about and therefore trains are operating at a lower speed.

Conversely, hot axle box (HAB) derailments are more likely to occur at higher speed because higher train speeds may induce the condition, and also because an impending HAB failure is not usually known about in advance (and hence is unlikely to be operating at a reduced speed).

We have made our own assessment in the following tables, using the following nomenclature:

- High Speed – greater than 40 km/h - (HS) indicates that derailments from these causes are more likely (although not exclusively) to be at higher train speeds.
- Low Speed (LS) indicates that derailments from these causes are more likely (although not exclusively) to be at lower train speeds.
- Speed Independent (SI) means that there is no observed pattern.

Using this scheme our models produce derailment frequencies for both high and low speed freight train derailments. We have tested this hypothesis as far as is possible against the accident data we have both individually and collectively. (In this regard, our accident data shows that freight train derailments occur slightly more frequently at low speeds – 40km/h or less - and this is replicated by our models.)

Table 3: Allocation of Cause and Speed (Infrastructure Failures)

Infrastructure	**E(nvironment)**	SI
	1. Failed substructure	
	a. Subsidence	SI
	b. Earth slide/tunnel collapse	SI
	c. Substructure wash-out due to flooding etc	SI
	d. Bridge failure	SI
	2. Structural failure of the track superstructure	
	a. Rail failures	SI
	b. Joint bar & plug rail failures	SI
	c. Switch component structural failure	SI
	d. Failure of rail support and fastening	SI
	e. Track superstructure unsupported by substructure	SI
	f. Other track and superstructure failure	SI
	3. Track geometry failure	
	a. Excessive track twist	LS
	b. Track height/cant failure	HS
	c. Lateral track failure	HS
	d. Track buckles (sun-curves)	HS
	e. Excessive track width	SI
	f. Other or unspecified track geometry causes	SI
	4. Other infrastructure failure	SI

Table 4: Allocation of Cause and Speed (Rolling Stock Failures)

Rolling Stock	**1. Wheelset failures (wheels and axles)**	
	a. Axle ruptures	
	i) Hot axle box and axle journal rupture	HS
	ii) Axle shaft rupture	HS
	iii) Axle rupture, location not known	HS
	b. Wheel failure	
	i) Rupture of monoblock wheel	HS
	ii) Failure of composite wheel with rim and tyre	HS
	iii) Excessive flange or wheel tread wear (wrong wheel profile)	LS
	2. Bogie and suspension failure	
	a. Failure of bogie structure and supports	SI
	b. Spring & suspension failure	SI
	c. Other	SI
	3. Twisted or broken wagon structure/frame	SI
	4. Wagon too high twist stiffness in relation to length	LS
	5. Brake component failure	SI
	6. Other or unknown rolling stock derailment cause	SI

Table 5: Allocation of Cause and Speed (Operational Failures)

Operations	**1. Train composition failure**	
	a. Unfavourable train composition (empties before loaded wagons)	LS
	b. Other	SI
	2. Improper loading of wagon	
	a. Overloading	LS
	b. Skew loading	
	i) Wagon wrongly loaded	LS
	ii) Wagon partly unloaded	LS
	c. Insufficient fastening of load	HS
	d. Other incorrect loading	SI
	3. Train inspection and brake testing	
	a. Speed not according to brake performance	HS
	b. Brakes not properly checked or tested	HS
	c. Brakes not correct set wrt. load or speed of brake application	HS
	4. Wrong setting of points/turnouts	
	a. Wrong setting in relation to movement authority	LS
	b. Point switched to new position while point is occupied by train	LS
	5. Mishandling of train en route	
	a. Overspeeding	
	i) Too high speed through turnout in deviated position	HS
	ii) Too high speed elsewhere.	HS
	6. Brake shoe or other object left under train	LS
	7. Other operational failure	SI

4.3.2 Combinational Causes

Derailments which have been assessed as having several equally important contributing causes account for 22% of derailments, [4]. For combinational causes we present a list of defects appearing most frequently, as derived from the accident analysis reported in Section 3.2:

1. Track geometry defects appear in about 50% of accidents where more than one cause is present, with track twist the most significant appearing in about 30%.
2. Wheel profile defects appear in about 20% of accidents where more than one cause is present.
3. Wagon wrongly loaded appears in about 10% of accidents where more than one cause is present.
4. Train mishandling appears in 10% of accidents where more than one cause is present.

For the purposes of our assessment, we have made the assumption that all accidents as a result of combinational defects are speed independent.

We also need to ask the question whether removal of one of the defects in the defect chain will prevent the accident. The answer to this is “probably”, but will depend on the exact circumstances of each accident.

For the purposes of our quantification we have taken two approaches to modelling these factors:

- If we assume that removal of one defect will eliminate all accidents containing that cause then removal of track twist defects will remove 30% of combinational cause accidents. This is termed the ***maximum*** risk reduction potential in the sections below.

  This assumption must be applied with care as it can imply that more than 100% of accidents can be eliminated. To illustrate this point let us assume there are 10 accidents each having two causes. Let us further assume that five of these accidents have track twist as a causal factor, another five have wagon loading as a causal factor and the remaining 10 causes are all unique. By assuming that removal of one defect removes the accident then it follows that removal of track twist eliminates five of the 10 accidents (50%). Removal of wagon loading similarly eliminates 50% of accidents and removal of each of the 10 unique causes removes one in 10 accidents (100%). The total is 200%. We can assume removal of each cause individually will remove the percentage of accidents in which it appears (i.e. track twist removes 50% of combinational accidents). We cannot however summate the total of all causes and apply this as doing so would imply removal of 200% of accidents, which is not correct.

- As a ***reference*** case we taken the percentage of times each cause appears amongst all combinational causes. Using this measure track twist defects for example contributes 12%.

4.4 Causal Frequency Model Usage, Summary and Outputs

We have described our approach to establishing freight train derailment frequency in the sections above, and we have drawn an equivalent fault tree [2] depicting the logical arrangement. For the data used, our model produces the following:

- Derailments at HS (above 40km/h) = 235 per year
- Derailments at LS (40km/h and below) = 265 per year

To use our model, we apply measures (previously identified at [7]) to a cause that it acts on.

As an example we consider HAB failures, which contribute as follows:

- 14 low speed derailments (LSD), and
- 49 high speed derailments (HSD).

If a measure could be found to eliminate say 90% of these, then the risk benefit would be:

- 14 * 0.9 = 12.6 prevented LSD, and
- 49 * 0.9 = 44.1 HSD

We shall use our model in this way to establish the potential benefit that each measure may secure.

In Table 6 we present output from our frequency model, showing the annual quantity of derailments attributable to each cause. In this table we have combined the total contributions from single and combinational cause contributions to provide one ***reference*** value. For the major combinational causes discussed above we show the ***maximum*** risk reduction potential that the elimination of each cause may give rise to.

We also present, at Table 7, the maximum potential annual benefit available from each measure. ***This assumes that the measure can be 100% effective in eliminating the causes that it is targeted towards.***

Table 6: Failure Contribution to Freight Train Derailments[10]

		Reference		Maximum	
	Failure	LSD	HSD	LSD	HSD
Infrastructure	**E(nvironment)**	5	2		
	1. Failed substructure				
	a. Subsidence	2	1		
	b. Earth slide/tunnel collapse	Negligible			
	c. Substructure wash-out due to flooding etc	1	1		
	d. Bridge failure	2	1		
	2. Structural failure of the track superstructure				
	a. Rail failures	10	4		
	b. Joint bar & plug rail failures	3	1		
	c. Switch component structural failure	6	3		
	d. Failure of rail support and fastening	8	3		
	e. Track superstructure unsupported by substructure	3	1		
	f. Other track and superstructure failure	3	1		
	3. Track geometry failure				
	a. Excessive track twist	26	8	37	13
	b. Track height/cant failure	4	9		
	c. Lateral track failure	2	1		
	d. Track buckles (sun-curves)	4	14		
	e. Excessive track width	25	11		
	f. Other or unspecified track geometry causes	6	3		
	4. Other infrastructure failure	3	1		
	U(nspecified)	3	1		
Rolling Stock	**1. Wheelset failures (wheels and axles)**				
	a. Axle ruptures				
	i) Hot axle box and axle journal rupture	14	49		
	ii) Axle shaft rupture	4	16		
	iii) Axle rupture, location not known	1	2		
	b. Wheel failure				
	i) Rupture of monoblock wheel	2	8		
	ii) Failure of composite wheel with rim and tyre	5	18		
	iii) Excessive flange or wheel tread wear (wrong wheel profile)	7	3	16	7
	2. Bogie and suspension failure				
	a. Failure of bogie structure and supports	9	4		
	b. Spring & suspension failure	15	6		
	c. Other	4	2		
	3. Twisted or broken wagon structure/frame	3	1		
	4. Wagon too high twist stiffness in relation to length	1	1		
	5. Brake component failure	5	2		
	6. Other or unknown rolling stock derailment cause	7	3		
	U(nspecified)	4	2		
Operations	**1. Train composition failure**				
	a. Unfavourable train composition (empties before loaded wagons)	8	3		
	b. Other	Negligible			
	2. Improper loading of wagon				
	a. Overloading	2	1		
	b. Skew loading				
	i) Wagon wrongly loaded	11	3	15	5
	ii) Wagon partly unloaded	3	1		
	c. Insufficient fastening of load	3	8		
	d. Other incorrect loading	Negligible			
	3. Train inspection and brake testing				
	a. Speed not according to brake performance	1	1		
	b. Brakes not properly checked or tested	3	10		
	c. Brakes not correct set wrt. load or speed of brake application	1	2		
	4. Wrong setting of points/turnouts				
	a. Wrong setting in relation to movement authority	6	1		
	b. Point switched to new position while point is occupied by train	9	2		
	5. Mishandling of train en route				
	a. Overspeeding				
	i) Too high speed through turnout in deviated position	1	6		
	ii) Too high speed elsewhere.	1	2		
	b. Other mishandling of train including driver caused SPAD	5	7	9	9
	6. Brake shoe or other object left under train	8	2		
	7. Other operational failure	4	2		
	U(nspecified)	6	2		

[10] In this table derailments are rounded to the nearest whole number, hence the reference total exceeds 500.

Table 7: Potential Maximum Benefit for Each Measure

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-1	Check rail in sharp curves (radius less than 250 metres)	Short - Medium	Check rails are normally installed at in rigid crossings in turnouts and as such are a requirement of most European countries. Additionally check rails may be used in curves, although to a lesser extent. They may act to prevent flange climbing which is a cause of derailments. Check rails may therefore be appropriate where other conditions (such as dry rails, inappropriately loaded wagons etc) have led to the possibility of flange climbing. Check rails are not effective against one specific failure cause listed in the Table 7, rather they are engineered features that may help to prevent derailments in some cases. We cannot therefore say that check rails will mitigate derailments from a specific cause. In place of this, we have reviewed the accident database [4], and from this we estimate that check rails fitted to sharp curves could have reduced derailments in 5% of derailment cases (based on accident reports which state this, or extrapolation). We believe this benefit to be achievable by a wider application of this measure.	**25 (mainly LSD)**
P-2	Track and flange lubrication (installed on track)	Short - Medium	The situation here is similar to that presented in P-1 above. We further note that in many countries traction unit based lubrication is an applied measure (certainly in the major freight carrying countries) and this provides a degree of protection from dry rails on main lines. The major additional benefit from this measure is therefore likely to be at locations that are not frequently operated, hence sidetracks and lightly used locations. As a conservative assumption we have used the same 5% value derived for check rails. We believe this benefit to be achievable by a wider application of this measure.	**25 (mainly LSD)**
P-3 to P-5	Not used			
P-6	Geo radars	Short - Medium	High water content and other superstructure failures (conditions that geo radars are able to detect) are contributors to track geometry failures. However, Infrastructure Managers (IMs) currently have other means to detect both the causes and consequences of such events. Whilst geo radars could make for a more cost-efficient identification of these conditions, we cannot conclude that they would detect more cases than traditional means. We therefore cannot conclude that such measures will lead to a measureable or quantifiable decrease in freight train derailment frequency/elimination of existing causes.	**N/A**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-7	Rolling stock mounted equipment for monitoring of rail profile conditions.	Medium	Equipment for monitoring rail profile (and more recently track geometry) that can be mounted on commercial rolling stock is being introduced to the market. However, IMs currently have other means, including special wagons or trains, to detect both the causes and consequences of such events. Whilst new equipment could make for a more cost-efficient identification of these conditions. Notwithstanding this discussion, it could be feasible that such equipment is able to detect rail profile and track geometry defects that occur between scheduled inspection intervals. Also, by application of such equipment on rolling stock travelling on infrequently used lines (often the places where freight train derailments occur), which perhaps have a longer inspection interval, such equipment may offer some safety benefit. For the purposes of providing an approximate assessment, we have assumed that a small number of rail profile and track geometry defects may be detected sooner than they would have using existing means, and that this may reduce the reduce the number of derailments accordingly. What is clear is that in the majority of cases track geometry / rail profile defects are known about, and so the potential benefit is relatively small. For illustrative purposes, we have assumed that this benefit may lead to a 5% reduction in derailments caused by rail profile or track geometry defects (on the basis that they are detected sooner). This would equate to 5% of I2a, I2b and I3. In general we conclude that such measures offer a commercial rather than safety benefit and they will not be considered further.	**Ref:** **5% * 131 (80 LSD and 51 LSD) = 7** **Max:** **5% * 147 (91 LSD and 56 LSD) = 7**
P-8	Track circuit	Medium	Track circuits are installed for train detection purposes although in some cases they may detect rail ruptures which can be a cause of derailments. However, because track circuits are not relied upon for the detection of rail ruptures we cannot suggest or propose that they are installed for this purpose. We therefore cannot conclude that such measures will lead to a measureable or quantifiable decrease in freight train derailment frequency/elimination of existing causes. **Note:** It may be prudent, in cases where track circuits are to be removed, for the IM to take into account this loss of secondary functionality.	**N/A**
P-9	Interlocking of points operation while track is occupied	Medium	Our accident analysis [4] indicates that approximately 2% to 3% of derailments are caused by points that are moved under a freight train. This is a phenomenon largely associated with old infrastructure in particular entries and exits from marshalling yards. This measure is likely to be effective against cause O4b, which is predicted to lead to 11 derailments, based on our risk model outputs (9 LSD, 2 HSD) We believe this benefit to be achievable by a wider application of this measure.	**11 (9 LSD and 2 HSD)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-10 P-12	Hot axle box (hot bearing) detectors Hot wheel and hot brake detectors	Medium	Theoretically the potential risk reduction associated with this measure is to eliminate all derailments that are caused by hot axle box conditions. (However, for this to be the case such devices need to be installed at a very high density and would need a side track for trains to stop.) These are coded RA1ai which our risk model predicts to result in 14 LSD and 49 HSD. In addition to the detection of hot axle boxes discussed above, hot wheel and brake detectors may help to prevent wheel failures (RS1bi and RS1bii), where these are caused by excessive heat. We do not have a root cause breakdown for wheel failures; however we have assumed that 50% result from this cause. Our estimate here is 50% * 33 ~ 17 (made up of 4 LSD and 13 HSD). This measure is already applied widely throughout the European Community, thereby limiting the potential benefit somewhat.	**63 (14 LSD and 49 HSD)** **17 (4 LSD and 13 HSD)**
P-11	Acoustic bearing monitoring equipment	Medium	As P-10. The European Community has invested heavily in measures such as P-10 and others to protect against hot axle box caused derailments. In this case, this limits the potential benefit that may be achieved by this measure.	**63 (14 LSD and 49 HSD)**
P-13	Wheel load and wheel impact load detectors	Medium	These devices potentially address derailment causes as follows: • HAB and axle journal rupture: RS1ai (as P-10) • Spring and suspension failures: RS2b, (15 LSD and 6 HSD) • Wheel flats that can cause rail breaks: I2a and I2b (combined total 13 LSD and 5 HSD) – we have assumed that rail breaks are caused on 50% of occasions by this cause; hence values of 6 LSD and 3 HSD are used. • Overloading and skew loading: O2a and O2b (16 LSD and 5 HSD) The European Community has invested heavily in measures such as P-10 and others to protect against hot axle box caused derailments. In this case, this limits the potential benefit that may be achieved by this measure.	**Ref:** **114 (51 LSD and 63 HSD)** **Max:** **120 (55 LSD and 65 HSD)**
P-14	Dragging object and derailment detectors	Not considered here – dragging objects, in the form of underframe equipment are considered elsewhere. Derailment detectors are considered as M1.		
P-15	Bogie performance monitoring/Bogie lateral instability detection (bogie hunting)	Medium	These are likely to be effective against incorrect wheel profile (RS1biii) and skew loading (O2bi and O2bii). Our risk model predicts contributions of 21 LSD and 7 HSD from these causes. We believe this benefit to be achievable by a wider application of this measure.	**Ref:** **28 (21 LSD and 7 HSD)** **Max:** **47 (34 LSD and 13 HSD)**
P-16	Wheel profile measurement system / Wheel profile monitoring unit	Medium	Incorrect wheel profile (RS1biii) is likely to cause derailments in combination with track geometry failures. Our risk model predicts a contribution from these conditions, amounting to 7 LSD and 3 HSD. We believe this benefit to be achievable by a wider application of this measure.	**Ref:** **10 (7 LSD and 3 HSD)** **Max:** **23 (16 LSD and 7 HSD)**
P-17	Not used			

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-18	Sufficient availability of maintenance resources (for Infrastructure maintenance)	Short	This is principally an organisational / funding issue. In theory all infrastructure failures could be significantly reduced through the application of greater resources, in particular to side tracks at stations and other locations where maintenance is perhaps less stringent. In particular track geometry failures that we have recorded under the category I3 fall into this category. The total contribution of all other causes is 67 LSD and 46 HSD.	**Ref:** **113 (67 LSD and 46 LSD)** **Max:** **129 (78 LSD and 51 LSD)**
P-19	Clearance of obstructions from flange groove (particularly at level crossings)	Short	This is a potential cause of derailment, although we have positively identified only one derailment attributable to this cause. In general we do not consider this benefit to be achievable without significant resource.	**Less than 5 derailment per year (no speed allocation)**
P-20	Ultrasonic rail inspection	Short	Rail failures (I2a and I2b), which this measure is aimed at detecting, contribute 13 LSD and 5 HSD as calculated from our risk model. This measure is already applied widely throughout the European Community, thereby limiting the potential benefit somewhat.	**18 (13 LSD and 5 HSD)**
P-21	Track geometry measurement of all tracks	Short	As P-18.	**Ref:** **113 (67 LSD and 46 LSD)** **Max:** **129 (78 LSD and 51 LSD)**
P-22	EU-wide intervention/action limits for track twist	Medium	Track twist is a major contributor to track geometry caused derailments. Further, there is an increasing use of single axle wagons with a very long wheel base which makes the derailment risk in twisted track even larger, and with an increased containerization the control of skew loading is more of a challenge. Both the above make it more important to have good control of track twist geometry aspects. We have noted also that accidents occur within the stated safety limit for this parameter. This measure would require the introduction of a stricter safety limit together with guidance regarding intervention limits for track twist. However, it is clear from our commentary in P-18 and P-21 that there is still a challenge regarding adherence to existing limits, hence a new – presumably stricter – limit would place additional burden on maintenance resources. European wide intervention and action limits should be considered, otherwise track twist could be an increasing problem due to increased use of long wheelbase wagons for specific purposes. From risk model we predict 26 LSD and 8 HSD are attributable to this cause (I3a).	**Ref:** **34 (26 LSD and 8 HSD)** **Max:** **50 (37 LSD and 13 HSD)**
P-23	EU-wide intervention/action limits for track gauge variations	Medium	As P-22. From our risk model we predict 25 LSD and 11 HSD from this cause (I3e).	**36 (25 LSD and 11 HSD)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-24	EU-wide intervention/action limits for cant variations	Medium	As P-22 From our risk model we predict 4 LSD and 9 HSD from this cause (I3b).	**13 (4 LSD and 9 HSD)**
P-25	EU-wide intervention/action limits for height variations and cyclic tops	Medium		
P-26	Flange lubrication - locomotives		The friction at the contact area between the wheel flanges of railway vehicles and the rails determine wheel and rail wear and the driving effort / energy required. Flange lubrication (on locomotives or track) is applied to reduce such wheel and rail wear (and hence maintenance costs), to reduce noise and also to reduce energy consumption. The main potential benefit from a safety point of view is lubrication in curves (see P-2). However, locomotive based lubrication is not likely to be as effective as fixed track based lubrication systems. Whereas track based lubrication can be fitted and ensure effective lubrication at specific locations, locomotive lubrication is applied as a function of speed and other parameters. In lightly used side tracks (which may be operated at low speed) locomotive based lubrication systems may not deposit sufficient (or indeed any) lubricant and therefore be much less effective than other solutions. As a derailment prevention measure we have assumed that this system may be, as a maximum, 50% as effective as track based alternatives. This measure will not be assessed further by this project.	**50% * 25 (mainly LSD) = 13**
P-27	Replace composite wheels with monoblock wheels	Medium	As can be seen from Figure 4, composite wheels contribute to derailments approximately twice as often as monoblock wheels. However, it is not clear the proportion of each wheel type in existence, and we have no reliable data to help us estimate these proportions. If we assume a 50/50 split then the potential benefit is equal to a halving of the number of derailments caused by failure of composite wheels (0.5 * 25 ~ 13). Although this could be used as a working assumption, we propose not to consider this further, because: • We already address many technical measures aimed at addressing the causes of wheel failures • A probable cause of composite wheel failures is the more complex maintenance programme, which is addressed implicitly by measures such as P-36 and F-2, etc • The potential benefit are likely to be relatively small (compared to the costs, unless done on an opportunistic basis)	**N/A**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-28	Replace metal roller cages in axle bearings by polyamide roller cages.	Medium	The potential benefit is of a reduction in hot axle box failures and derailments, P-10. (This is likely to be integrated with the maintenance cycle of axles / wheel sets and be implemented on an opportunistic basis. Therefore it would not be achieved within the short term, although would be at minimal cost.) This measure is partly implemented at present thereby limiting the maximum future potential somewhat. We are not aware of any authoritative research regarding the safety differential between roller cages of different materials (brass, polyamide, stainless steel); although we are aware that many RUs are replacing brass for polyamide on an opportunistic basis. (Internet information indicates that bearings with polyamide roller cages are more robust to vibrations.)	**63 (14 LSD and 49 HSD)**
P-29	Replace existing axles for stronger axles or axles with improved material properties with regard to crack initiation and crack propagation	Medium	Axle ruptures (RS1aii and RS1aiii) account for about 5 LSD and 18 HSD. The use of stronger materials has a maximum potential for reducing the quantity of derailments in this category A European wide research and development program is currently ongoing, EURAXLES with 23 partners. We do not feel that this project should comment on this on-going work programme,	**23 (5 LSD and 18 HSD)**
P-30	Increase the use of central couplers between wagons in fixed whole train operation	Long	The application scope for a measure of this type is probably currently limited to bulk material block trains composed of uniform standard wagons where it can be beneficial in many ways. However, it is noted that the White Paper on Transport (11) recommends that (for reasons other than safety) "*New rolling stock with silent brakes and automatic couplings should gradually be introduced.*" If an automatic central coupler with sufficient strength for rail freight operations can be identified then a possible reduction of derailment frequency may be an added benefit, see also our report [12]. In terms of potential safety benefit (if applied to freight train in general), the introduction of central couplers may reduce the likelihood of buffer locking derailments and also of derailments associated with compressive forces under braking. Buffer locking is a contributory cause in a number of derailment accidents. The data used for our risk model indicates at least 5% of derailments have this as a contributory cause. Train compression corresponds to failures O1a from our risk model which contributes 11 derailments, and it is a contributory in at least the same number. Because fitting to bulk material block trains worked by single operators on set routes is not consistent with an interoperable railway and because the alternative of fitting to a large part of the freight fleet comes at massive cost (and is probably a long term measures), we have not considered this measure further.	**47 (no speed allocation)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-31	Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis.	Medium	Bogie wagons offer better riding qualities that are more tolerant to sub-standard track conditions, thereby having a lower derailment rate. It is a measure generally applied for heavy bulk transport applications. For light weight goods and swap bodies this is not the case. For such operations, single wagons based on single axles allow a longer loading basis to be obtained at minimum weight and cost. Whilst this is advantageous commercially it is not beneficial with respect to minimising derailment risk (particularly in relation to track twist). It may be appropriate to assume that from a derailment safety perspective, many track twist derailments may be avoided. Whilst the exact number of avoided derailments cannot be precisely estimated, we have assumed that all track twist defects (contributing to combinational cause derailments) may be eliminated, and 50% of the remaining track twist single cause derailments may be eliminated. (For these assumptions to apply as stated, the majority of the freight fleet would need to have this measure applied.) Notwithstanding this, we have discounted this measure from further consideration, because: • The maximum potential benefit is relatively small compared to the cost of implementing the measure • It includes possibly lost business costs and other commercial issues which we are not considering and therefore the cost versus benefit assessment will be missing some important information	**Ref:** **24 (18 LSD and 6 HSD)** **Max:** **40 (29 LSD and 11 HSD)**
P-32	Install disc brakes instead of wheel tread brakes for new wagons.	Medium	The main motivation for this measure is likely to be in relation to achieving the Noise TSI. However, it may lead to less heat activation of wheels with a corresponding reduction in wheel failures. In that respect, the same reduction claimed for P12 is applicable here. This measure is already applied within the European Community (but to a limited extent by present rolling stock), although limiting the potential benefit somewhat.	**17 (4 LSD and 13 HSD**
P-33	Rolling stock design for track twists	Long	A requirement to have more fault tolerant rolling stock design could be applied for new wagon purchases. The benefits of this measure however may not be realised until the long term, governed by the time (and investments) necessary for the renewal of the targeted wagon scope. In terms of potential derailment safety benefit, we apply the same assumptions as discussed under P-31. (For these assumptions to apply as stated, the majority of the freight fleet would need to have this measure applied.) Whilst we have estimated a potential maximum risk reduction potential, this measure is not to be considered further in this project.	**Ref:** **24 (18 LSD and 6 HSD)** **Max:** **40 (29 LSD and 11 HSD)**
P-34	Secure brake gear underframe	Medium	This measure would address RS5, which we predict to result in 5 LSD and 2 HSD This measure is already applied within the European Community, thereby limiting the potential benefit somewhat.	**7 (5 LSD and 2 HSD)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-35	Regular greasing and checks of rolling stock buffers.	Short	Measures of this type could be introduced quickly, in the form or recommendation or other formal notification. These could be applied rapidly by RUs, Entity in Charge of Maintenance (ECMs) etc. This may involve greasing of the mechanical springs inside buffers and of the external buffer plates. The potential safety benefit is prevention of buffers becoming loose and / or falling off. This is a small contributor to freight train derailments, contributing no more than 1% of derailment causes. Renewed emphasis of this measure has the potential to reduce this contributory cause.	**Less than 5 (no speed allocation)**
P-36	Wheel set integrity inspection (ultrasonic) programs.	Short	Wheel sets failures are a major contributor to freight train derailments. They account for RS1a and RS1b categories with a contribution of 33 LSD and 96 HSD. This measure is already applied very widely, and other measures such as P-10 are also in place against these failures. This will limit the achievable risk reduction significantly.	**Ref: 129 (33 LSD and 96 HSD) Max: 142 (42 LSD and 100 HSD)**
P-37	Derating of allowable axle loads	Short	The Agency Joint Sector Support Group (JSSG) has identified an increase in allowable axle loads has been allowed nationally and has made a limiting recommendation. In this contest, axle ruptures (RS1aii and RS1aiii) account for about 5 LSD and 18 HSD. We do not feel this project should comment further on this on-going work programme.	**23 (5 LSD and 18 HSD)**
P-38	EVIC (European Visual Inspection Catalogue)-based inspection of freight train rolling stock axles	Short	The European Visual Inspection Catalogue for Axle Inspections is being applied on a voluntary basis and we have identified 23 countries that are using this programme. From our risk model, failures that may be avoided are RS1a and RS1b (with the likely exception of hot axle box conditions). These account for 19 LSD and 47 HSD. We do not feel this project should comment further on this on-going work programme.	**Ref: 66 (19 LSD and 47 HSD) Max: 79 (28 LSD and 51 HSD)**
P-39	Double check and signing of safety-classified maintenance operations	Short	There are a small number of accidents in our database that could be attributed to this cause, although this is not always stated. As a conservative estimate we have used a value of 5 per year Benefits are limited by the relatively small number of relevant derailments.	**5 (no speed allocation**
P-40	Qualified and registered person responsible for loading	Medium	Loading failures are calculated by item 02 within our risk model. They account for 19 LSD and 13 HSD. In practice this measure is widely applied (through the use of internal training or external qualification) thereby limiting the potential benefit somewhat. Extensions to this may include the use of checklists or other sign-off systems to ensure the process is applied correctly. We consider there to be some potential for realising some of these benefits.	**Ref: 32 (19 LSD and 13 HSD) Max: 38 (23 LSD and 15 HSD)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-41	Locomotive and first wagons of long freight trains in brake position G	Short	Train compression under braking is a derailment cause or contributory cause (especially with trains comprising loaded and empty wagons). In terms of direct causes, this corresponds to failures O1a from our risk model which contributes 8 LSD and 3 HSD. Additionally it is a contributory in at least the same number. Some forms of driver mishandling of the train may also be partly mitigated by this measure, hence O5b contributing 5 LSD and 7 HSD. The requirement for the use of the G position is in place in many countries, although it is apparent that it is not always applied.	**Ref:** **34 ((8 LSD and 3 HSD) * 2) + (5 LSD and 7 HSD)** **Max:** **40 ((8 LSD and 3 HSD) * 2) + (9 LSD and 9 HSD)**
P-42	Limitations on use of brake action in difficult track geometry	Short	As P-41	**Ref:** **34 ((8 LSD and 3 HSD) * 2) + (5 LSD and 7 HSD)** **Max:** **40 ((8 LSD and 3 HSD) * 2) + (9 LSD and 9 HSD)**
P-43	Dynamic brake test on the route	Medium	Risk model 03b and O3c applies which suggests 4 LSD and 12 HSD may results from failure to test brakes correctly. Such functionality could be applied to the new ETCS and ERTMS train control systems,	**16 (4 LSD and 12 HSD)**
P-44	Saw tooth braking to limit heat exposure to wheels	Short	We have identified no such derailments that are attributable to this cause, although heat activation of wheels is a potential cause of wheel failure. However, we consider this measure to be applied where it is required and will not consider it further.	**N/A**
P-45	Initiation of braking or speed reduction prior to passing signal showing reduced speed	Short	We have identified one derailment directly attributable to this cause. We consider this to be part of existing driver practice and will not consider it further.	**N/A**
P-46	Not allowing traffic controllers and drivers to override detector alarms	Short	Alarm management is an important issue, and increasingly so should more equipment be installed. It is also apparent that a number of derailments occur after passing a hot axle box which in some cases has identified the condition. We have made a conservative assumption that failures in this area contribute about to 15 derailments per year. The use of newer equipment with better alarm handling and lower false alarm rate is likely to secure benefits.	**15 (no speed allocation)**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
P-47	Wagons equipped with a balance to detect overload in visual inspection.	Medium	Loading failures are calculated by item 02 within our risk model. They account for 19 LSD and 13 HSD. This specific measure was advised as a local solution used by one RU. The use of this measure has some potential for improving the current situation, although it is unlikely that the maximum potential can be realised.	**Ref:** **32 (19 LSD and 13 HSD)** **Max:** **38 (23 LSD and 15 HSD)**
F-1	End of train device (brakes)	Medium	This measure is principally indented to speed up brake application in long trains, give more reliable brake application in emergencies as well as reduce train compression when braking long trains as the brakes are applied both from the front and rear of the train. If train lengths are increased this may become a more significant issue for the European railways than it is at the moment. But is not seen as an important element today and has been eliminated.	**N/A**
F-2	Awareness program and improved maintenance for Rolling Stock	Short	This is an issue relating to the safety management systems and culture of RU / keepers / wagon owners as well as the supervision of this by National Safety Authorities (NSAs). The identification of key maintenance issues that have led to derailment could facilitate this process at a national level. Excluding wheelset maintenance which is covered at various places above, other benefits include those quantified at RS2, RS3, RS4 and RS5. These account for approximately 37 LSD and 16 HSD The use of this measure has some potential for improving the current situation, although it is unlikely that the maximum potential can be realised.	**53 (37 LSD and 16 HSD)**
F-3	Heat sensitive material to reveal hot axle box conditions	Short	The effectiveness of this measure is limited by the chance that an indication provided by this measure can be detected in time for a derailment to be prevented. This measure may be effective for routes in which a HABD is not installed or where a HAB alarm has been raised – in this case providing assistance to the driver in identifying the defective axle box. In addition, it may be able to detect cases where a HAB is present, but below the detection threshold of HABDs. The effectiveness of this measure depends on the speed in which a HAB develops, which is variable and is based on train speed, track and wheel quality, wagon loading conditions amongst others. Of course this measure could be effective against most situations if wagons were inspected frequently (perhaps every 40 km) whilst on a journey. Such an inspection requirement however this is not feasible; our assumption is that a measure of this type may have a maximum risk reduction potential possibly 25% of the total number of HAB caused derailments. Given the significant investment in technical and other measures to address this problem, we cannot foresee a measure of this type being of significant benefit and it will not be considered further.	**25% * 63 (14 LSD and 49 HSD) = 16**

Measure Number	Description	Time Category	Description	Potential Max. Risk Red. (/yr)
F-4	Machine Vision Devices	Medium	3-D image capture systems are used in at least the USA and China, and at some test sites within Europe. They may detect loading errors, open hatches (which are the cause of a small number of derailments) and may be equipped with other modules including hot axle box and other heat sensing devices. They are also used to detect profile violations and fires, although these are not direct derailment causes. They may also detect some suspension failures. Loading failures are calculated by item 02 within our risk model. They account for 19 LSD and 13 HSD. Suspension failures are assessed (RS2b) to account for 15 LSD and 6 HSD	**Ref:** **53 (34 LSD and 19 HSD)** **Max:** **59 (38 LSD and 21 HSD)**
F-5	Telematics	Medium	Improved telematics solutions could enhance the capture of information and aid the maintenance function by providing better and more timely information provision. To be of use however these systems require trackside (or on-board) equipment able to capture this information. We conclude that this is not a measure in its own right and are not going to consider it further.	**N/A**
F-6	Anti-lock devices	Medium	These devices may reduce the instance of wheel locking under braking or other fault conditions, thereby potentially reducing the incidence of wheel flats. Wheel flats that can cause rail breaks: I2a and I2b (combined total 13 LSD and 5 HSD) – we have assumed that rail breaks are caused on 50% of occasions by this cause; hence values of 7 LSD and 3 HSD are used. Other potential benefits may include improved axle fatigue life due to less fatigue, although this potential improvement is not readily quantifiable. Anti-lock devices may help to prevent wheel failures (RS1bi and RS1bii), where these are caused by excessive heat. We do not have a root cause breakdown for wheel failures; however we have assumed that 50% result from this cause. Our estimate here is 50% * 33 = 17 (made up of 4 LSD and 13 HSD).	**27 (11 LSD and 16 HSD)**
F-7	Sliding wheel detectors.	Medium	These systems detect wheels that are not rotating correctly and raise an alarm, with similar benefits to the antilock device for freight wagons described above.	**27 (11 LSD and 16 HSD)**
F-8	Handbrake interlock.	Medium	This would prevent a freight train moving off with the handbrake applied and therefore reduce the likelihood of subsequent issues like wheel flats, overheating and track damage accounting for 7 LSD and 3 HSD as F-6. Handbrake interlocks may help to prevent wheel failures (RS1bi and RS1bii), where these are caused by excessive heat. We do not have a root cause breakdown for wheel failures; however we have assumed that 50% result from this cause. Our estimate here is 50% * 33 = 18 (made up of 4 LSD and 13 HSD). This however has to factored by the amount of times where the cause is a handbrake that is applied. For the purposes of this assessment we have used a conservative assessment that this is the case 50% of occasions.	**19 (9 LSD + 10 HSD)**

5.0 Derailment Scenarios and Consequences

5.1 Scenario Model and Data

In our report [2], we presented an event tree to describe the possible outcomes following a freight train derailment. For clarity, we replicate that here such that the scenario development can be followed.

In total there are 6 event trees; one for countryside (meaning locations outside main population areas); station (meaning railway stations); urban (meaning locations with the potential for a high population density). Each has a high and low speed variant.

Data used to populate the scenario models are presented in Table 8 and Table 9.

Figure 6: Partial Event Tree

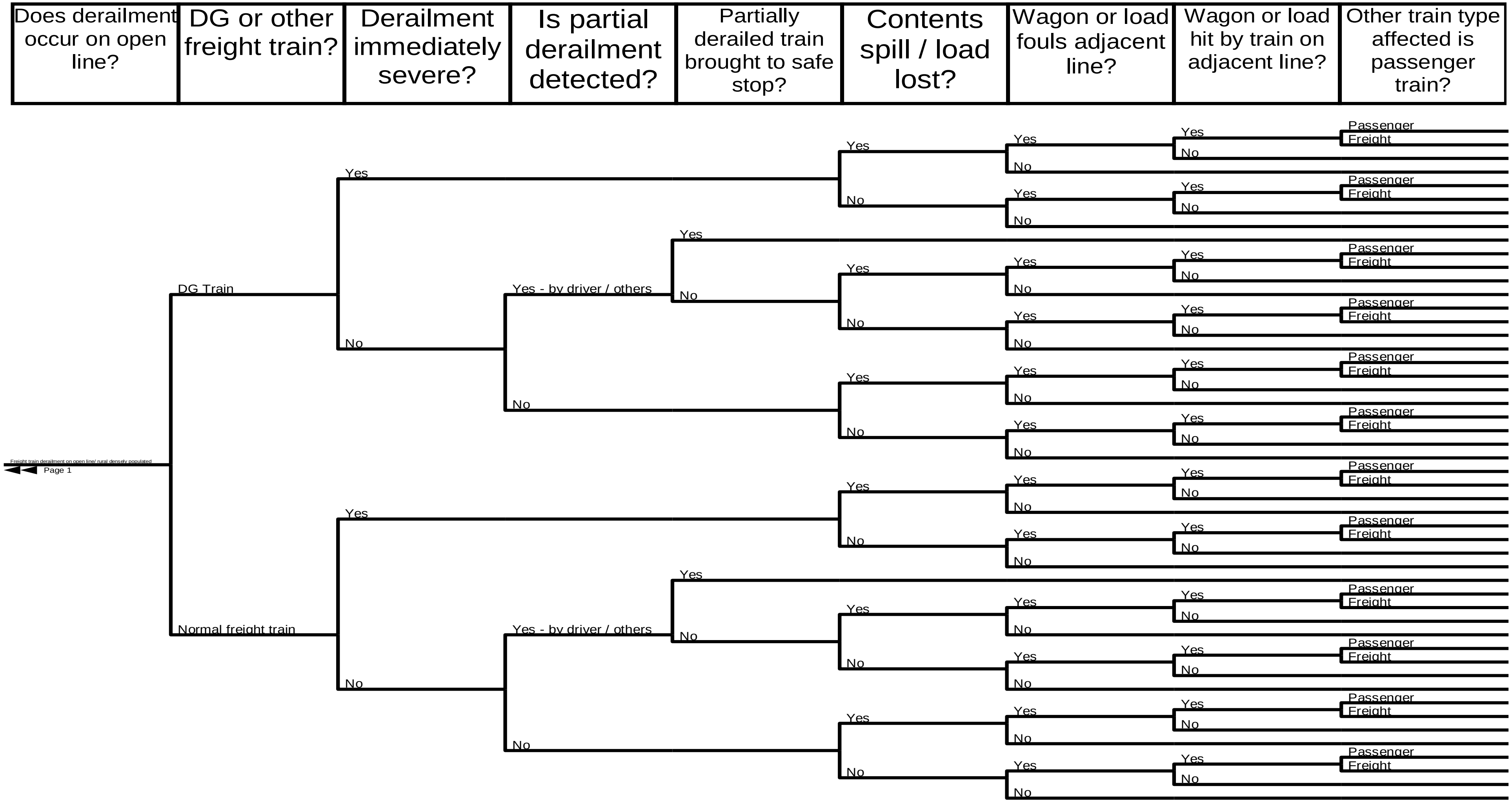


Table 8 Data Table: Low Speed Derailment

Item	Variant	Data	Description	Data Source
1. Derailment location	Station	71%	71% of LS derailments occur in stations. The method used was to identify the speed and location of each derailment, allowing the appropriate percentages to be calculated.	DNV Accident Analysis [4].
	Urban	3%	29% of LS derailments occur at urban locations. To calculate this data we apportioned the 29% of LSD that occur outside station between urban and countryside. We made a conservative assumption 10% of the time these occur in densely populated urban areas. Hence ~ 3%. (Our modelling therefore assumes that 74% of freight train derailments occur in either stations or urban, i.e. heavily populated areas.)	DNV Accident Analysis [4]
	Countryside	26%	26% of LS derailments occur outside stations. Calculation as above.	DNV Accident Analysis [4]
2. DG train[11]?	None	66%	The proportion of trains carrying at least one DG wagon. The probability of the derailed wagon carrying dangerous goods is addressed in the impact modelling, and uses the same assumptions regarding trains running in complete and mixed configurations as applied by the Agency [3]	Agency Impact Analysis, [3]. A review of freight transport data indicated the original value to be valid.
3. Immediately severe?	None	26%	Proportion of LS freight train derailments that are immediately severe calculated by summing the number of LSD that were immediately severe. (Note to check this data item against the previous Agency work, we have summed the total number of derailments that were immediately severe (i.e. LSD and HSD). This reveals a combined total of 32% of derailments are immediately severe. This compares closely with the Agency figure of 33% for the same parameter.)	DNV Accident Analysis [4] (and compared with Agency Impact Analysis, [3]).

[11] A DG train is one which contains at least one wagon carrying DG. It is possible that a derailment of a DG train does not involve a DG wagon.

Item	Variant	Data	Description	Data Source
4. Is partial derailment detected?	None	70%	This data item is conditional on the outcome of 3 and is the percentage of partially derailed freight trains that are detected (before the consequences become severe).	Agency Impact Analysis, [4].
5. Is the train brought to a safe stop?	None	96%	This data item is conditional on the outcome of 4 and is the percentage of detected partially derailed freight trains that are brought to a safe stop. This differs from the previous Agency analysis, [3], which assumed all such outcomes would be safely managed. We derived this information by identifying cases where a initial derailment had been detected, but the outcome was still a severe derailment.	DNV Accident Analysis [4]
6. Contents / load spill?	None	30%	This data item is conditional on the outcome of 5. There is limited to support an analysis based on accident data, so we have chosen to apply conservative assumptions to this field, as follows: • Probability of wagon being empty – 50% (this is a contributing factor to freight train derailments, where empty wagons can often increase the likelihood of a derailment). • Where not empty, we have assumed a DG release 60% of the time for a LS severe derailment • Value applied = 60% * 50% = 30%	Conservative assumption, supported by DNV Accident Analysis [4] (items 6, 7 and 8)

Item	Variant	Data	Description	Data Source
7. Foul adjacent line?	None	38%	This data item is conditional on the outcome of 6. There is limited to support an analysis based on accident data, so we have chosen to apply conservative assumptions to this field, as follows: • Probability of derailment on lines where there is other traffic; 50%. (Some derailments are on single line or lines where there is little traffic.) • Derailment infringes envelope of trains running on adjacent line: 75%. Value applied = 75% * 50% = 38% A small number of accidents of this type are included in our accident database, with a smaller number that lead to any consequences of significance.	
8. Secondary collision?	None	1%	This data item is conditional on the outcome of 7. Factors that are relevant here are traffic volume, communication systems, time of day, freight routing etc. We have applied a factor of 1% based on an analysis of accident data. The combination of the factors described above when used in our model result in a predicted event of this type about once per year, which correlates with the accident data we have studied.	
9. Passenger train hits derailed freight wagon	None	50%	We have applied an even distribution between a passenger and freight train being involved in a secondary collision.	DNV Accident Analysis [4]

Table 9 Data Table: High Speed Derailment

Item	Variant	Data	Description	Data Source
1. Derailment location	Station	33%	33% of LS derailments occur in stations. The method used was to identify the speed and location of each derailment, allowing the appropriate percentages to be calculated.	DNV Accident Analysis [4]
	Urban	7%	67% of LS derailments occur outside stations. Our assumption is that 10% of the time these occur in densely populated areas. Calculation as LSD.	DNV Accident Analysis [4]
	Countryside	60%	67% of LS derailments occur outside stations. Our assumption is that 90% of the time these occur in countryside or sparsely populated areas. Calculation as LSD.	DNV Accident Analysis [4]
2. DG train?	None	66%	No change from LS table.	
3. Immediately severe?	None	49%	Proportion of HS freight train derailments that are immediately severe.	DNV Accident Analysis [4]
4. Is partial derailment detected?	None	70%	No change from LS table.	
5. Is the train brought to a safe stop?	None	96%	No change from LS table.	
6. Contents / load spill?	None	40%	This data item is conditional on the outcome of 5. There is limited to support an analysis based on accident data, so we have chosen to apply conservative assumptions to this field, as follows: • Probability of wagon being empty – 50% (this is a contributing factor to freight train derailments, where empty wagons can often increase the likelihood of a derailment). • Where not empty, we have assumed a DG release 80% of the time for a LS severe derailment • Value applied = 80% * 50% = 40%	
7. Foul adjacent line?	None	38%	No change from LS table.	
8. Secondary collision?	None	1%	No change from LS table.	

Item	Variant	Data	Description	Data Source
9. Passenger train hits derailed freight wagon	None	50%	No change from LS table.	

5.2 Consequence Outcome Model Usage, Summary and Outputs

We presented in our report [2], and above, the event tree structure. In this report we have presented the data used to populate these models.

Based on the assumptions and data reported above our model predicts the following outcomes[12]:

- Immediately severe derailment involving a DG wagon; 13 out of 500 derailments ~ 3%.
- Not immediately severe derailment involving a DG wagon; about 8 out of 500 derailments ~ 2%.
- Immediately severe derailment involving a normal freight wagon; about 171 out of 500 derailments ~ 34%.
- Not immediately severe derailment involving a normal freight wagon; about 96 out of 500 derailments ~ 19%.
- Derailments detected (by staff or others) and train brought to a safe stop; about 204 out of 500 ~ 41%.
- Derailments detected (by staff or others) but not brought to a safe stop; about 8 out of 500 ~ 2%.

The model is principally to be used, in conjunction with the frequency model, to test the potential effectiveness of the measures we have identified.

With regard to the consequence model described in this section, one particular measure is to be specifically tested, and that is measure number M-1. Measures in this category are wagon devices to detect derailment and either apply train brakes automatically (M-1a) or inform the driver of the suspected derailment (M-1b).

Considering these measures, the following model output parameters are important:

- Our risk model predicts 104 freight train derailments (comprising 96 normal freight wagon derailments and eight derailments involving DG wagons) that are not immediately severe and are not detected. Wagon devices of type M-1 have the potential to bring these trains to a safe stop.
- The maximum potential benefit of such devices is therefore to prevent 104 derailments from becoming severe (assuming each and every wagon were to be fitted with devices of this type). However, we also know that some identified drawbacks must be considered for assessing the efficiency of this measure. These will be considered in the following study tasks.

[12] These add to 101% because of rounding errors

6.0 Derailment Impacts

6.1 Overview

For both normal freight and DG vehicles each outcome of the event tree is assigned an impact. The impacts represent severe derailments and non severe derailments. The latter only apply to derailments that are detected and stopped without contents spill or without affecting the adjacent line. All other derailments are classed as severe.

Each outcome of the event tree has been further considered to determine if the derailment was immediately severe. This categorisation has an impact on the effects to the track, wagons and operational disruption. Although each event tree (there are two event trees; one for HS and one for LS) has 150 end outcomes, some of these represent the same consequences and these have been grouped together. This gives the consequence models shown in Table 10 below.

Table 10 Model Outcomes and Impacts

Consequence	Description
SD1	Severe derailment occurring immediately, contents spilling, fouling adjacent line and affecting passenger train on adjacent line
SD2	Severe derailment occurring immediately, contents spilling, fouling adjacent line and affecting freight train on adjacent line
SD3	Severe derailment occurring immediately, contents spilling, fouling adjacent line but no affect on adjacent line
SD4	Severe derailment occurring immediately, contents spilling but no affect on adjacent line
SD5	Severe derailment occurring immediately , fouling adjacent line and affecting passenger train on adjacent line
SD6	Severe derailment occurring immediately , fouling adjacent line and affecting freight train on adjacent line
SD7	Severe derailment occurring immediately , fouling adjacent line but no affect on adjacent line
SD8	Severe derailment occurring immediately but no contents spill or no affect on adjacent line
SD9	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), contents spilling, fouling adjacent line and affecting passenger train on adjacent line
SD10	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), contents spilling, fouling adjacent line and affecting freight train on adjacent line
SD11	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), contents spilling, fouling adjacent line but no affect on adjacent line
SD12	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), contents spilling, but no affect on adjacent line
SD13	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), no contents spilling, fouling adjacent line and affecting passenger train on adjacent line
SD14	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), no contents spilling, fouling adjacent line and affecting freight train on adjacent line
SD15	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected), no contents spilling, fouling adjacent line but no affect on adjacent line
SD16	Occurring some time after initial derailment (detected by driver/others but unable to apply safe stop/undetected) but no contents spill or affect on adjacent line
NSD1	Number of non severe derailments per year. Must be without contents spill and no affect on adjacent line

6.2 Dangerous Goods Consequence Models

When a derailment of a DG train occurs, there can be a number of outcomes including loss of life should a DG leak occur. The calculation of the consequence from a DG incident is explained below.

The calculation starts from the total number of DG derailments involving a contents spill. The contents spill can affect persons in the vicinity of the derailment, with the quantity of people potentially affected defined by the location on the incident. In this regard previous Agency work [3] specified a population density taken as a mean average weighted by the railway network length, with this set at 144 per km^2. Our models however have three possible incident locations: stations; urban; countryside.

We note that a factor of 3:1 is used [5] to represent the density at stations compared with urban locations. As a conservative assumption, we have used a density of 144 per km^2 for urban locations and a density of 432 per km^2 in stations. For countryside we used a density value of 80 per km^2. (If we assume that a freight train travels 10% of the time in stations and heavily populated areas, 25% of the time in urban areas, and 65% of the time in countryside areas, the weighted average population density equals approximately 144 per km^2.)

Next we considered the likelihood of various accident scenarios involving a specific class of DG carried. To enable us to do this, the percentage of DG class carried was obtained by examining the total annual railway transport of DG in millions of tonne kilometres, taken from EUROSTAT [8]. (This is represented in the last column of Table 11 below.)

A further consideration is the train formation, and whether a DG train is carrying DG exclusively, or whether it is of mixed configuration. For this Agency data [3] was used, modified for recent DG transport figures, and is incorporated into the calculations (see also Table 8 and Table 9.)

For each class of DG the probability of accidents occurring has been calculated, using data as shown in the tables below. Pool fire has been excluded as the considered impact distance is 2 x 10 meters and it is assumed that the nearest population is 30 metres from the track.

Table 11 Considered Accident Scenario by Class of Dangerous Goods Vehicle

DG Class	Toxic (%)	Solid Explosion	VCE (%)	BLEVE (%)	Fire (%)	Jet Fire (%)	% goods in class
1							1.27
2	33		11	11		11	12.70
3	13				87		59.00
4.1, 4.2, 4.3	0				100		4.27
5.1	0				100		3.86
5.2	0		0		100		0.06
6.1, 6.2	84				16		2.77
7							0.23
8	6				11		7.70
9							8.14
All							**100**

The table above therefore shows the probability that a DG train derailment will involve a certain class of DG. For example incidents involving Class 2 DG a toxic release will result in 33% of occasions, [9]. Where the outcome is a potential fire, the probably of ignition is also applied using the factors in Table 12 below, [9].

Table 12 Probability of Ignition of a Flammable Release

DG Class	Toxic	Solid Explosion	VCE	BLEVE	Fire	Jet Fire
1						
2	0	0	0.7	0.7	0	0.7
3	0	0	0	0	0.2	0
4.1, 4.2, 4.3	0	0	0	0	0.5	0
5.1, 5.2	0	0	0	0	0.5	0
6.1, 6.2	0	0	0	0	0.2	0
7	0	0	*0*	*0*	*0*	*0*
8	0	0	0	0	0.2	0
9	0	0	0	0	0	0
All						

Hence, a VCE will occur in 11% * 70% of cases where a severe incident involves a Class 2 DG wagon.

The impact area in m^2 and the lethality parameters were taken from [10], as follows.

Table 13 Impact and Lethality Factors

DG Accident Scenario	Impact Area (m2)	Lethality (%)
Pool Fire	320	100
Vapor Cloud Explosion (VCE)	11300	100
Boiling Liquid Expanding in Vapor Explosion (BLEVE)	44000	100
VCE of Liquefied Propane Gas (LPG)	18000	100
Jet Fire og LPG	2400	100
Chlorine Release	540000	50
Amonia Release	20000	50
Class 4 Fires	1200	100
Less Significant	320	100

When a derailment of a dangerous goods vehicle occurs there will also be an associated environmental cost. The number of DG derailments involving a contents spill obtained from the event tree is multiplied by the environmental cost per event, for which we have used the Agency work [3]. Environmental damage has not been considered for normal freight derailments.

6.2.1 Normal Freight Human Fatalities and Injuries

When a normal freight vehicle derails there could also be a number of human fatalities or injuries if the freight train collides with a passenger train.

From our accident analysis [4] we note only one case where injuries have been recorded, and in this case the number of injuries recorded was 2.

The number of injuries from normal freight derailments is calculated one in 10 accidents. This is a conservative assumption as our accident database indicates something less than this.

These values are used, with an associated cost per injury, as previously used by the Agency [3].

Concerning fatalities, it is very rare for these to occur from the mechanical impact associated with a freight train derailment. In the accidents we have studied (see Section 3.2) there have been none reported over a 10 year period. We note that the Agency [3] used an estimate of one per year, however this would seem pessimistic based on available data.

Eurostat (table rail_ac_catvictin) records zero 3rd party fatalities associated with train derailments (with the exception of Viareggio) in the period 2006 to 2009 and 6 railway employee fatalities in the same period the (for the EU-27) although Eurostat includes both passenger and freight train derailments. For freight train derailments there are fewer railway employees at risk (usually the driver only), and we also note that it is unusual for the locomotive be directly involved.

These data lead us towards a fatality figure, resulting from the mechanical impact of a freight train derailment, as significantly less than one per year and for the purposes of our assessment we have selected a value of 0.2 fatalities per year.

6.2.2 Freight Train Derailment Railway System and Operational Disruption

When a freight train derailment occurs there will be additional impacts on the railway system and operations. The following parameters were used relating to the costs associated with these impacts, [3].

Table 14 Railway System and Operational Costs[13]

	Track Damage		Wagon Damage		Disruption Costs	
Scenario	Average Km	Cost (E/km)	# wagons	Cost/wagon (E/wagon)	Hours disruption	Cost/hour (E/hour)
Immediate severe, DG involvement	0.5	427746	7	23526	50	16040
Not immediate severe, DG involvement	5	160405	7	23526	50	16040
Immediate severe, no DG involvement	0.5	427746	7	12832	50	16040
Not immediate severe, no DG involvement	5	160405	7	12832	50	16040
Not severe derailment, safe stop	0.5	32081	2	5347	12	8020

6.3 Impact Model Usage, Summary and Outputs

We report above the development of our impact models. Using the model, with the parameters described, the following results are obtained (for the case of 500 derailments per year):

- Total cost of freight train derailments = Euro 505 million. (This may vary between Euro 195 million and Euro 701 million using minimum and maximum values in Table 14.)
- Average cost per freight train derailment = Euro 1.01 million. (Ranging between Euro 390,000 and Euro 1,402,000 using minimum and maximum values in Table 14).
- Number of fatalities = 3.9 (resulting mainly from incidents in which there is a release of DG).
- Major cost impact relates to operational disruption.

As a comparison, our database [4] has recorded 2 accidents with loss of life and these are associated with incidents in which there is a release of DG. These equate to a total loss of life of 34 over a 10 year period. This is consistent with our modelling.

The principal future use of our impact model is the calculation of benefits that may be achieved through the implementation of new measures.

[13] Updated for inflation using rates of 3.7%, 1% and 2.1% for 2008, 2009 and 2010 respectively.

7.0 Model Benchmarking

To test the output of our model, we compare the results of our model against the Agencies previous work, [3]. We have already shown at Section 5.2 a very close correlation, which we repeat below:

- Immediately severe derailment involving a DG wagon[14]; 13 out of 500 derailments ~ 3% (Agency value 4%).
- Not immediately severe derailment involving a DG wagon; about 8 out of 500 derailments ~ 2% (Agency value 3%).
- Immediately severe derailment involving a normal freight wagon; about 171 out of 500 derailments ~ 34% (Agency value 29%).
- Not immediately severe derailment involving a normal freight wagon; about 96 out of 500 derailments ~ 19% (Agency value 17%).
- Derailments detected and train brought to a safe stop; about 204 out of 500 ~ 41% (no equivalent Agency value).
- Derailments detected but not brought to a safe stop; about 8 out of 500 ~ 2% (no equivalent Agency value).

Our financial calculations are as follows:

- Total cost of 500 derailments = Euro 505 million, deflated back to 2008 = Euro 472 million[15].
- Average cost per derailment, deflated back to 2008 = Euro 944,000 per derailment.
- (Alternatively, using the Agency's 600 derailments per year = 600 * 944,000 = Euro 566 million. This compares with the Agency value for their reference case of Euro 470 million.)

We also predict 3.9 fatalities a year (3.7 from incidents that involve a release of DG and 0.2 from the mechanical impact of a derailment) for 500 accidents, compared with the Agency's assessment of 3 fatalities from 600 accidents. This is due to our more pessimistic consequence densities and other conservative assumptions we have made.

Differences arise from the following factors:

1. The DNV model has a consequence of a secondary collision with additional impacts not included in the Agency's previous work.
2. The DNV model does not assume that all detected derailments will result in a safe (non-severe) outcome, which is a more pessimistic assumption than used by the Agency [3].
3. We have used slight more pessimistic consequence models regarding human impact and population density.

We conclude however that although the models are different in many areas relating to their construction and quantification, the results derived are very closely aligned. This provides confidence in both the Agency's earlier results, and also the validity of our modelling approach.

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[14] A derailment involving a DG wagon may has two outcomes: one in which there is a mechanical impact that leads to a release of DG material; one which there is no release of DG material.
[15] All our financial figures have been updated by the rate of inflation from 2008 to 2010.

8.0 Conclusions and Way Ahead

In this report we have presented the data that is to be used to populate our risk and cost models, and also shown a close correlation with previous Agency work [3]. We have also demonstrated the way in which our models will be used to derive the effectiveness of the measures that have been previously identified.

In this regard, we note the maximum potential benefits will arise from reducing the most significant causes of freight train derailments. These are:

1. Track geometry failures contributing about 22% to total derailment frequency.
2. HAB failure contributing about 13% to total derailment frequency.
3. Wagon loading issues, contributing about 8% to total derailment frequency.
4. Wheel failures contributing about 7% to total derailment frequency.

Considering these for example, the maximum risk reduction potential is a reduction of approximately 63 freight train derailments per year. At an average cost of about Euro 1 million per derailment, this equates to Euro 63 million per year.

There is a larger benefit to be gained from better attention to maintaining track geometry within set limits. Indeed, almost all track geometry defects that lead to derailment are failures of the organisational systems in place. Either, there has been a failure to identify the defect, or there has been inappropriate priority in attending to a situation which is known about.

We also note that new technology is being marketed that has the intention of mitigating against human errors, such as those that may be associated with freight train loading. This new technology comes at significant expense, which suggests that alternative and cheaper organisational solutions should also be explored.

We also note that that is apparent that there are national differences in accident causes, and these appear to be significant. Better reporting of accidents, with a clearly identified root cause, together with some analysis of this information is likely to provide valuable insights into these differences, with a view to learning from best practice. This may be an area for further consideration by the Agency.

In the next stage of this project we will use the risk and cost models, together with the measures identified in Part A of this project to identify the top 10 most efficient measures from those identified.

9.0 References

1. Assessment of existing technical and operational measures against freight train derailments in the Community's railways, Contract ERA/2010/SAF/OP/01.
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MANAGING RISK DNV

Det Norske Veritas

Assessment of freight train derailment risk reduction measures:

Annex 1 to B2 – Risk model and potential effectiveness of measures (accident analysis)

Report for European Railway Agency
Report No: BA000777/07/A1
Rev: 00

08 July 2011

MANAGING RISK DNV

Assessment of derailment risk reduction measures: B2 – Risk model and potential effectiveness of measures. Annex 1 Accident Analysis Rev 0
for

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Contents

1.0 Introduction

This document presents the results of an analysis of freight train accidents, and is prepared in support of Contract ERA/2010/SAF/S-03, being completed by Det Norske Veritas (DNV) for the European Railway Agency (the Agency).

DNV has reviewed reports on derailment accidents in Europe. The information has been retrieved through National Investigation Body reports, European Railway Agency Database of Interoperability and Safety (ERADIS) incident reports and notifications, and in a few instances, also from other information sources.

It has been our objective to collect information from as many European countries as possible, although we note that the number of investigation reports available varies greatly between the European countries with little or no regard to the actual number of derailments in the various countries.

In selecting the accidents to be used we:

- Included accidents involving complete trains, eliminating marshalling operations accidents on the basis of their low severity and impacts.
- Used accident reports where it was possible to identify the cause(s).
- Used accidents that were recent (generally post 2000).

Error! Reference source not found. gives an overview of the number of accidents analysed for each country as well as the network length and the volume of freight traffic performance in the same countries.

Table 1: Accident Reports Studied

Country		**No of accidents included in analysis**	**Network length** (km)	**Traffic volume** (1000 mill tonnkm/år)	**Traffic volume per track unit** (mill tonn/km/år)
Belgium	BE	2	3513	8,57	2,43
Bulgaria	BG	0	4144	4,69	1,13
Czech republic	CZ	3	9486	15,44	1,63
Denmark	DK	3	2641	1,87	0,71
Germany	DE	32	33 855	115,65	3,42
Estonia	EE	1	919	5,94	6,46
Ireland (Republic)	IE	1	1919	0,10	0,052
Greece	EL	0	2552	0,79	0,31
Spain	ES	10	15041	10,48	0,70
France	FR	9	29901	40,63	1,36
Italy	IT	1	16861	23,83	1,41
Latvia	LV	0	2263	19,58	8,65
Lithuania	LT	0	1765	14,75	8,37
Luxemburg	LU	0	275	0,28	1,02
Hungary	HU	15	7892	9,87	1,25
the Netherlands	NL	8	2896	6,98	2,41
Austria	AT	24	5664	21,92	3,87
Poland	PL	6	19627	52,04	2,65
Portugal	PT	1	2842	2,55	0,90
Romania	RO	6	10 777	15,24	1,414
Slovenia	SI	0	1 228	3,52	2,87
Slovakia	SK	8	3 622	9,30	2,57
Finland	FI	16	5 919	10,78	1,82
Sweden	SE	8	11 022	23,12	2,1
United Kingdom	UK	17	16 218	24,83	1,53
Norway	NO	17	4 114	3,62	0,88
Switzerland	CH	13	3 557	12,27	3,45
		201			

2.0 Methodology

We have classified accidents based on the sub-system in which they belong, as follows:

1. Infrastructure
2. Rolling Stock
3. Operations

We have used the following nomenclature in achieving this task.

Derailments caused by ***infrastructure failures and defects*** are classified as follows:

1. Failed substructure, comprising:
    a. Subsidence
    b. Earth slide / tunnel collapse (leading to derailment, not collision)
    c. Substructure wash-out due to flooding etc
    d. Bridge failure (leading to derailment)
2. Structural failure of the track superstructure, comprising:
    a. Rail failures
    b. Joint bar & plug rail failures
    c. Switch component structural failure
    d. Failure of rail support and fastening
    e. Track superstructure unsupported by substructure
    f. Other track and superstructure failure
3. Track geometry failure, comprising:
    a. Excessive track twist
    b. Track height/cant failure
    c. Lateral track failure
    d. Track buckles (heat-curves)
    e. Excessive track width
    f. Other or unspecified track geometry causes
4. Other infrastructure failures

For referencing purposes, these derailment causes are classified using this numbering structure; for example derailment causes associated with substructure are classified I_1"n", where "n" represents the specific sub-cause.

Derailments caused by ***rolling stock failures and defects*** are classified as follows:

1. Wheelset failures (wheels and axles), comprising:
    a. Axle ruptures:
        i. Hot axle box and axle journal rupture
        ii. Axle shaft rupture

iii. Axle rupture, location not known

b. Wheel failure:

i. Rupture of monoblock wheel

ii. Failure of composite wheel with rim and tyre

iii. Excessive flange or wheel tread wear (wrong wheel profile)

2. Bogie and suspension failures, comprising:
   a. Failure of bogie structure and supports
   b. Spring & suspension failure
   c. Other
3. Twisted or broken wagon structure/frame
4. Wagon with too high twist stiffness in relation to length
5. Brake component failure
6. Other or unknown rolling stock derailment cause

For referencing purposes, these derailment causes are classified using this numbering structure; for example derailment causes associated with wheelset failures are classified RS_1A"n", where "n" represents the specific sub-cause.

Derailments caused by ***operational failures and defects*** are classified as follows:

1. Train composition failures, comprising:
   a. Unfavourable train composition (empties before loaded wagons)
   b. Other
2. Improper loading of wagon, comprising:
   a. Overloading
   b. Skew loading
      i. Wagon wrongly loaded
      ii. Wagon partly unloaded
   c. Insufficient fastening of load
   d. Other incorrect loading
3. Train check and brake testing, comprising:
   a. Un-suitable brake performance for route characteristics
   b. Brakes not properly checked or tested
   c. Brakes not correct set with respect to load or speed of brake application
4. Wrong setting of points/turnouts, comprising:
   a. Wrong setting in relation to movement authority
   b. Point switched to new position while point is occupied by train
5. Mishandling of train en route, comprising:
   a. Overspeeding:

      i. Too high speed through turnout in deviated position
      ii. Too high speed elsewhere
   b. Other mishandling of train
6. Brake shoe or other object left under train
7. Other operational failures

For referencing purposes, these derailment causes are classified using this numbering structure; for example derailment causes associated with improper loading/skew loading of wagons are classified O_2B"n", where "n" represents the specific sub-cause.

3.0 Summary Results

In the following tables we present the allocation of accidents by country. For each accident we identify the time and place, the number of causes and then identify those causes.

At the foot of each country table is a count of the derailment cause totals.

The tables presented have been used to within our project reports, and also to shape and populate our risk models. Not all information is shown on these tables. We present the complete versions in Section 4.0.

Table 2: Accident Data Summary Norway and Sweden

No	Date	Place	# Cause	Causes																																														
				E	Infrastructure																		Rolling Stock														Operational																	
				E	1a	1b	1c	1d	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4	U	1ai	1aii	1aiii	1bi	1bii	1biii	2a	2b	2c	3	4	5	6	U	1a	1b	2a	2bi	2bii	2c	2d	3a	3b	3c	4a	4b	5ai	5aii	5b	6	7	U
Norway																																																						
No-1	18.07.2002	Fetsund	3												1																					1				1														
No-2	13.08.2002	Fetsund	2												1																					1																		
No-3	12.02.2003	Halden	1																																																1			
No-4	06.07.2004	Mo - Skonseng	1																				1																															
No-5	12.05.2005	Middagselv tunnel	3												1																					1																		1
No-6	04.12.2005	Sandbukta	2																				1					1																										
No-7	23.12.2005	Bulken - Evanger	1	1																																																		
No-8	06.07.2006	Råde – Onsøy, km 77.5.	1																1																																			
No-9	26.07.2006	Dombås – Dovre, km339,80	1																1																																			
No-10	08.09.2006	Trettnes	1	1																																																		
No-11	12.12.2006	Dombås station	2													1														1																								
No-12	05.09.2007	Strømmen -Fjellhamar	1																																							1												
No-13	29.04.2008	Skogn	1																		1																																	
No-14	25.07.2008	Hval - Hønefoss	1																1																																			
No-15	12.10.2008	Halden station	1																1																																			
No-16	25.05.2009	Ørtfjell station	1																																											1							
No-17	22.12.2009	Hauerseter - Fjellhamar	1																				1																															
		Cause totals	24	2	0	0	0	0	0	0	0	0	0	0	3	1	0	0	4	0	1	0	3	0	0	0	0	1	0	1	0	0	0	0	0	3	0	0	0	1	0	1	0	0	0	0	1	0	0	0	1	0	0	1
17		**Single cause totals**	12	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0
Sweden																																																						
SE-1	22.04.1996	Kävlinge	1															1																																				
SE-2	04.07.1997	Kälarne	1															1																																				
SE-3	08.04.2000	Borlänge	1																																													1					
SE-4	30.03.2001	Strosmbro	1																																											1							
SE-5	28.02.2005	Ledsgård	2																			1																																1
SE-6	29.03.2006	Linköping - Vikingstad	3																				1					1											1															
SE-7	20.01.2008	Motala station	2						1	1																																												
SE-8	21.08.2008	Kimstad station	1																																										1									
		Cause totals	12	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	1	0	0	0	0	1
8		**Single cause totals**	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0

Table 3: Accident Data Summary Finland and Denmark

No	Date	Place	# Cause	Causes																																																		
				E	Infrastructure																		Rolling Stock														Operational																	
				E	1a	1b	1c	1d	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4	U	1ai	1aii	1aiii	1bi	1bii	1biii	2a	2b	2c	3	4	5	6	U	1a	1b	2a	2bi	2bii	2c	2d	3a	3b	3c	4a	4b	5ai	5aii	5b	6	7	U
FI-1	31.05.2003	Lahti station	1																				1																															
FI-2	08.05.2004	Joensuu Station	1															1																																				
FI-3	11.05.2004	Pieksamaki Station	1											1																																								
FI-4	30.07.2004	Kouvola	1																																		1																	
FI-5	27.04.2005	Eskola	2									1																			1																							
FI-6	28.04.2005	Heinävesi	1																1																																			
FI-7	13.07.2006	Tuupovaara - Joensuu	1															1																																				
FI-8	21.03.2007	Ylivieska railway station	2																									1		1																								
FI-9	03.07.2007	Saarijärvi - Äänekoski	2																1																														1				
FI-10	09.03.2009	Lahti railway yard	1																	1																																		
FI-11	17.09.2009	Kilpua station	2									1																			1																							
FI-12	20.03.2006	Luumaki Station	1																																												1							
FI-13	28.12.2005	Line Yppykkavarra - Vrtius	1																																1																			
FI-14	31.10.2005	Perasenia-joki Station	1									1																																										
FI-15	31.07.2003	Line Kallishti - Rantasalmi	1															1																																				
FI-16	16.07.2003	Line Hammaslahti - Tikkala	1															1																																				
		Cause totals	20	0	0	0	0	0	0	0	0	3	0	1	0	0	0	4	2	1	0	0	1	0	0	0	0	1	0	1	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
16		Single cause totals	12	0	0	0	0	0	0	0	0	1	0	1	0	0	0	4	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Denmark																																																						
DK-1	03.09.2001	Hedenstad Station	1																																											1								
DK-2	21.10.2004	Arhus	1									1																																										
DK-3	22.02.2005	Forlev	1													1																																						
		Cause totals	3	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
3		Single cause totals	3	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0

Table 4: Accident Data Summary UK and Republic of Ireland

No	Date	Place	# Cause	Causes																																																		
				E	Infrastructure																		Rolling Stock														Operational																	
				E	1a	1b	1c	1d	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4	U	1ai	1aii	1aiii	1bi	1bii	1biii	2a	2b	2c	3	4	5	6	U	1a	1b	2a	2bi	2bii	2c	2d	3a	3b	3c	4a	4b	5ai	5aii	5b	6	7	U
United Kingdom																																																						
UK-1	18.10.2005	Hatherley	1																																										1									
UK-2	18.01.2006	York station	1																											1																								
UK-3	21.01.2006	Waterside, East Ayrshire	1						1																																													
UK-4	31.01.2006	Cricklewood Curve	1																																																1			
UK-5	09.02.2006	Brentingby Junction	1																																																1			
UK-6	28.06.2006	Maltby North	2																																												1				1			
UK-7	08.09.2006	Washwood heath	2																										1															1										
UK-8	10.05.2007	Newcastle	2													1																	1																					
UK-9	22.06.2007	Ely Dock	3																				1								1																							1
UK-10	25.02.2008	Santon	3													1		1																																				1
UK-11	25.03.2008	Moor Street	1													1																																						
UK-12	10.08.2007	Duddeston Junction	2													1																								1														
UK-13	12.06.2008	Marks Tey	1														1																																					
UK-14	27.01.2009	Stewarton	1					1																																														
UK-15	01.05.2009	Sudforth Lane	1																		1																																	
UK-16	25.02.2009	Wigan North	2												1																		1																					
UK-17	04.01.2010	Cambridge Station	2	1																																															1			
		Cause totals	**27**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**4**	**1**	**1**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**2**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**4**	**0**	**0**	**2**
17		**Single cause totals**	**9**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**
Republic of Ireland																																																						
IE-1	10.01.2008	Skerries	1																				1																															
		Cause totals	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1		**Single cause totals**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table 5: Accident Data Summary Belgium and the Netherlands

No	Date	Place	# Cause	Causes																																																		
				E	Infrastructure																		Rolling Stock														Operational																	
				E	1a	1b	1c	1d	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4	U	1ai	1aii	1aiii	1bi	1bii	1biii	2a	2b	2c	3	4	5	6	U	1a	1b	2a	2bi	2bii	2c	2d	3a	3b	3c	4a	4b	5ai	5aii	5b	6	7	U
Belgium																																																						
BE-1	02.09.2007	Ottignies	1																								1																											
BE-2	29.01.2008	Houyet	1																																						1													
		Cause totals	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2		Single cause totals	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Netherlands																																																						
NL-1	30.03.2003	Apeldoorn	1																																														1					
NL-2	17.06.2003	Halfweg	1												1																																							
NL-3	06.05.2005	Amsterdam	1																								1																											
NL-4	10.05.2005	Amsterdam	2																		1																																	1
NL-5	14.09.2006	Dordrecht	1								1																																											
NL-6	23.08.2007	Duiven	3													1												1							1																			
NL-7	22.11.2008	Amsterdam	1																				1																															
NL-8	29.04.2010	Harmelen	1																																									1									
		Cause totals	11	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1
8		Single cause totals	6	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0

Table 6: Accident Data Summary Germany

No	Date	Place	# Cause	Causes																																																		
				E	Infrastructure																		Rolling Stock														Operational																	
				E	1a	1b	1c	1d	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4	U	1ai	1aii	1aiii	1bi	1bii	1biii	2a	2b	2c	3	4	5	6	U	1a	1b	2a	2bi	2bii	2c	2d	3a	3b	3c	4a	4b	5ai	5aii	5b	6	7	U
Germany																																																						
DE-1	06.08.1999	Bhf Lahr	1																1																																			
DE-2	21.12.1999	Bahnhof Raubling	1																				1																															
DE-3	22.11.2000	Backnang	1																																							1												
DE-4	15.05.2001	Strecke Werl – Soest	1																										1																									
DE-5	26.06.2001	Strecke Biederitz – Güterglück	1																																					1														
DE-6	16.02.2002	Bhf Osnabrück	1							1																																												
DE-7	16.04.2002	Strecke Grafing – Kirchseeon	1																											1																								
DE-8	29.08.2002	Bhf Ehrang (Trier)	1																																														1					
DE-9	24.01.2003	Bhf Rommers-kirchen	1																																							1												
DE-10	19.02.2003	Strecke Kobern-Gondorf	1																											1																								
DE-11	26.06.2003	Line Dachau - Rohrmoos	1																				1																															
DE-12	22.10.2003	Strecke Hamburg Billwerder	1																				1																															
DE-13	05.03.2004	Bhf Hatzenport	1																					1																														
DE-14	17.03.2004	Bhf Osnabrück	1																																										1									
DE-15	25.10.2004	Bhf Merzig	1																					1																														
DE-16	29.03.2005	Bhf Scwindegg	2																			1													1																					
DE-17	10.09.2005	Würzburg-Heidingsfeld	1																				1																															
DE-18	18.01.2006	Bhf Nienburg (Weser)	1																				1																															
DE-19	15.12.2006	Bhf Markt Einersheim	1																				1																															
DE-20	21.12.2006	Bhf Magdeburg-Buckau	1								1																																											
DE-21	23.01.2007	Elmshorn - Tornesch	2																																				1			1												
DE-22	28.02.2007	Rottenburg Wümme	1																				1																															
DE-23	12.06.2007	Bhf Blankenberg (Sieg)	1																								1																											
DE-24	22.08.2007	Bahnhof Schwerte (Ruhr)	1																																													1						
DE-25	19.12.2007	Brannenburg - Raubling	1						1																																													
DE-26	17.07.2009	Bruchmülen - Bünde	1																				1																															
DE-27	07.08.2009	Nürnberg Stein – Nürnberg Rbf	1									1																																										
DE-28	25.03.2010	Dinslaken – Oberhausen West	1																				1																															
DE-29	16.06.2010	Peine	1																								1																											
DE-30	26.07.2010	Bhf Falkenberg	1																								1																											
DE-31	01.09.2010	Bacharach	1																				1																															
DE-32	20.11.1997	Elsterwerda	1																																										1									
		Cause totals	34	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	1	0	0	1	10	2	0	0	3	0	1	2	0	0	0	0	1	0	0	0	1	1	0	3	0	0	2	0	0	1	1	0	0	0	0	0
32		Single cause totals	30	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	1	0	0	0	10	2	0	0	3	0	1	2	0	0	0	0	0	0	0	0	0	1	0	2	0	0	2	0	0	1	1	0	0	0	0	0

Table 7: Accident Data Summary Austria

No	Date	Place	# Cause	Causes																																																		
				E	Infrastructure																		Rolling Stock														Operational																	
				E	1a	1b	1c	1d	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4	U	1ai	1aii	1aiii	1bi	1bii	1biii	2a	2b	2c	3	4	5	6	U	1a	1b	2a	2bi	2bii	2c	2d	3a	3b	3c	4a	4b	5ai	5aii	5b	6	7	U
Austria																																																						
AT-1	01.03.2006	Salzburg	1																					1																														
AT-2	28.04.2006	Salzburg	1																																																		1	
AT-3	09.05.2006	Villach Sud	1						1																																													
AT-4	11.07.2006	BHF Ebenfurth	2																																		1														1			
AT-5	04.10.2006	BHF Hieflau	2																																1		1																	
AT-6	04.04.2007	Scharding	1																				1																															
AT-7	02.08.2007	BF Wien Matzleindorf	1																										1																									
AT-8	09.09.2007	BHF Wien Donaukai	1																										1																									
AT-9	31.10.2007	Tauern Tunnel	1																							1																												
AT-10	24.03.2008	BF Leoben Donawitz	2									1							1																																			
AT-11	16.08.2008	BF Neuleng Bach	3												1																		1																					1
AT-12	06.09.2008	BHF Rosenbach	1												1																																							
AT-13	18.10.2008	BHF Pochlam	1																																		1																	
AT-14	22.10.2008	Wien Zvbf	1																																					1														
AT-15	31.10.2008	Gummern	1																											1																								
AT-16	17.11.2008	Strecke Unter Purkersdorf	1																																					1														
AT-17	20.12.2008	Strecke 10102	1																				1																															
AT-18	08.04.2009	Leithabrucke	2												1																					1																		
AT-19	09.04.2009	St Peter Seiten	1																					1																														
AT-20	25.07.2009	Bruck Mur Graz	1												1																																							
AT-21	17.04.2010	Wakersbach & Prambachkirchen	1												1																																							
AT-22	28.04.2010	Bhf Hohenau	1																																																	1		
AT-23	16.06.2010	Braz Arlbergstrec	1																															1																				
AT-24	05.05.2010	Bf Selzhtal	1																															1																				
		Cause totals	30	0	0	0	0	0	1	0	0	1	0	0	5	0	0	0	1	0	0	0	2	2	0	1	0	0	2	1	0	0	1	2	1	1	3	0	0	2	0	0	0	0	0	0	0	0	0	0	1	1	1	1
24		Single cause totals	19	0	0	0	0	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	2	2	0	1	0	0	2	1	0	0	0	2	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	1	0

Table 8: Accident Data Summary Switzerland and France

No	Date	Place	# Cause	Causes																																														
				E	Infrastructure																		Rolling Stock														Operational																	
				E	1a	1b	1c	1d	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4	U	1ai	1aii	1aiii	1bi	1bii	1biii	2a	2b	2c	3	4	5	6	U	1a	1b	2a	2bi	2bii	2c	2d	3a	3b	3c	4a	4b	5ai	5aii	5b	6	7	U
Switzerland																																																						
CH-1	06.05.2000	Rodi - Fiesso	1																																1																			
CH-2	30.03.2004	Rodi - Fiesso	1												1																																							
CH-3	19.01. 2005	Chiasso Smista-mento	1																																		1																	
CH-4	08.02 2006	Amsteg	1																																							1												
CH-5	24.03.2006	Cornaux	1																1																																			
CH-6	09.05.2006	Olten Rbhf	1																																													1						
CH-7	26.07.2006	Brig entry to Simplon tunnel	1																					1																														
CH-8	27.07.2006	Bresonnaz VD – Ecublens	1												1																																							
CH-9	17.08.2006	Mühlehorn	1																					1																														
CH-10	30.09.2008	Meilen – Herrliberg-Feldmeilen	2												1																										1													
CH-11	19.01. 2009	Rbhf Limmattal	2																			1																													1			
CH-12	13.09.2009	Basel Rangierbhf	1																																													1						
CH-13	21.05.2010	Visp Station	1																											1																								
		Cause totals	**15**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**1**	**0**	**0**	**0**
13		**Single cause totals**	**11**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**
France																																																						
FR-1	18.01.2001	Montpellier station	2																				1					1																										
FR-2	13.06.2006	Ferté-sur-Chiers	2													1	1																																					
FR-3	21.07.2006	St. Parres le Vaudes Bar Seine	1															1																																				
FR-4	24.01.2007	St. Amour – Beny Aiguille-Ipcs	1																				1																															
FR-5	30.10.2007	Gex – Fort l'Ecluse-Collonges	1						1																																													
FR-6	24.11.2009	Orthez	2																	1									1																									
FR-7	22.05.2010	Neufchâteau	1																							1																												
FR-8	29.07.2010	Bully-Grenay station	2																									1																	1									
FR-9	09.03.2011	Artenay	1																					1																														
		Cause totals	**13**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**1**	**1**	**0**	**1**	**0**	**0**	**2**	**1**	**0**	**1**	**0**	**2**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
9		**Single cause totals**	**5**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table 9: Accident Data Summary Spain, Portugal and Italy

No	Date	Place	# Cause	Causes																																																		
				E	Infrastructure																		Rolling Stock														Operational																	
				E	1a	1b	1c	1d	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4	U	1ai	1aii	1aiii	1bi	1bii	1biii	2a	2b	2c	3	4	5	6	U	1a	1b	2a	2bi	2bii	2c	2d	3a	3b	3c	4a	4b	5ai	5aii	5b	6	7	U
Spain																																																						
ES-1	07.12.2003	Valencia de Alcántara	1						1																																													
ES-2	15.12.2004	Pola de Lena station	1																	1																																		
ES-3	15.03.2006	Los Ramos Alqueiras	1																1																																			
ES-4	12.12.2006	Tarragona Termino station	1																1																																			
ES-5	29.03.2007	Montabliz	1													1																																						
ES-6	25.06.2007	Venta de Baños	1																															1																				
ES-7	08.01.2008	Reus station	1																1																																			
ES-8	24.10.2008	Moncófar station (Castellón)	1																							1																												
ES-9	17.09.2009	Zumarraga station	1													1																																						
ES-10	14.06.2010	Cerdido y – Ortiguere, Coruna	1																																													1				
		Cause totals	10	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	3	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
10		Single cause totals	10	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	3	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Portugal																																																						
PO-1	20.12.2006	Linha do Norte	1																							1																												
		Cause totals	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1		Single cause totals	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Italy																																																						
IT-1	29.06.2009	Viareggio	1																						1																													
		Cause totals	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1		Single cause totals	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 10: Accident Data Summary Hungary and Romania

No	Date	Place	# Cause	Causes																																																		
				E	Infrastructure																		Rolling Stock														Operational																	
				E	1a	1b	1c	1d	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4	U	1ai	1aii	1aiii	1bi	1bii	1biii	2a	2b	2c	3	4	5	6	U	1a	1b	2a	2bi	2bii	2c	2d	3a	3b	3c	4a	4b	5ai	5aii	5b	6	7	U
Hungary																																																						
HU-1	10.08.2003	Budafok-Háros	1																								1																											
HU-2	15.09.2004	Fényeslitke	1																					1																														
HU-3	06.08.2006	Komarom Station	1																																																1		
HU-4	28.10.2006	Mende	1																				1																															
HU-5	07.12.2006	Debrecen	2																																1																			1	
HU-6	27.12.2006	Lebeny Mosonszent	1																				1																															
HU-7	25.01.2007	Szolnok	1																																																		1	
HU-8	07.02.2008	Budafok	1																1																																			
HU-9	26.03.2008	Kobanya	2								1																																											1
HU-10	22.07.2008	Rakos Station	1																																													1						
HU-11	09.09.2008	Szekesfeher	1												1																																							
HU-12	04.02.2009	Rajka Station	2												1																									1														
HU-13	23.03.2009	Pusztaszabo	2												1																									1														
HU-14	21.04.2009	Vamosgyork	1																																																1		
HU-15	15.03.2010	Miskolc Station	1																				1																															
		Cause totals	**19**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**3**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**2**	**2**	**1**
15		**Single cause totals**	**11**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**3**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**2**	**1**	**0**
Romania																																																						
RO-1	22.02.2007	Dej Triaj Station	1										1																																									
RO-2	22.02.2007	Cricov Station	1																								1																											
RO-3	15.12.2007	Milova	1																								1																											
RO-4	13.03.2008	Zavideni Station	1																				1																															
RO-5	28.05.2010	Halmeu Station	2																1												1																							
RO-6	18.07.2010	Aiud Station	2																								1	1																										
		Cause totals	**8**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**3**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
6		**Single cause totals**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table 11: Accident Data Summary Czech Republic, Slovakia, Poland and Estonia

No	Date	Place	# Cause	Causes																																																		
				E	Infrastructure																		Rolling Stock														Operational																	
				E	1a	1b	1c	1d	2a	2b	2c	2d	2e	2f	3a	3b	3c	3d	3e	3f	4	U	1ai	1aii	1aiii	1bi	1bii	1biii	2a	2b	2c	3	4	5	6	U	1a	1b	2a	2bi	2bii	2c	2d	3a	3b	3c	4a	4b	5ai	5aii	5b	6	7	U
Czech Republic																																																						
CZ-1	22.02.2008	Zabreh na morave	3										1		1																					1																		
CZ-2	24.04.2009	Cercany Station	1																																					1														
CZ-3	21.01.2010	Přerov - Prosenice	1																												1																							
		Cause totals	5	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3		Single cause totals	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slovakia																																																						
SK-1	07.10.2003	Ruskov	1																										1																									
SK-2	13.04.2004	Velke Kostol'any – Piest'any	1																				1																															
SK-3	27.12.2005	Bratislava Vychod station	1								1																																											
SK-4	30.03.2006	Trnava – Kuty	2	1			1																																															
SK-5	15.09.2006	Zvolen - Plesivec	1																													1																						
SK-6	27.07.2007	Zohor – Plavecky Mikulas	2															1										1																										
SK-7	06.09.2007	Lucenec – Zvolen	1																											1																								
SK-8	04.12.2007	Ziar nad Hronom	1																																																1		
		Cause totals	10	1	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
8		Single cause totals	6	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Poland																																																						
PL-1	10.08.2007	Walbryzch Fabrycny	1																1																																			
PL-2	23.10.2007	Line 7 Lublin station	1																1																																			
PL-3	17.11.2007	Kalisz station	1																											1																								
PL-4	25.11.2007	Line 91 Zurawica station	1																								1																											
PL-5	16.06.2008	Radziwillow - Miedniewice	1																				1																															
PL-6	10.09.2008	Line no 65	2																									1									1																	
		Cause totals	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6		Single cause totals	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Estonia																																																						
EE-1	04.12.2008	Rakvere, Kunda	1		1																																																	
		Cause totals	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1		Single cause totals	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

4.0 Detailed Accident Descriptions

Additional information on each individual accident is presented below. The following tables contain:

1. Reference to the accident (which can be cross-referenced with the summary tables)
2. Details of the accident location
3. Allocation of cause(s)
4. Accident description
5. Reference to the source of the data

No.	Date:	Place:	Category:	Description	Reference:
Norway, Source: SHT					
No-1	18.07.2002	Fetsund	I 3a + O 2bi + rs	Train 4661 was on route from Alnabru (Oslo) to Sweden over Charlottenberg. The train comprised of 33 wagons with a total length of 614 m and a train weight (exclusive of locomotive) of 716 tonne. This was a long but lightly loaded train. Between Fetsund station and the Glomma bridge the train derailed with the leading axle of a 2 axle wagon type Lgjns-w The derailed car was the 11th in the train. The derailed wagon was dragged on for 5 km before the train was stopped. The cause of the derailment was due to a number of faults and unfortunate circumstances related to track and the derailed wagon: - A specified track twist above the design limits of the infrastructure owner in the transition curve of the 289 m radius curve leading on to the bridge and due to a track fault the actual twist was for a short distance close to or above the safety limit. - Worn rails at the derailment location, but not above any immediate replacement limit. - The derailed wagon was twisted due to a wrongly loaded container leading to a significant skew loading on both leading and trailing axle. - The derailed wagon had a wheel base of 10 m and an overall length of 17.1 m. - The trapezoidal spring suspension was very stiff when the car was lightly loaded which was very unfortunate for a 2-axle wagon with such lo along wheel base. Further, it can be mentioned that the train passed Fetsund station in track 2 (a sidetrack) but at a constant speed of 40 km/h, and the acceleration had not started when the derailment occurred. The derailment was due to an **excessive track twist in combination with a skew loaded** wagon and unfortunate features of the derailed wagon as mentioned above.	HSLB JB 2003/03
No-2	13.08.2002	Fetsund	I 3a rs	Train 4661 was on route from Alnabru (Oslo) to Sweden over Charlottenberg. The train comprised of 27 wagons with and a train weight (exclusive of locomotive) of 824.1 tonne. Between Fetsund station and the bridge across Glomma the train derailed with the leading axle of a 2 axle wagon type Lgjns-w The derailed car was the 8th in the train. The derailed wagon was dragged on for 3 km before the train was stopped. - The cause of the derailment was similar to the derailment at the same location the month before apart from the fact that the derailed wagon at this occasion was not skew loaded and the wheel base of the derailed wagon was 9 m Further, it can be mentioned that due to traffic the train stopped at Fetsund station in track 2 (a sidetrack) and was under acceleration when the derailment occurred at a speed of 30 km/h. The derailment was due to an **excessive track twist** in combination with unfortunate design features of the derailed wagon.	HSLB JB 2003/03
No-3	12.02.2003	Halden	O 5b	Train 42511 from Alnabru (Oslo) to Gothenburg with 28 wagons and a train weight of 1102 tonnes	SHT JB 2004/08

No.	Date:	Place:	Category:	Description	Reference:
				(exclusive of locomotives) derailed with 3 empty wagons in the back of the train (wagons no 25, 26 & 27) during exit from track 3 (a sidetrack) at Halden station when passing the turnout to the main track. The train had a rear uncoupled helper engine from Halden due to the 25 per mille ascent between Halden and Tistedal. The cause of the derailment was a **too hard push from the helper engine combined with an unfortunate train composition.** A number of light empty 2 axle wagons in the back of the train combined with the curves in the turnout contributed to the accident. There was no open communication link between the drivers of the front and rear engines.	
No-4	06.07.2004	Mo - Skonseng	RS 1ai	Iron ore train 5954 from Ørtfjell to Mo i Rana with 34 loaded wagons with a total weight of approximately 3260 tonnes (exclusive of locomotive) derailed with a bogie on the 6th wagon due to a **rupture of the axle journal**. A fatigue crack had developed close to the bearing bush that was shrinked on the axle. Crack initiation had occurred in the transition zone between the bearing bush and axle at the end of the bearing bush. It is assumed that shock loads during loading of the wagons could have represented the largest load on the axles. Further, the allowable axle load had been increased to 24 tonnes for the axles without proper check of a need for adjustment of the inspection intervals.	SHT JB 2005/01
No-5	12.05.2005	Middagselv tunnel	I 3a + o + rs	Freight train no. 9906 on the Ofoten line derailed with wagons no 25-42 inside the Middagselv tunnel, km 27,285. The train, operated by Mamtrafikk AS (MTAS), was on its way from Kiruna in Sweden to Narvik in Norway, and consisted of 52 wagons loaded with iron ore. The train was pulled by a class Dm3 locomotive. The train dimensions inclusive of locomotive were: length of 472 m and a weight of 5500 tonnes. The braking weight was 1969 tonnes. The train speed at derailment was 55 km/h. The cause of the derailment was a combination of several factors: 1. The track had **an excessive twist** with a twist of 7.5 per mille (1:133) measured on a 2 m basis due to a frost heave in the tunnel. This is a twist above the safety limit. However, as the first wagon to derail was no 25 or 26 in the train this fact in itself was not sufficient to cause derailment. 2. One of the first wagons to derail, no.26, probably had some frame or bogie twist which had increased the wear of one of the wheels. 3. The driver did a brake application approximately 4 seconds prior to the initial derailment and the locomotive had activated brakes in position P whereas the rest of the train was set in brake position G. This was contrary to the specifications of the traffic rules. The brake application caused a compression of the train with push forces on the wagons that assisted in causing a train derailment. As the track twist was known for a couple of weeks with no action taken it seems that insufficient track	SHT JB 2006/08

No.	Date:	Place:	Category:	Description	Reference:
				geometry management was the main cause.	
No-6	04.12.2005	Sandbukta	RS 1ai	Freight train 4963 on route from Kongsvinger to Moss and Sarpsborg with containers with wood chips derailed due to **a rupture of the axle journal and a hot axle box.** The axle box was lost prior to the derailment. Parts of the wheel set suspension had also been disintegrated and fallen off the wagon. The investigation report concluded that the most likely cause of the failure was due to **faulty maintenance of the journal bearing and the axle box.** The investigation report recommended that trackside equipment for supervision of axle box temperature and bearing conditions should be evaluated for installation on the line.	SHT JB 2006/10
No-7	23.12.2005	Bulken - Evanger	E	Freight train 5505 from Alnabru (Oslo) to Bergen with a weight of 773 tonnes and length of 413 m derailed at the time 03.14 due to **large stones** from a large rockslide that came to rest **across the track** between Bulken and Evanger stations on Vossebanen. The train was travelling at line speed. The track at the accident position lacked avalanche and rock scree detection fence on the accident stretch. This is normal on other parts of this line.	SHT JB 2007/01
No-8	06.07.2006	Råde – Onsøy, km 77.5.	I 3d	Thursday July 6th 2006 at 15.05 Green Cargo freight train 45955 on route to Kornsjø and Sweden derailed with 5 wagons (wagons 5-7 and 9-10) at km 77.5 between Råde and Onsøy as a result of a track buckle (**sun curve)** that developed while the train was passing with a speed of approximately 85 km/h. The train consisted of one Swedish RC-locomotive and 12 empty Swedish registered autocar transport wagons type Laaeilprs belonging to NordWaggon AB. The train weight was 432 tonnes, exclusive of locomotive, with a length of 372 m. The direct cause of the accident was a sun-curve that developed while the train was passing. The cause of the sun-curve was the high temperature causing internal compression forces in the track that exceeded the lateral displacement resistance of the track. Probably due to a displaced track and uncontrolled neutral temperature in the track.	SHT JB 2007/11
No-9	26.07.2006	Dombås – Dovre, km339,80	I 3d	Wednesday July 26th at 16.40 CargoNet freight train 5718 on route from Trondheim to Alnabru (Oslo) derailed with its 7 first wagons at km 339.80 between Dombås and Dovre as a result of a track buckle (**sun curve)** that developed next to a short fixed bridge while the train was passing. The locomotive of the train did not derail. The sun curve occurred close to a short bridge (fixed point) in the track. Some days before the accident a sun curve at the same location was insufficiently corrected. CargoNet freight train 5718 consisted of 14 wagons (61 axles) weighing 571 tonnes, with a total length of 422 m, all figures exclusive of locomotive. The freight train speed at the accident location was approximately 80 km/h which is within allowable speed for the accident train at the accident location. The train was lightly loaded with an average gross axle load of less than 10 tonnes.	SHT JB 2007/10

No.	Date:	Place:	Category:	Description	Reference:
				The cause of the sun-curve was the high temperature causing internal compression forces in the track close to a fixed point of the track as well as a wrongly executed maintenance work some days earlier to control a previous sun-curve at the spot. Investigations after the accident found no direct contributing faults on the derailed wagons but the 5 first derailed wagons was of a type (auto transport wagons) that have shown a higher than normal susceptibility to derailments.	
No-10	08.09.2006	Trettnes	E	A freight train derailed at km 620.95 Trettnes on the Nordland railway due to **a large rockslide that blocked the railway line**. The locomotive of Type 66 and 8 freight wagons derailed. A total of about 500 m³ of rock stones had been released in a rock scree approximately 40 meter height above the railway cutting. The cause of the release could have been the different rock classes at the location. The locomotive was driveable after the crash once the plough was removed. The track had to be exchanged over a distance of 150 m. No human injuries occurred.	SHT JB 2007/01
No-11	12.12.2006	Dombås station	I 3b + RS 2b	Train 5709 on route from Oslo (Alnabru) to Trondheim derailed with one axle when entering track 3 at Dombås station via turnout no 1. The train weight was 908 tonnes with a train length of 466 m, all exclusive of locomotives. At the exit of the station another couple of axles had derailed. A total of 4 axles derailed altogether. The derailed axles belonged to 2 short coupled autocar wagons with a long wheel base. The overall length of the wagon assembly was 25.76 m. The derailment cause is judged to be a combination of 2 factors: 1. A track failure comprising a low left rail in front of turnout no 1 at the station. 2. Damage to spring suspension of the wagon, partly caused by a previous non-repaired failure. The wagon was also involved in the 26.07.2006 derailment between Dombås and Dovre. The accident cause was a **combination of faulty track and faulty rolling stock suspension**.	SHT/JB 2008/03
No-12	05.09.2007	Strømmen - Fjellhamar	O 2c	A 3.5 m rail part fell off work train 66024 for transportation of long rails to a work site. When it fell off it fastened in the wagon and lifted this wagon off the track. The wagon was later hit by freight train 5722 that also partly derailed. **Insufficient load fastening.**	SHT JB 2008/06
No-13	29.04.2008	Skogn	I 4	Freight train 5795 derailed with the 2 last wagons while entering Skogn station due to **a failure of the signalling system causing untimely switch of position of the point** in a turnout while the train was passing the turnout in deviated position with a speed of approximately 40 km/h. This was due to a cable fault in the signalling system.	SHT JB 2009/04
No-14	25.07.2008	Hval - Hønefoss	I 3e	Freight train 5505 with 14 wagons (8 of them with 6 axles and 6 with 2 axles) on route from Alnabru (Oslo) to Bergen derailed with the wagons in position 6-11 between Hval and Hønefoss at km 87. The	SHT JB 2009/05

No.	Date:	Place:	Category:	Description	Reference:
				total train weight was 941 tonnes and the length was 394 m. The main derailment cause was a track in very poor condition with old wooden sleepers without sufficient strength to keep the track fastened. The speed at derailment was 63 km/h. The derailment cause was **excessive track width.** A very high temperature (30^{o} C) at the accident day probably contributed to the excessive track width.	
No-15	12.10.2008	Halden station	I 3e	Freight train 4957 with 15 short coupled 4 axle double wagons with a total weight of 1230 tonnes and a length of 360 m was on route from Kongsvinger to Halden. In Halden the train had to pass the southern turnout of the station (point no 2) and then reverse into a track where they had to go around with the engine for pushing the wagons to the timber terminal of Saugbrugsforeningen. At 17.35 while passing switch no 2 at Halden the train derailed with wagon no 9 a short distance after the switch. Shortly after also wagons no 13 and 14 derailed. The speed was less than 40 km/h. The cause of the derailment was a track of poor general standard with some wooden sleepers of poor quality and partly excessive track width as high 1485 mm. The last track inspection identified a track width requiring immediate intervention. No action had been taken at the date of the accident which occurred 6 months after the track inspection.	SHT JB 2010/06
No-16	25.05.2009	Ørtfjell station	O 4a	The locomotive of the loaded iron ore freight train 5960 derailed at a manually operated station (sidetrack) when the train weighing 3200 tonnes was directed to a buffer stop instead of the main line due to a **faulty point position**. The train had a low speed. The cause of the faulty point position was an **act of omission from the local train dispatcher**.	SHT JB 2009/11
No-17	22.12.2009	Hauerseter - Fjellhamar	RS 1ai	Freight train 8264 consisting of 23 wagons loaded with timber was on route from Sørli timber terminal to Sarpsborg. The train weight was approximately 1200 tonnes inclusive of locomotive. El.14.2174. 20 of the wagons were 2 axle wagons of type Lps (412.8) and 3 were bogie wagons of type Laaps (430.9). The train was operated by CargoNet who was also owner of the wagons and the locomotive. The maximum allowable speed of the train was 90 km/h. When the train was between Strømmen and Fjellhamar the driver received a call from the control centre that they had to stop and inspect the train. The control centre had received message from the driver of a passing train that one of the wagons was running very skewed and something was wrong with train 8264. Inspection by the driver revealed that the left side axle box, the blade spring and the axle box guidance of the last axle of the 19^{th} wagon were lost, and the remaining axle journal stump had sheared half way through the carriage side beam. All wheels were running on the track when the train stopped atFjellhamar. Some of the missed parts were later found by the track at km 48 near Hauerseter which is approximately 30 km prior to where the train was stopped.	SHT JB 2010/09

No.	Date:	Place:	Category:	Description	Reference:
				Investigation by the National Investigation Body revealed that the incident probably developed as a result of metal build-up on the wheels' rolling surfaces caused by a stuck brake. This caused sufficient impact to damage the axle bearings. The carriage was fitted with axle bearings of an older type with a brass roller cage. These have previously proved to have a higher frequency of failure, and are no longer reinstalled in connection with wheel sets for CargoNet AS. The route of this train did not pass any wheel load detector nor a hot axle box detector.	
Sweden, Source: Statens Haverikommission (SHK) & Järnvägsinspektionen (JVI)					
SE-1	22.04. 1996	Kävlinge	I 3d	Freight train 6275 comprising 23 wagons was on route from Landskrona to Malmø. Wagons 2-6 were bogie tank wagons loaded with ammonia. 17 of the remaining 18 wagons were empty. The train weight was 744 tonnes and the train length was 356 m. 1 km south of Kävlinge station, at km 276,281 on the single track line from Kävlinge to Lomma, the train derailed at 16.30 with 9 of its wagons. The derailment was initiated by the 3rd axle of wagon no 5, a tank wagon with ammonia. The 6th wagon, also loaded with ammonia, and 6 following wagons derailed thereafter. Wagons 5 and 6 overturned. The train composition was broken between the 4th and 5th wagon and the last bogie of the 4th wagon also derailed. The front part of the train continued approximately 100 m before it came to a standstill. The accident occurred while the train was passing a right hand curve of 676 m radius with 85 mm cant with a descent of 7 per mille towards Kävlinge station. The train speed at the accident location was 71 km/h which is well below the allowable 90 km/h. The track at the accident location was jointed track with spike fastenings on old wooden sleepers spaced 70 cm apart.. The rail lengths were 40 m and the rail weight was 43 kg/m. 6 days prior to the accident at 16.04.96 the track at the accident location had been subject to track alignment involving a slight lifting of the track with 10 – 15 mm, according to those responsible for the work. Since the track alignment work the traffic over the track had amounted to 47 000 tons only while a traffic load of 100 000 tons are prescribed for the track to be fully stabilised. Temporary speed restriction had not been introduced after the track work until track stabilisation was ensured, although the day mean temperature had increased approximately 18^{o}C over the last 10 days prior to the accident. On the day of the accident the air temperature was above 25^{o}C and the sky was clear with strong sun. 24 hours after the accident the rail temperature was measured to 36 ^{o}C under equal weather conditions. This track section had previously experienced sun curves which were thought to be a result of the track decent towards Kävlinge and rail movements due to traction and braking. An excess amount of rail had collected in the accident track section. Preparations had been made to rectify this situation by track adjustments and the work had started some km further south. Since no other possible faults were identified, **the cause of the derailment was considered to be a track buckle (sun curve) that had developed under the train as the train was passing**. The track was completely destroyed at the accident location an hence it was difficult to verify the cause, but clear	Järnvägs-inspektionen Undersökningsrapport 1997:2

No.	Date:	Place:	Category:	Description	Reference:
				openings between sleepers and ballast outside of the immediate derailment location made further indications of a lateral movement of the track. During salvage of the overturned ammonia wagons up to 9000 persons were evacuated from the nearby societies of Kävlinge and Furulund. The overall cost of the accident was not stated.	
SE-2	04.07. 1997	Kälarne	I 3d	Freight train no 5800 was on route from Gävle to Skelleftehamn. The train consisted of 37 wagons with a total train length of 626 m and a total weight of 1587 tonnes. The allowable speed of the accident train at the accident location was 90 km/h. The actual speed was 87 km/h. 4 km SSW of Kälarne station the train derailed with 15 wagons from wagon no 19 and backwards due to a to a **track buckle (sun curve)** that developed in the track as the train was passing. The brakes were applied automatically due to a train pressure main line rupture at the same time as the driver initiated an emergency brake. The accident occurred at the time of 17:00. The temperature in the air was measured to 25.1 ^{o}C at the SMHI station at Krångede not far from the accident location. Several wagons with hazardous materials derailed. Some of them developed small leaks without causing further damage. Large material damage to track and rolling stock	SHK rapport RJ 2000:1
SE-3	08.04. 2000	Borlänge	O 5ai	A block train on route from Gothenburg to Borlänge loaded with approximately 450 tonnes of LPG (Liquefied Petroleum Gas) to SSAB in Borlänge derailed in Borlãnge at the time 02.30. The train contained 9 bogie wagons each loaded with 50 tonnes of LPG. The total train weight was 774 tonnes exclusive of locomotive. At Borlänge station the maximum speed is 40 km/h. The station lacked ATP-protection. The train passed a signal in stop and derailed when it passed a set of points in deviated position with a speed of 70 km/h. The design speed for the points was 40 km/h. An emergency brake was also applied by the SIFA-system (driver vigilance control) 7 s after passing the first deviated point. Six of the nine wagons derailed of which 5 overturned. No leaks of LPG occurred even if some of the wagons were significantly damaged. After a long and tedious rescue operation lasting 8 days, involving hot tapping, the wagons were emptied and the situation normalised. During part of this operation 635 persons living in the surroundings were evacuated and more than 500 persons took place in the rescue. No persons were injured. The total cost of the accident was estimated to SEK 40.5 million. (2000-value) Investigation after the accident showed that the driver of the train was drunk (intoxicated by alcohol) with a blood alcohol content of 1.58 per mille. The driving showed a number of other irregularities along the route. **The cause of the derailment was judged to be the excessive speed caused by an incapacitated driver due to alcohol consumption.**	Tågolyckan I Borlänge 8th -16th April 2000; Räddnings-verket. Järnvägs-inspektionen Undersökningsra pport 2000:3
SE-4	30.03 2001	Strömsbro (Gävle)	O 4a	In the evening of 29.03 an empty passenger train had torn down the contact line at Gävle freight terminal and shunting yard and the train blocked the southern entry to the freight terminal completely. The voltage of the whole yard was also cut. The passenger station at Gävle C and the main tracks to and from Gävle C was open for traffic. Several departing freight train was locked in the freight terminal	Järnvägs-inspektionen Undersökningsra pport 2001:1

No.	Date:	Place:	Category:	Description	Reference:
				due to lack of appropriate traction units to leave the yard. During the night freight train 5883 was arriving towards Gävle from Ånge (from north). The train comprised 30 wagons with a total weight of 997 tonnes and a length of 466 m. In order to get this train into the yard at Gävle and free its engine for further operation it was decided to use a diesel locomotive type T-44 that was north of the train to push train 5883 into arrival track 120 of the shunting yard, decouple the electric locomotive then pull the train away from that track and push the train minus the electric locomotive into another arrival track. The diesel locomotive should then get the electric locomotive over to a departing train and assist that train out of the yard. When pulling train 5883 out of track 120 the diesel locomotive cut open a trailing point into the main tracks and passed the point with the locomotive and the first wagon at the time 3.27. When pushing the train back into another arrival track the wagon immediately behind the locomotive derailed and overturned also obstructing the free gauge of the 2nd main track. At the time of 3.40 passenger train 875 was allowed passing the overturned wagon even if there was not sufficient clearance. Train 875 partly collided with the overturned wagon. Damage occurred to the rolling stock of the passenger train but it did not derail. The shunting operation that was carried out with train 5883 occurred on the border between the tracks controlled by the train dispatcher at Gävle C and those controlled by the shunting leader at the freight terminal control tower. The trailing point that was cut open belonged to the track controlled by the train dispatcher and once the point was free of train 5883 as it was first pushed into track 120, the point was switched to allow a train route for freight train 5680 from Gävle C towards the main line to Sundsvall. When the train was pulled out to go into another arrival track the driver of the diesel engine did not notice the switched position of the entry point and cut the point open with the locomotive and the first wagon. Once pushing the train backwards the first wagon derailed as it followed another track than the rest of the train. The cause of the derailment was that **the controller at the shunting tower was ordering shunting movements on tracks outside of his control without having a firm agreement with the train dispatcher at Gävle C, and that the driver of the diesel locomotive did not verify the position of the point** prior to passing it. A misunderstanding had occurred between the shunting controller and the train dispatcher at Gävle C, and once the derailment had occurred there was also some misunder-standing in relation to which tracks were blocked by the derailed and overturned wagon. No fatality and injury occurred by the accident. The damage cost was estimated to SEK 510 000,- (2001 value) which is equivalent to € 60 000 by present exchange rate.	
SE-5	28.02 2005	Ledsgård	O 3e + i	Train 5525 consisting of 12 tank wagons of type Zagns loaded with chlorine on the route from Göteborg (Sw) to Rotterdam (NL) passed an end stop and subsequently derailed at the Ledsgård station on the west-coast line between Göteborg and Kungsbacka. The train was 169 m long and weighed 1070	SHK rapport RJ 2007:2

No.	Date:	Place:	Category:	Description	Reference:
				metric tons with a specified braking weight of 696 tons according to the train dossier. All figures exclusive of the locomotive. The same day the wagons had been conveyed in train 6605 from Bohus to Göteborg. The tank wagons had a manual brake load switch (empty vs loaded). The driver of train 6605 did not control or move the position of this manual switch while checking the train and brake testing the train prior to leaving the Bohus station. This was an omission of the driver who had not done this work shift before. The braking performance of the train therefore was only about half of what was specified. In Göteborg a new engine was attached at the other end of the train. According to operational instructions, a limited functional brake test was carried out without a full train inspection. When leaving Göteborg the braking performance of the train was only 0.34 m/s^2 instead of 0.63 m/s^2. The maximum allowable speed of the train was 80 km/h. The train driver did a functional brake control along the route after having left Göteborg and felt the brakes was ok. At Ledsgård train 5525 was routed into a sidetrack in order to be overtaken by a passenger train. At the entry to the station the pre-signal showed "expect stop at exit signal". Prior to the entry signal at Ledsgård station the train speed was in excess of the allowable 80 km/h and the driver received an ATC-warning for overspeeding. 300 m after the pre-signal "expect stop at exit" the driver applied brakes consistent with the brake percentage in the train dossier. The braking performance was not sufficient to stop the train at the exit signal. It passed the exit signal and ran into the track end stop at a speed of 39 km/h. The end stop was not able to stop the train at such speed and the locomotive and 3 of the wagons derailed into a clayey field. There were no injuries and no chlorine leakage. The track at Ledsgård station had a 9 per mille descent which had not taken account of in the design of the ATC-system. This caused a delayed action of the ATC-system. With a proper design the ATC-system would have taken action earlier. The cause of the accident was the **lack of switching the brake load lever from "empty" to "loaded" for all wagons**. This was due to an act of omission of the train driver of train 6605 but there was no check list to follow when preparing the train at Bohus for the journey. A correctly designed ATC-system at Ledsgård could not have prevented the accident but would have reduced the consequences.	
SE-6	29.03. 2006	Linköping - Vikingstad	RS 1ai + O 2a	Train 49302, a timber train with 20 wagons (56 axles), was on route from Nässjö to Hallstavik. The train length was 400 m and the total train weight was stated as 994 tonnes in the train dossier. An Lps wagon loaded with timber derailed between Vikingstad and Linköping due to a **broken axle journal caused by a hot axle box** that had fallen of the train. The originally derailed wagon was the 7th behind the locomotive. The wagon toppled to the side and the timber load fell off and hindered the neighbouring track and was hit by a train shortly after train 49302 came to a stop. The wagons behind had also derailed due to the track damage done by the initially derailed car. A passenger train in the	SHK rapport RJ 2008:01

No.	Date:	Place:	Category:	Description	Reference:
				opposite direction collided with the timber and derailed. 2 persons onboard the passenger train were lightly injured, 3 persons were chocked. The cause of the **hot axle box and** was probably due to an **unround wheel** above allowable operational limit. The wagon should have been taken out for repair. The accident investigation found a lack of proper management system for rolling stock inspection and maintenance. Control weighing of some of the wagons after the accident indicated that the actual train weight was significantly higher than given in the train dossier. Some of the wagons in the train had a significant overload (30 %) compared to the load stated in the train dossier. The allowable speed 100 km/h was therefore set too high. Based on a correct axle load of the train wagons the allowable speed should have been 80 km/h. The actual load for many of the wagons in the train was also above the specified maximum allowable load for the wagons. The train passed two hot box detectors on its route prior to derailment. The first detector shortly after the start of the journey. The last one was passed 21 min prior to the derailment. This detector noticed an increased temperature, but below the alarm limit.	
SE-7	20.01. 2008	Motala station	I 2a+b	Freight train 4372 loaded with timber on route from Grevaryd to Norrsundet derailed at the time 19.30 at track 4 at Motala station. The train comprised of a locomotive and 33 wagons with a train weight exclusive of locomotive of 1426 tonnes and a length of 457 m. The derailment occurred as the train was running with a constant speed of 38 km/h in track no 4, a sidetrack with jointed rails and gravel ballast, at Motala station. Wagons no 15, 17 and 18 – 23 derailed, and wagons no 19 – 22 had overturned and spread their timber load across other tracks at the station. A train breakage occurred between wagons 17 and 18 and the train brakes went on automatically. When inspecting the site it was noticed that a 1.4 m section of one of the rails were missing in the track where the derailment started. The lost rail piece was found 56 m further forward in the direction of the train travel and hit marks under wagon 15 indicated that the rail piece had been thrown up under the wagon. The lost rail piece was ending in a joint where the joint bars (fish plates) were broken and where rust was found indicating an old break or fracture. At the other break end the rail was weakened by a lost part of the foot at the break position. Further, several of the wooden sleepers of the track were partly rotten and due for replacement. Weighing of the wagons that had not overturned indicated a slight overload on several of the wagons ranging from 0.5 to 2.4 tonnes. No human injuries occurred and the total cost of the accident was estimated to approximately € 200 000. The cause of the derailment **was a broken rail and joint under the train due to previous fractures.**	Banverket accident investigation dated 2008-04-25.
SE-8	21.08. 2008	Kimstad station	O 3b	A short haul train (“vagnuttagning”) derailed when **passing through a buffer stop** after **passing a signal at stop**. The train **main air pressure line was not opened** between the two locomotives. The train therefore had very low braking performance due to this operational fault. A proper brake test had	SHK rapport RJ 2009:09

No.	Date:	Place:	Category:	Description	Reference:
				not been performed. The derailed train came into the loading profile of the neighbouring track which luckily had no traffic.	
Finland, Source: Onnettomuustutkintakesus (Accident Investigation board) http://www.onnettomuustutkinta.fi/en/Etusivu/Tutkintaselostukset					
FI-1	31.05. 2003	Lahti station	RS 1ai	Freight train T7038A was on route from Joutseno to Tampere. The train comprised a locomotive type Sr-1 and 36 wagons. The train weight was 1954 tonnes and the train length 641 metres. As the train entered Lahti station with a speed of 75 km/h at the time of 23.42 the train dispatcher noticed that the last wagon of the train had derailed. The driver was ordered to stop the train. The derailed wagon was dragged along the train in derailed position for more than 1 km and substantial track damage had occurred to 3 turnouts, a contact line mast and 1 km of track. The total cost was estimated to €220 000,-. The derailment was caused by a hot axle box resulting from a broken brass roller cage.	Tutkintaselostus C5/2003R
FI-2	08.05. 2004	Joensuu station	I 3d	Freight train T7452 was on route from Ilomantsi to Joensuu loaded with timber. The line is a freight only line, mostly for timber transport. The allowable train speed on the line is 40 km/h. The train comprised two diesel locomotives type Dv12 and 26 loaded timber wagons of which 9 were 4 axle bogie wagons and 17 were two axle wagons. The train weight was 1457 tonnes with a length of 453 metres. The 4th last wagon of the train derailed as the train entered the southern end of Joensuu station. The derailment was caused by a buffer locking due to a track buckle (heat curve) 4 km before the actual derailment. Due to the weak track structure the train continued with the wagons in buffer locked position until the train arrived at Joensuu station. The actual derailment occurred when the train arrived at the more rigid track structure of the entry turnout to Joensuu station. When the train arrived at the turnout the left wheel flange of the front wheelset of the 4th last wagon climbed on top of the rail and the right wheel fell inside the track and the wagon derailed. The train with the derailed wagon continued for 150 m until the train stopped. The derailed wagon tipped over and some of the timber was spread at neighbouring tracks at the yard. The train main pressure pipe was broken but the derailment was also noticed by person at the track entrance to the station. At the sun curve location exchange of sleepers had been going on, but the track was left unpacked over the weekend. The derailment occurred on a Saturday. The temperature had been rising and was 25^{o}C at the day of derailment. No human injury occurred. 150 m track was damaged and the derailed wagon was damaged beyond repair. The total cost of the derailment was estimated to € 76000,-.	Tutkintaselostus C3/2004R

No.	Date:	Place:	Category:	Description	Reference:
FI-3	11.05.2004	Pieksämäki station	I 2f	Freight train 2211A was operating from Kouvola to Pieksämäki. The train comprised an electric locomotive type Sr1 and 29 wagons. The total train weight was 1474 tonnes with a length of 482 metres. The train derailed with wagons 5 & 6, (both Russian bogie wagons) as the train was moving in track 808 on Pieksämäki station. The bogies of the sixth wagon were badly damaged and the track was damaged over a distance of about 80 metres. The incident was caused by the poor condition of the track. The wooden sleepers were in poor condition and lateral deflections had generated at the rail joints. Another factor having contributed to the incident was the carriage of rails that the train was performing. In fact the first three wagons of the train that were carrying rails may have generated torsion in the rail of the outer curve and hence when proceeding, they had probably deteriorated the strength of the track.	Tutkintaselostus C4/2004R
Fi-4	30.07. 2004	Kouvola station	O 1a	Freight train T3023 from Lahti to Mikkeli comprised a Sr1 locomotive with 37 wagons of mixed type and loading. The train weight was 1531 tonnes inclusive of locomotive, with a length 572 m. The weight distribution was rather uneven with many heavy wagons at the rear behind the derailed wagons. At the time of 3.12 pm two wagons (no 27 & 28) derailed as the train was entering the western end of Kouvola passenger station. The speed at the time of derailment was approximately 25 km/h. The accident was caused by longitudinal forces created by braking of the freight train at low speed. The initially derailed wagon was a light 2 axle empty wagon, which was followed by heavy 4-axle bogie wagons of which one was unbraked. The derailment occurred in a switch crossing. The train was broken at the derailment and the brakes were automatically applied. The cost of the derailment damage was estimated to € 60000.-.	Tutkintaselostus C10/2004R
FI-5	27.04. 2005	Eskola station	RS 2c + i 2d	Freight train T 5387 was travelling from Vartius to Kokkola with wood pellets. The train comprised 29 Russian bogie wagons with central couplers pulled by 3 diesel locomotives. The axle weight of the wagons was in the range 21.5 – 22 tonnes. The train weight was 2513 tonnes exclusive of locomotives and the train length was 446 metres. The first bogie of the last wagon of the train derailed while jumping the outside rail in the contra curve after the entry points to track 3 at Eskola station with a speed of 20 km/h. The train pressure main was opened as the derailed wagon was detached from the rest of the train and the brakes were applied on the whole train Track 3 at Eskola station consisted of jointed rails in wooden old sleepers with screw fastenings. The rails were worn with weight 43 kg/m. The resulting damage was relatively small comprising 10 m of track and 2 damaged balises. The **cause of the derailment was judged to be the stiff ungreased bogie pivot of the Russian**	Tutkintaselostus C3/2005R

No.	Date:	Place:	Category:	Description	Reference:
				wagon in combination with a week track superstructure in track 3 at Eskola station.	
FI-6	28.04. 2005	Heinävesi station	I 3e	Freight train T 4920 was travelling from Joensuu to Varkaus comprising 19 loaded four axle bogie wagons, mainly with timber, but the 3 foremost wagons carried rails. Exclusive of the 2 locomotives the weight of the train was 1467 tonnes and the length 303 m. At the Heinävesi station 5 of the wagons loaded with timber derailed and 2 of them, wagons 6 and 7, overturned. The derailment occurred in track 2 at the western end of the station as the train was departing. The speed at derailment was approx. 20 km/h. The cause of the derailment was generally poor track condition and **excessive track width.** 2 of the derailed wagons were condemned, 3 of them were repaired. The total cost of the accident was €133,700.	Tutkintaselostus C4/2005R
FI-7	13.07. 2006	Tuupovaara - Heinävaara	I 3d	Freight train T 4586 was travelling from Tuupovaara to Joensuu comprising: a DV-12 diesel locomotive and 15 loaded timber wagons (2 of them 4 axle bogie wagons, 13 of them 2 axle wagons). The weight of the train was approximately 800 tonnes exclusive of locomotive with a length of 252 m. The 5 last wagons of the train derailed along the line on the route from Tuupovaara to Heinävaara. The **cause of the derailment was a track buckle (suncurve).** The line at the location had a weak structure made of light rails, wooden railway sleepers and gravel ballast and is a freight only railway. The speed at derailment was 32 km/h.	Tutkintaselostus C3/2006R
FI-8	21.03. 2007	Ylivieska station	RS 2b	The freight train T 5406 on route from Oulu to Ylivieska comprised of Sr1 electric locomotive and 23 wagons. One of the wagons derailed at the northern turnout of the railway station in Ylivieska as the train entered a sidetrack at the station. The train speed at derailment was approximately 35 km/h. The cause of the derailment was **damage to the suspension of the wagon.** A top leaf of the suspension spring had broken and fallen off before the derailment. The cause of the suspension damage was probably a wheel flat having caused fatigue damage to the suspension blade.	Tutkintaselostus C2/2007R
FI-9	03.07 2007	Saarijärvi - Äänekoski	I 3e + O 5 aii	Train 3364, a freight train with timber comprising 2 diesel engines and 28 loaded timber wagons with a total train weight of 1808 tonnes derailed with 8 loaded wagons at line km 438,925 on the line Saarijärvi – Äänekoski. The derailment cause was generally poor track condition and **excessive track width.** Contributing to the accident was also an excessive speed (50 km/h) of the train in relation to allowable speed (40 km/h) which also was on the high side in relation to the poor track conditions. In particular accounting for a possible overload of some of the wagons with pinewood. The high temperature (25^{o}C) and strong sun on the day and time (16.00) of accident also contributed to weaken the lateral stability of the track.	Tutkintaselostus C4/2007R

No.	Date:	Place:	Category:	Description	Reference:
FI-10	09.03. 2009	Lahti railway yard	I 3f	The accident involved freight train 2895 on the route from Lahti to Kouvola comprising 2 DV12 diesel engines and 33 wagons. As the train was leaving the yard a flash was seen in the mirror and the driver could see a contact wire portal and the contact wire falling down. The train was stopped and 6 domestic wagons had derailed. The **cause of the derailment was ice packed in the flange way between the crossing frog and the check rail in a turnout.** The ice was sufficiently hard to lift the wheel flange of a lightly loaded wagon over the wing rail of the turnout.	Tutkintaselostus C2/2009R
FI-11	17.09.2009	Kilpua station	I 2d + rs 2c	Freight train 5418 was on route from Oulu to Kokkola with wood pellets. The train consisted of 45 Russian owned bogie wagons pulled by 2 electric locomotives type Sr1. The total train length was 670 m. The total weight of the train inclusive of locomotives was 4095 tonnes. At Kilpua station the train was directed into track 3 due to other traffic occupying tracks 1 & 2. Track 3 was a sidetrack not often used and in a relatively poor condition. The maximum speed in track 3 was 20 km/h. The derailment occurred when the train was leaving track 3 and was on its way into the main track. The speed was 22 km/h and the driver made some braking using the dynamic brakes of the locomotives. The main pressure line ruptured in the accidents and the brakes were applied. When inspecting the situation the driver discovered that 5 of the wagons in the rear of the train had derailed in the exit curve due to a failure of the outer rail to support the train. The train composition was broken in front of the derailed wagons. The very last 3 wagons were still on the track. The cause of the derailment was a combination of the poor condition of the track, the stiff bogie pivot of the Russian wagons not being lubricated, and the dynamic braking in the front of the train. No persons were injured and the total cost of the accident was estimated to €112000. The main cause of the derailment was judged to be the **poor conditions of track 3 at Kilpua station**, with spike-fastened wooden railway sleepers (K43) that was not in sufficient condition for this heavy train.	Tutkintaselostus C3/2009R
FI-12	20.03.2006	Luumäki station	O 4a	On Monday March 20th at 21.41 hours two wagons and the rear bogie of a locomotive in freight train 2723on route from Kuovala to Imatra derailed in the east end of Luumäki railway yard. The incident entailed no personal injury. The derailed wagons damaged two point mechanisms of the opening switch crossing, and stretcher rods, and they caused rail fastening parts to detach. The chain of events resulting in the derailment started from the heating fuse of the crossing with a movable frog having burnt, thus preventing an adequate heating of the crossing. When the turnout was switched the crossing and the points failed to take the proper controlled position. Neither the remote control operator nor the train driver was familiar with the high speed turnout with turning point frogs at Luumäki. The remote control operator granted the train the permission to travel via a sidetrack to the turnout, but the pair of switches was set to the straight track, and the train forced open the frog of the turnout. When trying to reverse the derailment occurred. The speed at derailment was 20 km/h or less.	Tutkintaselostus C1/2006R

No.	Date:	Place:	Category:	Description	Reference:
				The cause of the derailment was misoperation from the remote controller and the train driver due to insufficient training with the new infrastructure element and those persons acted beyond ther qualifications.	
FI-13	28.12.2005	Line Yppykkä-vaara - Vartius	RS 6	On Wednesday December 28th 2005, on the Ypykkävaara – Vartius section of the line between Kontiomäki and Vartius in Finland, an incident took place with freight train 5630 where a detached coupling and pulling assembly for the Russian coupling SA-3 of a Dr16 locomotive fell down on the track and caused the derailment of the rear bogie of the third wagon in the train as well as pierced the fuel tank of two of the locomotives which lost their fuel. The train comprised 3 locomotives of type Dr16 and 9 empty 4-axle timber wagon of Russian design. The total train weight was 449 tons of which the locomotives weighed over 250 tonnes. The pulling and coupling device of the locomotive detached due to the unfastening of the retention screw of the clamp disc of the pulling device wedge. The clamp disc and the wedge fell down and the coupling/pulling head was pulled off the locomotive and fell down on the track. And the brakes were applied. No person was injured The derailed wagon damaged some sleepers. The track was repaired the day after. The cost of the incident was estimated to €108 000. The underlying cause of the incident was that these items were left out of the inspection and maintenance program of the locomotives.	Tutkintaselostus C8/2005R
FI-14	31.10.2005	Peräseinä-joki	I 2d	On Monday October 31, 2005 at 14.35 hrs at Peräseinäjoki in Finland, an incident occurred where the locomotive and one wagon of a freight train with roundwood load, derailed. The train was heading toward Seinäjoki. The derailment took place when the train was leaving track 3 and entering turnout V008, where first the locomotive derailed and then the first roundwood carrying wagon, that the locomotive had pulled along. The costs generated by the incident amounted to 175 000 Euros. No personal injury was caused by the incident. Both track and track equipment were damaged. In addition overhead line equipment was damaged over a distance of several hundreds of metres. As a result of the incident, the bogies and the axle control equipment of the derailed locomotive had to be replaced. Moreover the flank of the locomotive as well as its buffer and railings suffered damage. The wheelset, buffer, some handles and steps of the derailed wagon had to be replaced. The incident was not caused by one particular factor, but by the joint effect of several circumstances. The causes of the incident included the poor condition and fastening of the sleepers, thus permitting a yielding of the rails at the turnout. The V008 turnout was worn and hence it failed to meet all of the measurement requirements set thereupon. Furthermore the locomotive displayed very worn wheelsets	Tutkintaselostus C7/2005R

No.	Date:	Place:	Category:	Description	Reference:
				which again may have contributed to the wheel slipping over to the wrong side of the turnout check rail.	
FI-15	31.07.2003	Line Kallislahti - Rantasalmi	I 3d	Freight train T7939 comprising 2 locomotives type Dv12 and 30 loaded timber wagons of mixed 4-axle and 2-axle design was operated on route from Savonlinna towards Pieksämäki. The train was 535 m long with a weight of 1757 inclusive of locomotives. On Thursday July 31, 2003, an incident took place at Rantasalmi where nine wagons of a freight train derailed. In the incident, the nine derailed wagons were damaged as well as about 200 m of track. The direct cause of the wagon derailment incident was a heat curve having been generated in the track. The heat curve again was a result of the high temperature of the track combined with the poor condition of the rail fastenings and the sleeper bed, as well as the dislocation of rail joints. In addition the sleeper replacement work in the track and the on-going tamping operations contrib-uted to the vulnerability of the track.	Tutkintaselostus C9/2003R
FI-16	16.07.2003	Line Hammas-lahti - Tikkala	I 3d	Freight train T5726 comprising 3 locomotives type Dv12 and 44 empty 4-axle Russian timber wagons was on route from Ulimaharju towards Niirala on the Russian border. The train length was 719 meter and the length 1031 tons exclusive of locomotives. On the line between Hammaslahti and Tikkala at the time 15.48 the train derailed by 14 wagons, wagons 24-37 from the front of the train. The train was travelling at a speed of 73 km/h when the accident occurred. The cause of the derailment was a heat curve that developed as the train was passing. No person was injured and the total cost of the derailment was estimated to €400 000.	Tutkintaselostus C7/2003R
Denmark: Source: Havarikommissionen for Civil Luftfart og Bane					
Dk-1	03.09.2001	Hedenstad	O 3c	Freight train GF 8467 operated by TraXion was on route from Tinglev to Århus Østhavn. The train comprised of 2 diesel locomotives type My and 50 two-axle wagons of type Lgs loaded with new empty containers from a container factory in Tinglev. The train length was 740 m with a total weight of 993 tons inclusive of the 2 locomotives. The brakes on one of the container wagons were bypassed, but still maintaining a braking percentage of 90 %. The brakes of the 2 locomotives were set in position P which was against the regulations, requiring locomotives to be set in brake position G for train lengths exceeding 600 m. The allowable speed of the train was 100 km/h. The train was running 90 min late when leaving Tinglev and it was decided to take train GF 8467 into track 3 at Hedenstad station to be bypassed by another train. The maximum allowable speed at entry to track 3 at Hedenstad was 60 km/h. While running towards the entry signal at Hedenstad station the train received a lengthy call from the traffic controller in Skanderborg that had discovered that track 3 at Hedenstad was not long enough for the overhauling operation that was planned, and the driver was	Jernbanetilsynet 2002. J.nr: 6110/01-686.21

No.	Date:	Place:	Category:	Description	Reference:
				instructed to continue the journey. The speed of the train while running towards the entry signal to Hedenstad for track 3 was too high according to the ATC setting and an ATC emergency brake of the train was initiated and took the train to a stop in front of the entry signal. When continuing the journey wagons were derailed and as the train passed the entry point to Hedenstad a total of 4 wagons were derailed, comprising wagons 26 – 29, of which wagon 28 overturned and to the left. The train was broken and the main pressure brake line was broken and the brakes applied. The immediate cause of the derailment was judged to have been due to a buffer climbing and buffer locking between wagons 27 and 28 due to the ATC-braking. The main cause to this occurrence was judged to be the **brake setting in P of the 2 locomotives of this long train causing significant compressive forces in the train** during the emergency braking. A complementary cause was the fact that wagon couplings were not properly tightened between some of the wagons.	
Dk-2	21.10.2004	Århus	I 2d	Freight train 9216 was leaving the shunting yard at Århus when it suddenly was braked to a stop. Some of the wagons at the rear had derailed and the train main pressure line was broken. The cause of the derailment was judged to be a track section with high water content where a distance rod between the rails had corroded off and caused an excessive track width in loaded condition.	Havarikommissionen 07.03.2005. J.nr 04-620/1
Dk-3	22.02.2005	Forlev	I 3b	Train 44735 consisted of 31 wagons with a total weight of 1320 tonnes and a length of 530 m. The allowable maximum speed of the train was 100 km/h. At the accident location the allowable speed was reduced to 80 km/h due to lack of proper track support for lengths at two consecutive positions with height faults. 80 km/h was also the actual speed of the train. The 15th wagon of the train, a 2-axle wagon, derailed with both axles in the right track near Forlev. The cause of the derailment was degraded track due to insufficient drainage of the track substructure. The track sleepers were left unsupported in muddy conditions at two consecutive locations both with a length of 5-6 m with 6 m solid track in between. The height fault in loaded condition was estimated to 50 – 60 mm which is far beyond allowable conditions. The derailment cause was judged to be **height fault of the track and possibly excessive track twist in loaded conditions**. The train continued for a length of 700 m after derailment before being stopped due to a broken train main pressure line. Severe damage to the track occurred.	Havarikommissionen 07.11.2006. J. nr 610-000017
GB (UK): Source: Rail Accident Investigation Board					
UK-1	18.10.2005	Hatherley, near Cheltenham	O 3b	At 05:20 hrs on Tuesday 18 October 2005, freight train 6V19 was travelling between Bescot and Margam on the *Down* Birmingham to Bristol line when all the wheels of one of its wagons became derailed near Hatherley, just south of Cheltenham Spa station. The train was hauled by locomotive	RAIB report 08/2006

No.	Date:	Place:	Category:	Description	Reference:
		Spa		66221 and comprised an unpowered locomotive, 60018, 5 empty BYA type wagons and 12 empty SSA type wagons. The derailed wagon, SSA 470028, was the 14th vehicle in the formation. **The immediate cause** of the derailment was **the interaction between *false flanges* which had developed on the leading wheel-set of SSA 470028 and 673B *trailing points* at Hatherley**. This resulted in the wheel-set riding up over the railhead and derailing to the right side. The false flanges had developed as a result of the leading wheel-set being dragged from its origin at Bescot Yard to the point of derailment with the handbrake applied. **Causal and contributory factors** The handbrake on SSA 470028 was not released during pre-departure train preparation at Bescot Yard, either because the train preparer did not adequately check the status of the handbrake on that vehicle. Contributory factors which are likely to have led to this error were: - Time pressure to complete the preparation of train 6V19, the locomotive for which had arrived 77 minutes late at Bescot and only 20 minutes before the booked departure time of train 6V19; - The wagon's handbrake assembly had not been adequately maintained to ensure ease of operation, resulting in a stiff handbrake wheel which may have misled the train preparer. The applied handbrake was not detected during the roll-by examination as the train departed Bescot Yard. Contributory factors which are likely to have led to this were: - Insufficient illumination in the vicinity of the shunters' cabin at the north end of Bescot Yard; - Lack of any distinctive features or markings on the wheels to enable staff to reliably check whether the wheels of train 6V19 were rotating; - Confusion amongst ground staff at Bescot Yard about whether or not the roll-by examination was mandatory, which may have adversely affected the vigilance exercised that night. The dragging wheelset was not detected during the subsequent 68 mile journey of train 6V19 between Bescot and the point of derailment. Contributory factors were: - The incident occurred in the early hours of the morning when there were few railway staff along the train route. Usually such problems are detected by staff who spot the tell tale signs from skidding wheels with *flats* on their rolling surface; - The rear view mirror fitted to the locomotive was not used during the journey; - No automatic track mounted devices for detecting dragging wheelsets, such as *hot wheel detectors* – HWDs on that route. **Severity of consequences** Following the derailment, the train remained coupled together and travelled for a distance of 4 miles with the derailed wagon, causing extensive track damage before the train was brought to a stop. There were no collisions with structures and no other train involved. The track was blocked for eight days.	

MANAGING RISK

No.	Date:	Place:	Category:	Description	Reference:
UK-2	18.01.2006	York station	RS 2b	Freight train 6V49, the 22:03 hrs service from Tees Yard to Newport, was travelling through York station on 18 January 2006 at 23:22 hrs when one wheelset on *KIB* wagon 7008990380 became derailed. The wheelset re-railed at the first set of *points* south of the station. **Immediate cause, contributory factors, underlying causes:** The immediate cause of the incident was *flange climb* of an unloaded wheel onto the railhead. The displaced *wheelset* then fell outside the railhead and in the direction of the adjacent platform. The causal factor was the loss of a suspension spring link pin. The subsequent collapse of the suspension at one wheel caused the diagonally opposite wheel to become significantly unloaded and thus susceptible to flange climb. The contributory factors that promoted flange climb at the particular location were (i) high adhesion at the wheel-rail interface and (ii) right hand horizontal track curvature. Both were normal conditions that, when combined with wheel four's significantly reduced vertical wheel load, increased its susceptibility to flange climb. The likely underlying causes were: (i) the loss of the link pin due to degradation, fatigue cracking and rapid overload and (ii) the inability of the maintenance and inspection regime to detect link pin degradation and fatigue cracking sufficiently early in its inception to avoid failure between scheduled examinations. However, the likely underlying causes could not be proved conclusively as the missing link pin was not located.	RAIB report 21/2006
UK-3	21.01.2006	Waterside, East Ayrshire	I 2a	At 03:45 hrs on 21 January 2006, the driver of train 6C64, forming the 03:00 hrs coaltrain from Chalmerston colliery to Carlisle via Ayr, reported that the rear six wagons of the train had become derailed. The train was stood at Patna, close to the 51¼ milepost, on the single line between Chalmerston and Dalrymple Junction, near Ayr. The train, formed of locomotive 66056 and 21 loaded *HTA* wagons, had come to rest on Network Rail infrastructure, with the derailed wagons lying upright in the ballast. The immediate cause of the derailment was found to be a transverse fracture in the running rail within the section of track owned by Scottish Coal at 53 miles 889 yards. The break, located on the outside rail of a right hand curve, presented an obstruction which allowed the leading wheelset of wagon HTA 310724, positioned 16th in the train, to climb onto the rail head. It continued in this manner for a short distance before derailing to the left. The following five wagons making up the rear section of the train remained on the track and were derailed as the train came to a stand. Over 2 miles (3 kilometres) of track were damaged in the derailment. No-one was injured in the accident, and there was no risk to any part of the system other than the freight-only branch to Chalmerston.	RAIB report 05/2007

No.	Date:	Place:	Category:	Description	Reference:
				Causal factors were: - Failure of the track support; - A track inspection regime which was inadequate to identify and rectify track and geometry defects; - A 4-weekly reporting regime which did not adequately record work required; and - The lack of a mutual understanding of the arrangements for track inspection and maintenance activities between Scottish Coal and EWS. This resulted in confusion among those undertaking this activity and allowed gaps in responsibility to remain unresolved. A contributory factor was the poor condition of the line overall, leading to a high workload being reported by EWS inspection staff. As a consequence, evidence of sleeper deteriorationat the side of the derailment was either not detected or not reported.	
UK-4	31.01.2006	Cricklewood Curve	I 3a	On 31 January 2006 at 02:25 hrs a freight train was traversing the Cricklewood Curve in North London on its way from St. Pancras to Acton Yard. The linespeed on this part of the curve is 10 mph (16 km/h) and the train was travelling at 7.5 mph (12 km/h) when two of the wagons derailed. The derailed wagons overturned and started to slide down the embankment but were held by the couplings between them and the remainder of the train. One of the wagons was loaded with aggregate which discharged from the wagon down the bank. The other derailed wagon was empty. There were residential flats at the foot of the embankment, the residents of which were evacuated by the police as a precaution in case the derailed wagons moved further down the bank. **Conclusions** The derailment was caused by severe track *twist* brought about by movement of the embankment at the site of embankment repair works. Prior embankment movement had been taking place for a number of years and was the reason why the repairs were being undertaken. The embankment movement was mainly in the surface layers of the soil and had the effect of increasing the *cant* of the track. The track maintenance staff had not appreciated the severity of the movement before the derailment and did not carry out remedial works to correct the irregularities. The repair contractor was monitoring the cant of the track but was not monitoring track twist and so did not notice the hazard to trains. The designer's risk assessment identified that the greatest risk during construction of the works was movement of the embankment leading to derailment of a train. The risk control measures were to excavate the bank in short lengths, work from the top down and monitor the embankment for movement during the repair works. This risk assessment was not fully considered by the Network Rail	RAIB report 02/2007

No.	Date:	Place:	Category:	Description	Reference:
				staff involved in planning the work.	
UK-5	09.02.2006	Brentingby Junction near Melton Mowbray	O 5b	At 05:31 hrs on 9 February 2006, train 6Z41, the 05:17 hrs freight train, operated by EWS, from Mountsorrel, Leicestershire, to Barham, Suffolk, derailed at *trap points* at the end of the *Up Goods Loop* at Brentingby Junction, near Melton Mowbray. The derailment of the class 66 locomotive and the first three wagons occurred after the train passed signal 53 at the end of the Up Goods Loop at danger. No-one was injured as a result of the accident.. **Immediate cause, contributory factors, underlying causes:** The immediate cause was that the driver had a microsleep approaching signal 53 at danger and was only woken up again after the train had derailed at the trap points beyond the signal. Causal factors were: - The driver was suffering from fatigue because he had not slept for about 22 hours. Also, the time of the day the accident happened coincides with the period when levels of alertness are naturally low. - The use of trap points as an overrun mitigation measure beyond signal 53. The derailment occurred at 11.2 mph (18 km/h), causing minor damage to the locomotive and third wagon that derailed and more significant damage to the first and second derailed wagons. There were no injuries caused as a result of the accident. The trap points did not prevent the train being directed towards the adjacent *Up Main* line and although not obstructing it, the potential existed for a collision to occur with a passing train if the passage of and distance travelled by the derailed vehicles had been different.	RAIB report 01/2007
UK-6	28.06.2006	Maltby North	O 4b + o 5b	On 28 June 2006 train 6C51, a Freightliner Heavy Haul coal train from Redcar to West Burton, was traversing the facing *turnout* in the *crossover* (points number 31B) from the single South Yorkshire Joint Line to the loop at Maltby North when three of the wagons became derailed. The derailed wagons remained upright and did not spill their loads. The track was damaged for a distance of 80 m. The train was travelling at 17 mph (27 km/h) at the time of the derailment and was quickly brought to a halt by the *automatic air brake*. Nobody was injured in the accident. **Key conclusions** The immediate cause of the derailment was **number 31B points moving from the normal position to the reverse position as the train traversed them**. The '*time of operation locking'* for these points, which is listed in the *control tables*, was not implemented. Had it been, the accident would have been prevented. Though it cannot be proven positively, on the balance of probabilities given the evidence, it is likely that the driver of train 6C51 did not observe signal M36 and passed it at danger. Signal M36 is poorly sited	RAIB report 24/2007

No.	Date:	Place:	Category:	Description	Reference:
				with only 3 m between it and 31B points. It does, however, have a sighting time, at the line speed of 25 mph (40 km/h) of over 13 seconds, which adequately meets the requirements of Group Standard GE/RT8037. Though it cannot be proven positively, on the balance of probabilities given the evidence, it is likely that the signaller pulled the lever for 31 points just as the locomotive reached signal M36. This action would not have caused an incident had the train not passed signal M36 at danger at the same time. The length of the shifts being worked by the signallers at Maltby made them prone to fatigue during the night shift.	
UK-7	08.09.2006	Washwood Heath	RS 2a + I 3a	Train 4O26 was the 11:47 hrs service from Burton to Southampton Docks, operated by EWS. It comprised locomotive 66070 hauling 17 *flatbed* wagons. At about 15:48 hrs on the 8 September 2006 the train departed from Washwood Heath *Up* Side sidings. It left the yard along a reception siding from where it was routed onto the *Down* Goods via the series of four *crossovers* that link all tracks at the southwest end of Washwood Heath. As the train passed over the crossover between the Down & Up Goods line and the Up Main line the leading *bogie* of the 13th wagon, 609001, derailed to the left-hand side. **The immediate cause** of the derailment of wagon 609001 was the flange of the wheels on the leading bogie climbing the *gauge face* of the left-hand rail as they traversed a right hand curve. **Causal factors:** The design and condition of the side bearer assembly on the FAA wagon produced high levels of *bogie rotational resistance* and *wheel unloading*. A combination of the above factors gave rise to high lateral forces against the *gauge corner* of the outer rail on curves and significant levels of wheel unloading when the wagon was subjected to track twist. The actual behaviour of the bogie/*side bearer* assembly was not accurately predicted during the design scrutiny or during tests carried out in 2003 to validate a proposed modification of the underframe wear plates. The *track twist* of 1 in 108 encountered by train 4O26 as it traversed the SY274 crossover.	RAIB report 39/2007
UK-8	10.05.2007	King Edward Bridge, Newcastle	I 3a + RS 3	At 06:40 on May 10th 2007 the empty coal train 6S22 from Drax power station to Thornton derailed by one axle of the 23rd wagon of the train while passing through King Edward Bridge South Junction on the approach to Newcastle station. The actual train speed at the derailment was 16 mph (25 km/h). The maximum allowed speed was 25 mph (40 km/h) Just after the initial derailment the 23rd wagon overturned whilst dragging the 22nd wagon off the rails. The 23rd wagon was later up-righted. The train continued across the bridge and further derailment to wagons 24 & 25 occurred in front of Newcastle station. This caused an automatic brake application	RAIB report 02/2008

No.	Date:	Place:	Category:	Description	Reference:
				which brought the train to a stop. The train consisted of a class 66 locomotive and 39 empty 2-axle hopper wagons of type HAA & HMA. The tare weight of each wagon is 13.5 tonnes causing a nominal tare wheel load of 3.375 tonnes. The suspension of the wagon consisted of trapezoid formed blade springs. The immediate cause of the derailment was the left leading wheel flange of wagon 352421 climbing over the left hand rail immediately following the insulated joint between points 2375A and 2375B. The cause of this flange climb was a combination of 3 main factors: 1. **Excessive track twist** within the crossover which equated to 1:164 (34 mm over the wheelbase of the wagon). The twist was above allowable limit. 2. **A wagon frame twist of 33 mm** prior to the derailment. In addition it had a compensatory packing above the right leading axle box that made the situation worse. A Wheelchex reading for the accident car earlier on the route indicated a significant skew loading leaving only 1.9 tonnes of load on the left wheel of the leading axle on horizontal track. This caused a wheel skew loading of 2,5:1. 3. The initially derailed wagon was torsional stiff due to the **stiff trapezoidal suspension**.	
UK-9	22.06.2007	Ely Dock junction	RS 2b + i + o	Train 6L58 on June 22nd 2007consisted of 36 wagons of which 35 self loading hopper REDA wagons with a short wheel base. The wagons are short coupled in blocks of 10 + 10 + 10 + 5 wagons. The maximum allowable axle load is 25.5 tonnes. Due to the loading arrangement at the quarry the wagons had a tendency to be rear heavy. This was verified by control weighing of not derailed wagons after the accident. The self-loading feature of the aggregate hopper wagons also resulted in a higher than normal centre of gravity. The train dossier indicated a total train load of 1941 tonnes. Maximum allowable speed was 60 miles/h (96 km/h). The speed at the derailment point was 16-17 miles/h only. The 15th wagon REDA 16002 in the train, derailed in a left hand curve (minimum radius of 329 m) on the approach to the underbridge 2235 across the river Ouse near Ely. The derailed wagon overturned and was dragged onto the bridge and the neighbouring wagons derailed. The track and the bridge structure received considerable damage by the derailed wagons. The railway was closed for 6 months. Investigation after the accident found a track twist of 1:222 that was above maintenance limit, but below safety limit. This twist was followed by a twist in the opposite direction. This was not considered the main cause of the derailment. The derailed wagon, 16002, had a frame twist that caused a significant skew loading of the wheel sets of the wagon. Neither was this considered the main cause. The wagon type with a pedestal spring suspension of GFA type had previously shown a higher than normal derailment rate. Contributing to the high derailment rate had been a tendency for the GFA suspension of the wagons to experience a frictional lock in loaded position and this was considered to be the most likely cause of derailment.	RAIB report 02/2009

No.	Date:	Place:	Category:	Description	Reference:
				The main cause of the derailment was thought to be a **frictional locking of the suspension of the right hand wheel** of the leading wheel set of the wagon when passing the local top in the twisted track which then **became unloaded** due to the locked suspension as the track twist changed direction. **The unloaded leading right wheel then climbed the outer rail of the curve**. The track twist contributed to the derailment circumstances. The same may apply to the wagon frame twist causing skew loading of the wheels as well as the overload of the rear axle. The initial derailed wagon as well as the wagon in front derailed.	
UK-10	25.02.2008	Santon near Foreign Ore Branch, Scunthorpe	I 3a + I 3c + o	Freight train 6M49 was on route from Immingham Docks to Rugeley Power Station and consisted of a diesel-electric locomotive Class 66 and 18 loaded type HHA 4-axle bogie hopper wagons. When fully loaded a wagon weighs 102 tonnes. The wagons were less than 90 % loaded and the total weight of the train, exclusive of locomotive, was therefore approximately 1600 tonnes. The maximum speed of a fully loaded HHA-wagon is 60 mph (97 km/h). The train derailed with the 10th wagon at Mp 26.17. The immediate cause of the derailment was that the front right-hand wheel flange of the leading bogie of wagon 370 157 climbed the rail as train 6M49 traversed a left hand curve at Santon. This was again caused by a number of contributing factors: - An excessive track twist of 1:90 on a 3 m basis at the derailment location which is above safety limit. - A lateral track fault of approximately 25 mm in front of the derailment location. - A track cant of 178 mm in the 480 m radius curve which is above maximum allowed cant. - A skew loaded wagon with a 57/43 % subdivision of weight between the two wheels of the front end axle. - Reduced train speed through the highly canted curve. All wheels of the front bogie of the tenth wagon derailed. The train pressure mainline was not opened due to the accident, and the train continued for a mile before stopping. No one was injured but there was considerable track damage due to the derailment.	RAIB-report 10/2009
UK-11	25.03.2008	Moor street station	I 3a	Train 6M15, an empty scrap iron train consisted of 30 empty 2 axle open box wagons for scrap iron. While travelling at a speed of 15 mph (24 km/h) wagons 15 and 16 of the train derailed on plain line at the approach to Moor Street station in Birmingham. The derailment occurred on a freight line track. **An excessive track twist of** 1:74 was measured in loaded condition. This is higher than what is allowed for traffic. In unloaded condition a twist of 1:120 was measured which requires attention within 36 hours. 4 of the wagons were derailed. Following the initial derailment the train travelled a further 90 metres before being brought to a stand following an automatic brake application. At this point, \the locomotive and leading wagons were standing on the down Snow Hill line; the wagons at the rear of the train remained on the up and down	RAIB report 07/2009

No.	Date:	Place:	Category:	Description	Reference:
				goods line. The 15th and 16th wagons were completely derailed to the left and turned onto their sides. The 14th and 17th wagons were partially derailed. All four of the derailed wagons had run derailed through 677 *points*. The 14th wagon ran with its *trailing* wheels derailed through 678B *facing points*.	
UK-12	10.08.2007	Duddeston Junction, Birmingham	I 3a + O 2bi	Train 4O84 was travelling from Lawley Street Terminal in Birmingham to the Isle of Grain. The train composed of 24 container wagons of mixed loading condition. The train became derailed on points 715B, part of Duddeston junction, just outside the terminal. The train was travelling at just under 15 mph (24 km/h) while derailing. During the derailment, all wheels of the 7th and 8th wagons left the rails. The brake pipe ruptured, leading to the train being brought to a stop. The direct cause of the derailment was the climbing of the front right-hand wheel flange of wagon 640 262 over the right hand closure rail of 715B points as a result of the **combination of track twists and the unevenly loaded wagon with regard to lateral as well as transverse distribution of load**. No one was injured in this accident. Both derailed wagons suffered damage to their running gear and 200 m of track required repair or replacement. One empty container fell from the train onto the neighbouring track.	RAIB-report 16/2008
UK-13	12.06.2008	Marks Tey, Essex	I 3b	On June 12th 2008, a wheel set on a wagon within train number 4L41 from Davenport to Felixstove derailed as it passed through the Marks Tey junction on the Great Eastern Mainline. The immediate cause of the derailment was the left-hand wheel of the trailing wheel set of the rear bogie of the derailed wagon running over the cess rail head and derailing as train ¤L41 traversed a section of plain line between trailing points 2390B and facing points 2392A at Marks Tey junction. The train was in general relatively short and light with 16 flat container wagons, partly empty and partly light loaded. The actual train speed at the location was 77 mph (124 km/h). The main cause of the wheel set running over the rail was a dip in the track followed by a cyclic top causing the derailed wheel to be completely unloaded, i.e. **height faults in the track.** The track at the derailment location had for a significant period been classified as very poor regarding geometry. The track condition was not in a state requiring immediate correction or closure, but in a state where the track should be scheduled for maintenance and corrections. The track had been in this state for a very long time. The suspension of the wagon bogies consisted of nested pairs of coil springs, in which the outer spring of the pair was the “tare” spring in use through all loading conditions and the inner spring (the “laden” spring) engages progressively as the load on the wagon increases.	RAIB report 01/2010
UK-	27.01.2009	Stewarton,	I 1d	Derailment of the last 6 tank wagons of train 6B01 due to a **collapse of a steel underbridge** (Bridge	RAIB report

No.	Date:	Place:	Category:	Description	Reference:
14		Ayrshire		88) across road A735 as the train crossed the bridge. The derailed wagons overturned. The train carried consignments of dangerous goods and fuel was leaking out of 4 of the derailed wagons. The cause of the bridge failure was heavy corrosion of the main girders.	02/2010
UK-15	01.05.2009	Sudforth Lane, North Yorkshire	I 3f	2 wagons of a freight train derailed at a set of points in a siding which formed the entrance to a crossover leading to a main line. The train comprised a locomotive and 19 empty 4 axle hopper wagons for coal. The first wheelset to derail was the leading axle of the trailing bogie on the 11th wagon (bogie 11T). The cause of the derailment was the previous exchange of a switch rail of point 2150B without adjusting the switch rail sufficiently to match to the worn stock rail. One **wheel of the 11th wagon therefore climbed on the switch rail** and derailed.	RAIB-bulletin 07/2009
UK-16	25.05.2009	Wigan North Western station	I 2f+ RS 3	A derailment occurred on the night of 25/26 August 2009 at Wigan North Western station. A 40 wagon (160 axles) container train with mainly empty wagons, operated by DB Schenker, travelling from Glasgow to Manchester and Birmingham was slowing down to stop at Wigan when one of its wagons derailed. The speed of the train at the point of derailment was 12 km/h (7.5 mph). The allowable speed was 10 mph. The wagon which derailed was an empty container wagon and its front bogie derailed at low speed whilst running through a sharp curve into the platform. The derailment was caused by a **combination of infrastructure and rolling stock failures** as specified below: - the **lack of a *check rail*** on the track; - the track alignment with a 140 m radius curve; - **a twist in the wagon chassis** that was wrongly; compensated for, and - high friction between wheel and rail due to dry conditions without lubrication and newly-turned wheels.	RAIB report 14/2010
UK-17	04.01.2010	Carrbridge station	I + RS + O +E	Freight train 4N47 was running from Inverness to Mossend yard, North Lancashire. The train comprised a locomotive of Class 66 and 10 FKA double element wagons each element loaded with one empty 40' wagon. The train weight exclusive of locomotive was approximately 560 tonnes. The Rail Accident Investigation Branch made the following conclusions: The Immediate cause was that Train 4N47 passed over trap points 116, while they were set for the run-out. **Causal factors** The absence or reduction in braking forces in some or all of the vehicles making up train 4N47 was caused by a combination of the following factors: a. A reduction in the coefficient of friction between the brake blocks and the wheel tread surface due to the ingress of snow, ice and water between them (a probable causal factor) and b. Snow and ice ingress restricting movement of brake rigging and reducing the force that the	RAIB report 03/2011

No.	Date:	Place:	Category:	Description	Reference:
				brake block applies to the wheel surface (a possible causal factor) Other causal factors were: c. points 118 at Carrbridge had been set to direct trains into the loop whilst simultaneously points 116 had been set to direct trains entering the loop over the run-out; d. Train 4N47 passed signal AC336 at danger and e. The way the driver applied the running brake test rules meant he did not have a correct understanding of the brake forces available. It is probable that the following factor was causal; a. The disturbance of snow lying close to the line by train 4N47 due to the speed at which it ascended the Slochd summit. It is possible that the following factor was causal; a. Snow accumulating to a level where it could directly contact components on the bogies of the wagons. Another possible contributory factor was that the composition brake block material on train 4N47 may have had its coefficient of friction slightly reduced. **Underlying factors** An underlying factors were the requirement for running brake tests to be undertaken in snow contained in Module TW1 were neither an effective detection of loss of braking force in snow nor an effective preventative measure against the ingress of snow into braking equipment when trains are climbing steep gradients. A possible underlying factor was Network Rail's Scotland winter working arrangements that did not contain a suitable warning that the prolonged use of miniature snow ploughs might leave an accumulation of snow lying near the line The design of the braking arrangement of the FKA wagon might have been an underlying factor..	
Republic of Ireland: Railway Accident Investigation Unit (RAIU)					
IE-1	10.01.2008	Skerries	RS 1 ai	Iarnród Éireann (IÉ) Block train no M107 loaded with Zinc concentrate departed Tara Mines outside of Navan 10th of January at 22.00 destined for Alexandra Road depot in North Wall, Dublin 3. The train consisted of a locomotive and 11 bogie wagons. The mass of the train was 953 tonnes and the length approximately 139 m. The train derailed south of Skerries station on the line Belfast – Dublin. The first wagon of the train suffered a burnt off axle journal due to a catastrophic bearing failure. It derailed at MP 17 ½ and continued to travel for a further 230 yards before it was stopped. 5 further wagons derailed. The train speed at derailment was 25 mph, well below the allowable speed of 50 mph (80 km/h) for the train. Components of crossover SK 244 was broken as well as rail in its vicinity. There were no injuries and no release of zinc concentrate. A Hot Axle Box Detector reading of 56 deg C was recorded 11 miles before the point of derailment. No	Derailment of Tara Mines freight train. Report no 08011001

No.	Date:	Place:	Category:	Description	Reference:
				alarm was triggered due to the detector's alarm temperature settings and the train continued its journey. The bearing appears to have been in operation since its manufacture in 1981 without undergoing overhaul. The RAIU investigation report gave the following conclusion regarding the cause: The immediate cause of the accident: - **The catastrophic failure of bearing 633A leading to a burnt off journal.** Probable contributory factors were: - **The HABD settings did not trigger an alarm;** - **The lack of a robust bearing maintenance regime.** Underlying cause: - **Failure to detect bearing deterioration.**	
Belgium: Source: Organisme d'enquête accident ferroviaires					
Be-1	02.09.2007	Ottignies - Genval	RS 1bii	A derailment occurred with the empty coal train E47896 on route from Creutzwald in France towards Antwerpen in Belgium. The train consisted of 44 empty coal wagons with a total train weight of 1091 tonnes and a length of 570 m. The maximum allowable speed was 100 km/h. The primary derailment occurred with axle no 1 of the 4th wagon of the train at turnout no 78 at Ottignies station. The second axle of the first bogie of the same wagon derailed 20 m later. The train continued for 6.5 km to Genval station with the 2 derailed axles making damage to the track. At point 4AC in Genval the last bogie of the third wagon derailed and the pressure main of the train was broken and the train brakes were applied. The train speed at passing Ottignies was 60 km/h, while it was approximately 90 km/h when passing Genval. The **cause of the derailment was a displaced wheel tire** on the wheel rim of the first axle of the 4th wagon. This had caused an excess 35 mm in the flange distance of the wheel set. This excess distance caused the initial derailment as the wheel hit the crossing of turnout no 78 at Ottignie station. The cause of the displacement of the wheel tire on the wheel rim was damage to the locking ring. The displacement of the wheel tire had occurred over some time and marks of the too wide wheel set could be observed at other stations. The damage cost of the derailment was estimated to € 1.1 million. Traffic disruption cost in addition to the material damage has not been estimated and is not included in the above estimate.	
Be-2	29.01.2008	Houyet	O 2bii	A derailment occurred with empty coal train E48816 on route from Creutzwald in France towards Antwerpen in Belgium. The train consisted of 44 empty coal wagons with a total train weight of 1091 tonnes and a length of 570 m. the maximum allowable speed was 100 km/h. This was a train in the	

No.	Date:	Place:	Category:	Description	Reference:
				same service as train E 47896 involved in a derailment 02.09.2007. The derailment occurred when the 23rd wagon of the train passed a deviated route across a turnout at the entry to Houyet station. The speed across the turnout was 40 km/h. The derailment also caused wagon 24 & 25 to derail. The cause of the derailment was the failure to unload one side of the wagon at Creutzwald leaving the wheels of the axle very unevenly loaded with approximately ¾ of the gross weight on one side and ¼ of the weight on the other side. The **severe skew loading** caused the derailment when passing the deviated route across the turnout at Houyet station. The skew loaded wagon should have been detected and removed from the train prior to the train being returned to Antwerpen for reloading.	
Netherlands: Source: Dutch Safety Investigation Board www.onderzoeksraad.nl					
NL-1	30.03.2003	Apeldoorn	O 5ai	Freight train no 47555 loaded with steel coils with a gross weight of 1758 tons derailed close to Apeldoorn due to **overspeeding through a set of points**. The points were passed at 70 km/h whilst a speed of 40 km/h was permitted. This excessive speed was due to lack of alertness of the driver caused by sleepiness. Another factor which probably contributed to the derailment was the **insufficient securing of the steel coils** allowing them to shift while the train passed the points with excessive speed. The excessive speed across the points was caused by too high train speed in front of the entry signal to Apeldorn which indicating the diverted route and associated speed reduction. The high speed here was due to a descending track and lack of driver attention. Once the ATB system was activated the braking distance was too short to control the speed prior to the points.	Report dated February 2005.
NL-2	17.06.2003	Halfweg	I 3a	Freight train 57860 was running from Sittard towards Beverwijk. The train left Beverwijk 1 hour late at the time 22.25. The train consisted of an electric locomotive type 1600 and 16 bogie tank wagons loaded with ammonia. The total train weight was 1469 tonnes with a length of 273 m. The allowable train speed was 95 km/h. The line through Halfweg has a slight left hand curve in the driving direction with a nominal left hand cant of 40 - 45 mm in the main tracks. In anticipation of a driver change at Halfweg station the train was routed through track 3, a sidetrack to the right of the main track. The driver change did not occur and the train was given clear signals through the station. The train speed at Halfweg was 20 – 35 km/h which was below the allowable speed of 40 km/h in track 3. At the exit from track 3 the 11th wagon of the train derailed with the last bogie to the right at the time 0.47. The buffers of the 12th wagon overrode the buffers of the 11th wagon during the derailment. The train continued for an additional 1200 m before the train stopped as the driver felt there was something wrong with the train. No leakage of ammonia occurred and there were no human fatalities or injuries. The derailment caused damage to 1.5 km of track, a level crossing and the derailed wagon. Further,	IVW report DR-03U011 dated April 29th 2004.

No.	Date:	Place:	Category:	Description	Reference:
				the rail line was closed for traffic some hours. Investigations after the accidents revealed that the cause of the derailment was **due to an excessive track twist of 1:122 over a 5 m measuring base** in the track between the turnouts 9a and 9 b at the Halfweg station. The maximum twist on a length of 1,5 – 2 m was less larger than 1:100. This is significantly above allowable conditions. According to the investigation report it seemed from visual observation that track 3 was located at a somewhat lower level than the main tracks but no measurements was carried out, and track 3 had a right hand cant at 19 mm at the point tip of turnout 9a. The 10 first tank wagons of the train had blade springs whereas the derailed wagon had Y25 bogie with coil springs. A flange height slightly below nominal at the initially derailed wheel as well as some faulty Lenoir dampers of the Y25 bogie that was first derailed might have contributed to the derailment.	
NL-3	06.05.2005	Amsterdam Central	RS 1bii	On May 6th 2005 during the afternoon a derailment occurred to a ballast train in Amsterdam Central station. The train consisted of 50 loaded 2-axle ballast wagons. The train speed at the derailment occurrence was 30 km/h and within allowable limits. The locomotive and the 20 first wagons were not derailed and were detached from the remaining part of the train during derailment. Wagons 21 to 26 were derailed and some had overturned emptying their ballast load across neighbour tracks. The damage to the infrastructure at the station was substantial with damages to cables and overhead lines. Wagons 27 – 50 were also detached from the other parts of the train and had not derailed. **The immediate cause of the derailment was a loose wheel tire on one of the wheels of the derailed wagons.** The wheel tire had loosened and came off the wheel rim because the lock ring was lost. It was further noticed that the thickness of the wheel tire was 33 mm only which is less than the minimum allowed for operational wagons. Markings on the wheel in order to be able to identify a loose wheel tire were also missing or not easily visible.. The investigation report concludes that the background cause to the derailment was an insufficient rolling stock inspection and maintenance management program by the operator.	Report dated November 2005

No.	Date:	Place:	Category:	Description	Reference:
NL-4	10.05.2005	Amsterdam Central	I 4 + o	An empty coal train from Emmerich (D) to Amsterdam Westhaven derailed when passing switch no 63 at Amsterdam Central station during the night. The derailment is due to unfortunate actions after the derailment at 06.05.2005. The accident at 06.05.2005 had caused severe damages to the infrastructure at the station. In order to allow as much traffic as possible across the station during the repair it was decided to clamp switch 63 in a fixed right position as the control cables to the switch had been damaged. Further, in order to allow signalled train routes across the switch a by-pass was made in the signal interlocking. This was not normal action but allowed or, at least, not directly forbidden. The problem occurred when the control cables to the turnout were repaired and the clamp at switch 63 was removed. Unfortunately, the interlocking by-pass was not removed at the same time. At this stage it was possible to shift position of the turnout which had not received any damage in the accident at 06.05.2005. The train dispatcher at duty was not aware of the by-pass made in the interlocking. Due to the by-pass, however, the signalling system did not get any indication of the actual position of the turnout. The indication at the train dispatcher panel was still for a turnout in the right hand position even when the switch had been moved to the left hand position. A train route in the trailing point direction of turnout 63 was set across the turnout assuming a right-hand position. The turn-out was cut open by the train but that was not shown on the dispatchers display. He was still of the opinion that the turnout was in the right-hand position. When a new train route in the facing point direction was set across the turnout, a derailment occurred. The tongues of the turnout were not in proper contact and locked to any of the stock rails due to the fact that the turnout had been cut open by the previous train in the opposite direction. The **cause of the derailment was insufficient control of the infrastructure and signalling after repair actions** and lack of proper information to the train dispatcher about the by-pass in the interlocking.	IVW report dated November 2005
NL-5	14.09.2006	Dordrecht station		Freight train 44800 operated by Railion Nederland was operated from Kijfhoek Zuidzijde towards Rosendaal. The train comprised an electric locomotive Type 25.5 and 25 wagons of which 10 were bogie tank wagons with dangerous goods. The locomotive belonged to the Belgian railways NMBS (Nationaale Maatsschappij der Belgische Spoorwegen). In point no 1183B at Dordrecht the locomotive of train 44800 derailed at the time 12.05 due to substandard condition of the tongue rail of point 1183 B that did not satisfy the specified minimum conditions for traffic. The accident investigation did not find faults with the rolling stock, nor with the operation of the train. The derailment occurred at a speed of 35 km/h while the allowable speed was 40 km/h. No persons were injured and dangerous goods did not leak leaked out in the accident. In the accident investigation report criticism is raised both Strukton the company responsible for track	IVW report RV-06U0761 dated September 14th 2007.

No.	Date:	Place:	Category:	Description	Reference:
				maintenance at Dordrecht who had not acted even if they were informed about the condition of the tongue rail of the point as well as against ProRail, the infrastructure holder of the railway, that did not follow up their maintenance contracts with Strukton sufficiently.	
NL-6	23.08.2007	Duiven	I 3b + RS 6	Freight train 47719 operated by Veolia cargo was on route from Rotterdam Maasvlakte via Utrecht – Arnhem – Emmerich to Dortmund Obereving (D). The train comprised a Class 66 diesel locomotive and 28 Fals hopper bogie wagons loaded with iron ore. Exclusive of locomotive the train weight was 2182 tons with a length of 366 m. Due to the brake percentage of the train the maximum speed was 90 km/h on the track operated. According to wagon specification the maximum allowable speed of a loaded Fals wagon was set at 100 km/h and 120 km/h for an empty wagon. The track at the accident location also allowed a speed of 100 km/h for freight trains. At the time 0.50 at km 100,80 near Duiven, between Arnhem and Zevenaar, the train derailed with the 2nd wheel set of the first bogie of the 12th wagon in a straight track. The train speed at the time of derailment was 104 km/h. The driver did not notice the derailment and continued the journey. The traffic controller received fault messages from 2 level crossings and ordered a signal technician to investigate the situation and make necessary repairs. When the signal technician arrived at the site of the first level crossing at 1.15 he noticed the damage and alarmed the traffic controller. Train 47719 continued until it arrived in track 4 at Emmerich (D) station at the time 1.15. Investigations after the accident did revealed the following: - The track infrastructure immediately in front of the derailment location showed an ondulating cant that was not motivated by a track curve. This also resulted in a significant track twist that was not outside of allowable conditions. - The wheels of the derailed axle showed some essential measurements that was slightly outside allowable conditions and wheel profile with a very steep flange angle. No single definite derailment cause was found, but **the derailment is judged to be a combined effects of rolling stock and infrastructure faults, which on their own could not have caused the derailment.**	IVW report RV-07U0721 dated February 17th 2009.
NL-7	22.11.2008	Amsterdam – Muiderport	RS 1ai	Freight train 48642 operated by Railion with 25 loaded bogie wagons on route from Hermelle sur Huy in Belgium to Beverwijk in the Netherlands derailed at Amsterdam Muiderport. The wagons were loaded with chalk and each car weighed approximately 85 – 90 tonnes. Total train weight was approximately 2140 tonnes. Initially it was the first wheelset of wagon no 11 that derailed due to an **axle journal breakage caused by a hot axle box**. The train speed at derailment was approximately 60 km/h. The train continued with the derailed axle unnoticed for approximately 500 m. When passing a point the derailed wagon overturned and the 8 following wagons derailed as well. A total of 5 of the derailed wagons overturned, while the remaining derailed wagons were upright.	IVW report dated March 2010

No.	Date:	Place:	Category:	Description	Reference:
				The cause of the hot axle box and the rupture of the axle journal was increased bearing friction causing a seizure of the bearing. In NL hot axle box detectors have only been installed on the new **Betuwe** freight line as well as the high speed line **HSL suid.** There was no hot box-detector along the route. The overall cost of the derailment was estimated to approximately € 5 million including follow-on delay cost to the traffic through Amsterdam Central station.	
NL- 8	29.04.2010	Harmelen Aansluiting	O 3b	Freight train 42375 operated by ERS Railway was on route from Maasvlachte in the Netherlands to Melnik in the Czech republic. The train comprised a locomotive type Siemens E-189 (Eurosprinter) and 22 loaded container wagons type Sggmrs (6 axle wagons with 3 bogies). The train had to change direction at Kijfhoek and travel via Rotterdam - Utrecht as the normal route was closed. The train left Kijfhoek at the time 09.22. The train stopped at 10.18 in a right hand curve at signal 1016 showing a stop aspect at Harmelen Aansluiting. The train left signal 1016 at 10.28 and the central bogie of wagon 8 derailed immediately after train start from signal 10.16. Within a distance of less than 1 km, the train derailed by 2 wagons, no 8 & 9, between Harmelen Aansluiting and Vleuten. The axles and bogies derailed were as follows: - the centre bogie of wagon 8 derailed to the right in the travelling direction of the train by both axles - the last axle of the last bogie of wagon 8 derailed to the right in the travelling direction of the train - the front bogie of wagon 9 derailed to the left in the travelling direction of the train by both axles. Investigations revealed that the handbrake of wagon 8 working on the centre bogie had not been properly released prior to the train departure from Maasvlachte. **The handbrakes had been active while the train had been running and caused excessive heating of brake blocks and wheel treads**. For periods the wheels of the initially derailed bogie have been completely blocked and hot metal has been scraped of the wheels and deposited on the rail or collected in front of the wheel/rail contact area. Such a lump of metal had probably collected in front of the wheel/rail contact area when the train stopped in front of signal 1016. The cant of the curve prior to signal 1016 was measured to 100 mm after the accident. This was significantly above the 60 mm cant specified in the track design documents. When the train 42375 started moving again after the stop at signal 1016 **the combination of the metal lump under the wheels, the track cant and the low speed caused the right hand wheels of the centre bogie to climb the lower rail of the track and derail**. The driver had not noticed the derailment and the train continued for another 4.5 km before being stopped. The derailed train made significant track damage during this run and estimated to a cost of € 5.7 million.	IVW Report dated April 29th 2011

No.	Date:	Place:	Category:	Description	Reference:
Germany: Source: EUB, ERADIS					
DE-1	06.08.1999	Bhf Lahr	I 3e	A freight train derailed at the time 20.01 at Lahr station due to an excessive track width. The train main pressure pipe was broken and the train came to a standstill. No human fatalities or injuries occurred. Total cost were estimated to € 760 000,-. Dangerous goods were involved, but no leakage occurred.	ERA
DE-2	21.12.1999	Bahnhof Raubling	RS 1ai	A freight train derailed at 01.21 at the Raubling station due to a hot axle bearing and broken axle journal. The main train pressure pipe was not broken, but the derailment was noticed by a person at nearby tracks and the driver was noticed and the train came to a standstill. No human fatalities and injuries occurred. The total cost of the accident was estimated to € 1 322 000,-. No dangerous goods were involved.	ERA
DE-3	22.11.2000	Strecke Oppenweier – Backnang	O 2c	A freight train derailed at the time 08.06 at the line Oppenweier – Backnang due to a displaced load. The train main pressure pipe was not broken but the driver noticed the derailment and stopped the train. No human fatalities or injuries occurred. Total cost were estimated to € 171 000,-. Dangerous goods were not involved.	ERA
DE-4	15.05.2001	Strecke Werl – Soest	RS 2a	A freight train derailed at the time 08.04 at the line Werl – Soest due to failure of bogie structure. The train main pressure pipe was broken and the train came to a standstill. No human fatalities or injuries occurred. Total cost were estimated to € 554 000,-. Dangerous goods were not involved.	ERA
DE-5	26.06.2001	Strecke Biederitz – Güterglück	O 2bi	A freight train derailed at the time 16.10 at the line Biederitz – Güterglück due to skew loading. The train main pressure pipe was broken and the train came to a standstill. No human fatalities or injuries occurred. Total cost were estimated to € 628 000,-. Dangerous goods were not involved.	ERA
DE-6	16.02.2002	Rbf Osnabrück	I 2a	The locomotive and 8 out of 26 wagons derailed at the time 01.27 at the entry to Osnabrück freight yard due to a rail rupture. The train main pressure pipe was broken and the train came to a standstill. ¤ 6 tank wagons overturned of which 4 contained acrylnitril and 2 were unloaded propane wagons. No human fatalities or injuries occurred but dangerous goods were involved, leaked out and were ignited. A total of 170 persons were involved in fighting the fire. The total cost of the accident were estimated to € 640 000,-.	ERA
DE-7	16.04.2002	Strecke Grafing – Kirchseeon	RS 2b	A freight train derailed at 02.08 at the line Grafing – Kirchseeon due to failure of a suspension spring support. The train main pressure pipe was broken and the train came to a standstill. No human fatalities or injuries occurred. The total cost of the accident was estimated to € 560 000,-. Dangerous goods were involved but no leakage occurred.	ERA
DE-8	29.08.2002	Bhf Ehrang (Trier)	O 5ai	A freight train weighing 1115 tonnes with a length of 661 m derailed at 13.04 at the exit of Ehrang (Trier) station due to excessive train speed. The train travelled with a speed of 70 km/h through a set of points allowing a speed of 40 km/h. The train main pressure pipe was broken and the train came to a standstill. Three wagons derailed of which 2 were tank wagons with dangerous goods. A wagon with dangerous goods (isopropylbenzen) overturned. Liquids leaked out and ignited, and two wagons were	ERA

No.	Date:	Place:	Category:	Description	Reference:
				engulfed in the fire. The fire service managed to control the fire with foam within 3-4 hours. No human fatalities occurred but 1 person was injured.	
DE-9	24.01.2003	Bhf Rommers-kirchen	O 2c	A freight train derailed at 10.50 at the Rommerskirchen station due to load displacement caused by insufficient load fastening. The train main pressure pipe was not broken but the driver noticed the derailment and the train came to a standstill. No human fatalities and injuries occurred. The total cost of the accident was estimated to € 862 000,-. No dangerous goods were involved.	ERA
DE-10	19.02.2003	Strecke Kobern-Gondorf – Hatzenport	RS 2b	A freight train derailed at the time 10.14 at the line Kobern-Gondorf – Hatzenport due to a broken suspension spring. The train main pressure pipe was broken and the train came to a standstill. No human fatalities and injuries occurred. The total cost of the accident was estimated to € 4.8 million. Dangerous goods were not involved.	ERA
DE-11	26.06.2003	Line Dachau - Rohrmoos	RS 1ai	A freight train derailed at 01.30 at the line Dachau - Rohrmoos due to an axle bearing failure resulting in a hot axle box that was lost. The main train pressure pipe was not broken, but the derailment was noticed by the driver and the train came to a standstill. No human fatalities and injuries occurred. The total cost of the accident was estimated to € 3 million. No dangerous goods were involved.	ERA
DE-12	22.10.2003	Strecke Hamburg Billwerder – Hamburg Allermöhle	RS 1ai	A freight train derailed at 03.05 at the line Hamburg-Billwerder-Moorfleet – Hamburg-Allermöhle due to a hot axle box resulting in axle journal rupture. The main train pressure pipe was broken and the train came to a standstill. No human fatalities and injuries occurred. The total cost of the accident was estimated to € 4 205 000,-. No dangerous goods were involved.	ERA
DE-13	05.03.2004	Bhf Hatzenport	RS 1ai	A freight train derailed at 07.10 at Hatzenport station due to a hot axle box resulting in an axle journal rupture. The main train pressure pipe was broken and the train came to a standstill. No human fatalities and injuries occurred. The total cost of the accident was estimated to € 1 565 000,-. No dangerous goods were involved.	ERA
DE-14	17.03.2004	Bhf Osnabrück	O 3b	A derailment occurred to freight train 50002 in the entry tracks of Osnabrück station. The train came from Maschen Hamburg. At the entry to the Osnabrück station the train received a signal to slow down to negotiate the entry route. The train had nearly no braking performance and derailed in a deviated turnout which was passed with a speed of 65 km/h instead of the specified 40 km/h. The locomotive and the 4 first wagons of the train derailed and overturned. The tank of a derailed tank wagon was holed and pressurised hydrocarbon gas was released and ignited. The lack of braking performance is found to be caused by a **blocked air pressure main** between the locomotive and the first wagon**. It seems that a correct brake test had not been carried out at Maschen.** This must have been an act of omission of several parties. The total cost of the accident is estimated to € 4.6 million. 2 persons were injured, but no fatalities occurred.	EBA Unter-suchungsbericht 58413 Uub 5/04

No.	Date:	Place:	Category:	Description	Reference:
DE-15	25.10.2004	Bhf Merzig	RS 1 aii	A freight train derailed at 00.14 at the Merzig station due to an axle rupture. The main train pressure pipe was broken and the train came to a standstill. No human fatalities and injuries occurred. The total cost of the accident was estimated to € 2 973 000,-. No dangerous goods were involved.	ERA
DE-16	29.03.2005	Bhf Scwindegg	I 3 & RS 6	A freight train derailed at the time 16.17 at Schwindegg station due to a combination of failure of track geometry parameters and rolling stock parameters. The main train pressure pipe was broken and the train came to a standstill. No human fatalities and injuries occurred. The total cost of the accident was estimated to € 2 080 000,-. The train contained dangerous goods but any release did not occur.	ERA
DE-17	10.09.2010	Strecke Ger-oldshausen – Würzburg-Heidingsfeld	RS 1ai	A freight train derailed at 02.05 at the line Geroldshausen – Würzburg-Heidingsfeld West due to an axle bearing failure resulting in a hot axle box and axle journal rupture. The main train pressure pipe was broken and the train came to a standstill. No human fatalities and injuries occurred. The total cost of the accident was estimated to € 1, 3 million. No dangerous goods were involved.	ERA
DE-18	18.01.2006	Bhf Nienburg (Weser)	RS 1ai	A freight train weighing 1231 tonnes with a length of 659 m derailed at 07.39 at Nienburg station due to an axle bearing failure resulting in a hot axle box and axle journal rupture. The main train pressure pipe was broken and the train came to a standstill. No human fatalities and injuries occurred. The total cost of the accident was estimated to € 1 732 000,-. No dangerous goods were involved.	ERA
DE-19	15.12.2006	Bhf Markt Einersheim	RS 1ai	A freight train weighing 1061 tonnes with a length of 688 m derailed at 02.55 at Markt Einersheim station due to an axle journal rupture caused by a hot axle box. The main train pressure pipe was broken and the train came to a standstill. No human fatalities and injuries occurred. The total cost of the accident was estimated to € 1 695 000,-. No dangerous goods were involved.	ERA
DE-20	21.12.2006	Bhf Magdeburg-Buckau	I 2c	A freight train derailed at the time 04.18 at Magdeburg-Buckau station due to a rail rupture in a turnout. The train main pressure pipe was not broken, but the driver discovered the derailment and stopped the train. No human fatalities or injuries occurred. The turnout and 22 m of track was damaged. Further, rolling stock damage amounting to € 44000,-. Environmental damage was estimated to € 29 600,-. Total cost exclusive of track damage cost was estimated to € 73 600. No dangerous goods were involved.	ERA
DE-21	23.01.2007	Elmshorn - Tornesch	O 2a + O 2c	Freight train TEC 40013 for intermodal cargo, including containers and truck semi-trailers, was on route from Malmo (Sw), & Taulov (Dk) to Gallarate (It) via Padborg, Maschen and Basel. At the day of accident the train weight of the wagons was 1355 tonnes. The maximum allowable speed of the train was 100 km/h. The train derailed at the time 1.30 am at km 25.2 km on the line section Elmshorn – Tornesch. The initial derailment was at the first wagon of the train of type Sdggmrrs, a wagon for intermodal loads including containers and truck semitrailers. The train speed at the accident location was 93 km/h. 12 of the 21 freight wagons of the train derailed and some overturned. A tank container loaded with chlorine acetic acid, a dangerous material, was holed and started to leak. Large material damage to track and rolling stock occurred but no cost figure is given. The cause of the derailment was the loss of a steel coil weighing 11.65 tonnes through the floor of a	EUB Untersuchungs-bericht, dated 14.09.2010

No.	Date:	Place:	Category:	Description	Reference:
				container loaded with two steel coils. The steel coil fell on the track and caused derailment of the following bogies and wagons. The steel coil load was without a proper crib that could distribute the load over a sufficient length of the container. Further, the floor strength of the container was reduced due to faulty welds of the cross beams of the floor. The accident investigation found no other faults with the rolling stock or the track. The container was loaded with the steel coils at a steelwork in Tornio, Finland. From there the container was trucked to Luleå where the container was loaded on a train to Malmø where the container was transferred to the wagon in the accident train. The 2 transfers could have exposed the container floor to dynamic loads. The **cause of the derailment was due to incorrect loading of the steel coils** in terms of: - Insufficient load fastening - Wrong load distribution with too concentrated load exceeding the allowable load per m by close to 100 % - Insufficient floor strength of the container. The transport of steel coils in containers was stopped after the accident.	
DE-22	28.02.2007	Rottenburg Wümme	RS 1ai	Freight train FIR 51284 on route from Seelze to Maschen derailed by the exit of the Rotenburg / Wümme station. Wagon 23 derailed and all following wagons. Significant material damage occurred. The immediate **cause of the derailment was an axle journal rupture caused by a hot axle box.** The report recommends a review of the distance between hot axle box detectors in order to be able to detect development before an accident occurs.	EUB Jahres-bericht 2007
DE-23	12.06.2007	Bhf Blankenberg (Sieg)	RS 1bii	A freight train was derailed at the time 13.27 at Blankenberg station due to a broken wheel tyre (Radreifen). The train main pipe was broken and the train came to a standstill. No human fatalities or injuries occurreed. The total cost of the accident was estimated to € 5 020 000,-. No dangerous goods were involved.	ERA
DE-24	22.08.2007	Bahnhof Schwerte (Ruhr)	O 4b	A freight train weighing 1432 tonnes was derailed at the time 22.45 during entry or exit at Bahnhof Schwerte due to a position movement of a turnout while the turnout was occupied by the train. The cause of the untimely movement of the turnout was due to human failure by the train dispatcher. The driver discovered the derailment and stopped the train. The train main pipe was not broken. No human fatalities or injuries occurred. The total cost of the accident was estimated to € 15 500,-. No dangerous goods were involved.	ERA
DE-25	19.12.2007	Brannenburg - Raubling	I 2a	Freight train DGS 45861 on route between Kufstein and Salzburg derailed between Kufstein and Rosenheim due to a rail rupture that could have been in place when the train arrived. The ruptured rail was located on the bridge across the Autobahn. The entire train derailed. The cause of the derailment was a **fatigue rupture of the right rail i**n the traffic direction. Whether the	EUB Jahres-bericht 2007

No.	Date:	Place:	Category:	Description	Reference:
				final rupture had occurred prior to or during the passage of the accident train is not possible to determine. The material damage cost of the accident is estimated to € 900 000,-	
DE-26	17.07.2009	Bruchmülen - Bünde	RS 1ai	Freight train 61084 triggered a hot-box alarm at km 102.190 on the line from Löhne to Rheine between Bruchmülen und Bünde at the time 00.20. The train was directed to a sidetrack at Bünde station and came to a stop at km 99.2 at Bünde. The train driver inspected the train and found that the 16th wagon, a tank wagon loaded with fuel oil, had derailed with the first bogie. (Dangerous Goods UN 1202). No persons were injured and no leakage of material occurred. However, the track was significantly damage. The immediate **cause of the derailment was an axle journal rupture caused by a hot axle box.** A recommendation was made to change of brass roller cages with polyamide roller cages.	ERADIS DE-745 & EUB Jahresbericht 2009.
DE-27	07.08.2009	Nürnberg Stein – Nürnberg Rbf	I 2d	Freight train FIR 51629 on route from Seelze to Nürnberg Rbf comprised E-lok 152068 and 24 wagons The train weight exclusive of locomotive was 1483 tonnes and the train length was 466 m. The train derailed with several wagons at a freight line between Nürnberg Stein and Nürnberg Rbf. The allowable speed of the line is 80 km/h. The train speed at the derailment was 57 km/h. The train derailed at the time 15.07 with wagons in position 6 to 18 in a curve with radius 310 m. The train was broken between wagons 6 and 7 and the brakes were applied. Some of the wagons overturned. The temperature was high with a strong sunshine on the day of derailment with rail temperatures well above 40^{o}C at the derailment location. No damage was found with the rolling stock of the train. The track superstructure was 38 years old and consisted of 54 kg/m rails and concrete sleepers. The track cant design value was 70 mm which is consistent with the allowed speed and a cant deficiency of 150 mm. Measurement of track cant after derailment found values between 69 and 95 mm, with an average of 80 mm. Various faults due to age deterioration were found in the infrastructure after the accident, of which some where already noted in last regular inspection report. The most important in relation to the derailment was a number of loosened or broken screws in the rail/sleeper fastening of the outer rail in the curve. The measured width of the track were it was not damaged by the derailment was in the range 1441 – 1451 mm, which is within allowable variations No human injury occurred, but large material damage to rolling stock and track occurred. The material damage quantified by DB Netze AG amounted to € 632 609,- The **cause of the derailment was a lost support of the outer rail in the curve which** occurred under the train. The cause was due to combination of train load and temperature expansion forces due to the high temperature at the time of derailment.	ERADIS DE-755 & EUB Untersuchungs-bericht, Bonn 10.02.2011
DE-28	25.03.2010	Dinslaken – Oberhausen	RS 1ai	Freight train 48471 on route from Rotterdam to Dillingen with a weight of 4000 tonnes derailed with one bogie in switch 481 when passing Oberhausen West station at the time 21.53. Outside the station	ERADIS DE-884

No.	Date:	Place:	Category:	Description	Reference:
		West		Dinslaken 15 km from the detected derailment site a sheared axle bearing and axle box was found and derailment marks were present. It seems that an axle had derailed at that location and thereafter been rerailed until the final derailment occurred at Oberhausen West. The accident created severe damages to the infrastructure. Nobody was injured. **The cause seems to be a hot axle box and a sheared axle journal.**	
DE-29	16.06.2010	Peine	RS 1bii	Freight train 93274 comprising 49 two-axle hopper cars owned by the Dutch company Railpro derailed with several wagons during exit from the Peine station at the time 23.23. Seven wagons of the freight train derailed and some overturned. **The cause of the derailment seems to be a displaced wheel tire** on one of the wagons according to unofficial reports from EUB. The investigations of the accident are not finalised. The oncoming passenger train RE 14019 with 66 passengers and a train crew of 2 persons collided with the derailed wagons of the freight train. The locomotive and two double deck wagons of the passenger derailed and turned over. A total of 16 persons were injured according to police reports at the accident scene. The driver of the passenger train RE 14019 was seriously injured.	ERADIS DE-931
DE-30	26.07.2010	Bhf Falkenberg	RS 1bii	When the freight train DBV 88665, operated by BBL Logistik GmbH, was passing Falkenberg station, the last two empty hopper wagons derailed in the switch 214a. The cause of the derailment seems to be a displaced wheel tire on a hopper rail wagon owned by the Dutch company RailPro according to unofficial reports from EUB. The investigations of the accident are not finalised. Several sleepers in track 5 and the switch 221 were severely damaged; wagon 23 84 6437 395-6 derailed with two axles and wagon 23 84 6437 389-9 was overturned.	ERADIS DE-963
DE-31	01.09.2010	Bacharach	RS 1ai	Freight train no 47925 derailed during the passage through the station Bacharach at the time 18.29. Prior to the derailment the freight train had been stopped at the station Brohl, 75 km in front of the accident location, due to an alarm by a hot axle box detector. After check by the driver the journey was continued. At Bacharach it was discovered that the 2nd loaded Fals wagon was derailed with the rear bogie. Nobody was injured. The cause seems to be a **hot axle box and an axle journal rupture**.	ERADIS DE-978
DE-32	20.11.1997	Elsterweda	O 3b	Freight train KC 71153 comprising 22 tank wagons hauled by electric locomotive 155 103 with petroleum products from the refinery at Schwedt on route to the tank farm at Rhäsa derailed in the morning at Elsterweda station in an entry turnout set for a sidetrack. 17 of the 22 tank wagon derailed and several overturned. The speed at derailment was 80 km/h while allowable speed was 40 km/h. The cause of the derailment was a closed pressure main line cock between the locomotive and the rest of the train. By change of locomotives in the Berlin-Grünau station the cock between the locomotive and the rest of the train was left closed. The locomotive only had operational brakes. The driver therefore had no possibilities to reduce the speed to the signalling speed of 40 km/h when entering Elsterweda	Wikipedia – Eisebahnunfall von Elsterweda. Elsterweda: Kesselzugexplosion im Bahnhof. Magasin der Feuerwehr

No.	Date:	Place:	Category:	Description	Reference:
				station. One of the tank wagons with gasoline exploded immediately and the pressure wave ripped off the roof of the station building. When the fire brigade arrived a second wagon exploded. Altogether 17 tank wagons burnt out completely and damaged everything on the station area and in nearby buildings. 2 firemen were fatally injured and the total accident cost was very large. An electric locomotive parked at the station and most wagons of the accident train was totally damaged. The main station building and several other buildings at the station was totally damaged. 122 persons were given damage compensation of €1,2 million by DB. 2 employees of DB were taken to court charged for manslaughter due to negligence and found guilty.	23(1998)4. S198 - 202
Austria: Source: Bundesanstalt für Verkehr; Unfallsuntersuchungsställe des Bundes – Fachbereich Schiene					
AT-1	01.03. 2006	Salzburg Gnigl	RS 1aii	Train 64346, a local freight train from Salzburg Gnigl towards Hallein, consisted of 4 wagons of which 2 tank wagons for dangerous goods. Total train weight was 338 tonnes with a total length of 79 m. While departing the Bf Salzburg Gnigl at a speed of 40 km/h an axle rupture occurred in the third wagon, a tank car not loaded with dangerous goods for this journey. An automatic emergency brake occurred due to loss of main line pressure and the train came to a stop after approximately 70 m. The **axle shaft rupture** occurred between the wheels, but close to one of the wheels and was **due to fatigue**. The derailed car was a private car owned by VTG with Heimatbahnhof Maschen.	BMVIT-795.011-II/BAV/UUB/SCH /2006
AT-2	28.04. 2006	Salzburg Gnigl	O 7	Train 51950 was on route from Bf Villach Süd Gvbf over Salzburg Gnigl towards Linz Vbf. The following particulars was specified in the train dossier: - 26 wagons (11 loaded, 15 empty) - train weight 1195 tonnes (exclusive of locomotives) - train length 531 m. A non-operational locomotive of Type 1044 was following the train from Salzburg Gnigl immediately after the operational locomotive. This was not shown in the train dossier. Train 51950 received an exit signal from Salzburg Gnigl allowing a speed of 40 km/h. Even though the speed of the train was 28 km/h an uncontrolled brake action was initiated by the PZB automatic train control within the station limits. This could have been caused by an active PZB of the 2nd, non-operational, locomotive. **The braking action caused buffer locking (Überpufferung)** between wagons 10 and 11, and the 4th axle of the empty 10th wagon was lifted of the rails. Further derailment of the 3rd axle of wagon 10 occurred due to compression forces in the train due to the braking. The 10th wagon was an empty wagon for auto transport type Laaeks, an articulated wagon with a short couple in the middle and 4 single axles, registered to Czech owners. The Laaeks wagon had a long wheel base and low axle	BMVIT-795.020-II/BAV/UUB/SCH /2006

No.	Date:	Place:	Category:	Description	Reference:
				weight, and is easily derailed by longitudinal forces in the train if such are applied while passing a station area via a train route with many turnouts as was the case in this event.	
AT-3	09.05.2006	Villach Süd	I 2a	Train 48246 was on route from Bf Tarvisio in Italy to Bf Villach Süd Einfahrgruppe. The train consisted of 12 tank wagons loaded with diesel oil with a total train weight of 1244 tonnes and a length of 235 m. The derailment occurred to the leading axle of the last bogie of wagon 3 between the trailing points 601 and 602 in the departure tracks **due to a rail rupture** 1 m after the end of point 601. **The rail rupture was caused by a faulty thermite weld** of the rail. Further, the ruptured rail lacked some of the rail fastening to the sleeper and was moved outwards by the wheel of the derailed wagon. The train speed at the derailment point was 29 km/h and relatively minor damages occurred.	BMVIT-795.022-II/BAV/UUB/SCH /2006
AT-4	11.07.2006	Strecke 10601 Bhf Ebenfurth	O 1a + O 5b	Train 45380 was on route from Sopron towards Wien Zvbf and derouted via Wiener Neustadt due to track work by the ROeEE-line. The train comprised 23 wagons of which 8 loaded. The train weight exclusive of locomotive was 806 tonnes with a length of 424 m, exclusive of locomotive. The weight distribution of the train was as follows: - wagons 1 – 9: 8 empties & 1 loaded with total weight 242 tonnes - wagon 10: empty 2x2 axles weighing 27 tonnes - wagons 11 – 23: 6 empties & 7 loaded with total weight 537 tonnes. At Ebenfurth station the line speed was reduced to 20 km/h across points 5/6. A deviated train route utilising track 6 was set for Ebenfurth station passing points 8, 7 and 5/6. The signalled speed was 40 km/h, but temporary restrictions to 20 km/h existed across points 5/6. During the exit route from Ebenfurth station at a speed of 16 km/h the train received an emergency braking by the PZB-system. The driver released the brakes and continued the journey without examination of the train. Operators at the signal box discovered the derailed wagon and advised the driver over the train radio about the situation, and the driver initiated a new emergency braking from 15 km/h. Additional derailments occurred by wagons 9 & 10 due to the second emergency braking. The initial PZB-braking was due to a PZB warning of the 20 km/h speed reduction that was not acknowledged by the driver, although the train was moving 16 km/h only. The initially derailed wagon was an empty 4 axle wagon of the type Laaeks for autocar transport. The wagon consists of 2 short coupled 2 axle sections with a long wheel base that has proved prone to derailments. Further, the driver did not examine the train after the first emergency braking as required by the regulations when emergency braking are initiated by a speed < 40 km/h. The main causes of the derailment were: 1) an unfortunate train composition with several heavy loaded wagons behind a light empty Laaeks wagon in the middle, 2) a PZB-initiated emergency braking due to a not acknowledged warning by the train driver.	BMVIT-795.032-II/BAV/UUB/SCH /2006
AT-5	04.10.2006	Strecke	RS 6 +	Train 63637 local freight train of ÖBB Rail Cargo Austria was operating from Hieflau Vbf towards	BMVIT-795.034-

No.	Date:	Place:	Category:	Description	Reference:
		22001 Bhf Hieflau	O 1a	Selztal. The train comprised 26 wagons and 2 locomotives at the head. The composition was as follows Wagons 1-18 loaded 4 axle wagons, wagons 19 – 20 empty 2 axle wagons followed by a ballast cleaning machinery (252 t) covering wagons 20 – 26. The total train weight was 1810 tonnes with a train length of 520 m. The line from Hieflau Vbf to Hieflau Bhf includes a links curve of R=194 m and a 7 per mille decent in the running direction of the train. The train departed Hieflau Vbf and accelerated to a speed of 23 km/h. Due to a stop aspect in entry signal AS “R1” to Hieflau Bhf the train was braked from 23 km/h to 9 km/h by using the electro-dynamic brake of the locomotives as well as the direct pneumatic brake of the first locomotive. The resulting compression force of the train in combination with the curve of R=194 m caused damage to the buffer R1 of the 20th wagon, buffer locking between wagon 19 and 20, and subsequently derailment of the same wagons. The train air pressure main line was damaged and the train brakes applied. Investigations after the accident found no faults with the track. Examinations of the buffers of wagon 20 identified pre-accident cracks in the fastening welds of the buffer R1 of wagon 20 which significantly reduced the strength of the buffer and it was broken off in the accident. The accident investigation also found faults in relation to the maintenance documentation of the buffers of wagon 20. Further, the buffer plates of wagons 19 and 20 were of a small type with diameter of 370 mm. The cause of the accident was considered to be a combination of several factors: - unfortunate train composition with empty 2 axle wagons in the middle of an otherwise heavy train, - strong longitudinal forces in the train due to braking the train at low speed with a combination of electro-dynamic brake and direct pneumatic brake of the forward engine only in a narrow curve of R=194 m, - a buffer of the 20th wagon with reduced strength in terms of the bending load due to the skew compressed load on the buffer in the narrow curve, - small buffer plates of wagons 19 & 20.	II/BAV/UUB/SCH /2006
AT-6	04.04.2007	Strecke 20501 Taufkirchen - Schärding	RS 1ai	Train Z 45902 operated by ÖBB Rail Cargo Austria was on route from Wien Zvbf towards Passau in Germany. The train consisted of 30 wagons. The total weight of the train was 1368 tonnes with a length of 628 m, all inclusive of locomotive. The allowable speed of the train composition at the line was 110 km/h. The train was not overspeeding, and the speed at HOA Taufkirchen was 86 km/h. After passing a hot axle box detector at Taufkirchen, km 58.2, the train driver received a warning from the traffic controller at Bf Schärding about a hot axle box at the 28th axle (6th wagon 4th axle left bearing) with a temperature of 138^{o}C. The driver immediately after receiving the message reduced the train speed and planned to stop in front of Bf Schärding. Shortly after an emergency braking of the train occurred due to loss of pressure in the train main line, and the train stopped with the locomotive at km 61.57. The driver requested the	BMVIT-795.057-II/BAV/UUB/SCH /2007

No.	Date:	Place:	Category:	Description	Reference:
				neighbouring line to be blocked and the power to the overhead line cut. Upon inspection of the train he discovered that wagons 6-11 were derailed and the train coupling had ruptured between wagon 6 and 7. **The cause of the derailment was a hot axle box and a ruptured axle journal.** 5 of the derailed wagons, including the initially derailed wagon, were of the type Shimms, a 4axle bogie wagon for transport of steel coils. The total weight of the initially derailed wagon was 74 tonnes which is below maximum load. No indication of high bearing temperature was received at any of the previous hot axle box detectors the train had passed. The latest was at Haiding at km 5.3, which is 53 km distance and 38 min driving prior to passing the detector at Taufkirchen. Nobody was injured. Material damage to 6 derailed wagons, 1.6 km of track, a turnout and signalling equipment. Total damage cost was estimated to €1,5 million.	
AT-7	02.08.2007	Bf Wien Matzleindorf	RS 2a	Train 54093 from Linz Vbf Ost to Wien Zvbf consisted of 38 wagons with a total train weight of 1622 tonnes and a total train length of 643 m. 34 of the wagons were loaded, 14 were empty. When passing the Wien Matzleindorf station wagon 23 of the train, an empty tank wagon, derailed and overturned. The neighbouring wagons 22 & 24 also derailed with their closest bogies. The train came to a quick stop as the train speed was relatively low (40 km/h) and the pressure main line of the train had ruptured. The cause of the derailment was a **failure of a structural member** of the bogie supporting the brake gear. The loss of the support **caused the brake gear to fall** down on the track and subsequently lifted the bogie off the track and the wagon overturned. Further investigations showed that the broken rail-gear support of tubular form was not according to the design drawing for this type of bogie. It was further concluded that the inspection of the wagon was lacking in quality.	BMVIT-795.075-II/BAV/UUB/SCH /2007
AT-8	09.09.2007	Bhf Wien Donaukai	RS 2a	RoLa train 41328 was on route from Bf Kiskundoroszma (Hu) to Vbf Wels. The train consisted of a locomotive, a car for lorry drivers and 23 loaded RoLa wagons. The train weighed 1294 tonnes with a length of 493 m. The RoLa wagons are of a very special design for loading of road trucks. Each wagon has 10 axles divided on 2 bogies in each end comprising respectively 2 +3 axles. The wheels have a small diameter and lorries, articulated vehicles (semitrailers) and road trains can drive along the entire train when loading and unloading the train. The derailment occurred during train entry to Bf Donaukai at the time 03.38 in the night. The 8th axle of the 10th wagon derailed and was subsequently lost from the 3-axle bogie assembly and was found at the side of the track. The derailment location was in a left curve of 200 m radius and with a fall of 12 per	BMVIT-795.077-II/BAV/UUB/SCH /2007

No.	Date:	Place:	Category:	Description	Reference:
				mille. The speed at derailment was 33 km/h. The cause of the accident was a broken spring carrier beam that was also lost from the train. Various broken parts were found along the train route. Due to the loss of the 8th axle the bogie structure was lowered towards the end, and the 7th axle overloaded and the axle housing damaged. The train driver did not notice the accident and the train continued until it was stopped for examination at Klosterneuburg – Weidling due to damage of axle counters being part of the signalling installations along the track. The train passed a wheel diagnostic station at Himberg at the time 02.58 which noticed a significant lateral skew loading of the axle load of the two last bogies of the 10th wagon and it seams that the spring carrier beam must have broken prior to that diagnostic station. The later derailed and lost axle showed a skew loading of 2.44:1 which is far above the allowable. The rearmost 2-axle bogie of the car had a skew loading to the opposite direction. It is apparent from the wheel diagnostic station that the spring carrier beam was already broken at this location. No action was taken due to these measurements. The cause of the derailment and the associated damage **was a broken and lost spring carrier beam** of the last (in driving direction) 3 axle bogie of the RoLa wagon CFR 81 53 498 3 066-2. The cause of the broken spring carrier beam was a faulty weld. This type of damage to RoLa wagons had appeared previously at two previous occasions in May 2004 and July 2005. Nobody was injured in the accident but damage to the track as well as the wagon occurred.	
AT-9	31.10. 2007	Tauern-tunnel	RS 1bi	Train 54352 comprising 32 wagons and a total weight of 1425 tonnes and a length of 567 m was en route from Villach Süd Gvbf towards Salzburg Hbf through the Tauern tunnel. The train contained two 4-axle bogie tankwagons loaded with NaOH, each with a content of approximately 62 tonnes. The actual speed of the train was less than the maximum allowable, 100 km/h. Approximately at 02.55 am, shortly after entering the Tauern tunnel **one of the wheels of the 3rd axle of the 7th wagon (one of the tank wagons) developed a rupture** (km 41,941) and lost significant parts of the rolling surface (km 41,698). The wheel was of a monoblock type. Some distance further (km 40,326) there are clear marks of a derailment of the wheel. During the onward travel until the train stopped the derailment involved the entire last bogie of wagon 7 as well as the first bogie of wagon 8. The brakes were automatically applied as the pressure main was broken due to the derailment and the train was stopped with the locomotive at km 36,635. A small leak of NaOH developed. **The cause of the wheel rupture was considered to be fatigue. H**igh temperature development due to braking was considered an important aspect. Too high brake load might have been a factor in the excess heat loads of the wheel.	BMVIT-795.087-II/BAV/UUB/SCH /2008
AT-10	24.03.	Bf Leoben	I 2d	Train 47490 was on route from Luka Koper over Jesenice to Leoben Donawitz. The train had 18 loaded	BMVIT-795.096-

No.	Date:	Place:	Category:	Description	Reference:
	2008	Donawitz	I 3e	wagons and weighed 1576 tonnes with a train length of 256 m. The train derailed as it entered track 16 at the Leoben Donawitz station. Altogether, wagons 3 to 1 derailed of which 4-9 derailed with all axles. Wagon 10 derailed with the first bogie. The cause of the derailment was **damage to the rail fastening system** on several sleepers which caused an **excessive track width** as the train entered the track. The rail fastening was of the Pandrol type and the outer fixed hoop in the sleeper was broken due to corrosion and fatigue of the rail fastening spring of several sleepers next to each other.	II/BAV/UUB/SCH /2008
AT-11	16.08. 2008	Bf Neuleng-bach	I 3a + RS 4+ o	Train 94435, for intermodal cargo, was on route from Hamburg (Ger.) to Hegyeshalom (Hu). The train comprised 24 six axle container wagons. The total weight of the train was 1676 tonnes with a train length of 664 m. The maximum allowable speed of the train was 100 km/h. The train was stopped at the entry signal at Bf Neulengbach between St. Pölten and Wien Wbhf. A route through the Neulengbach station was set via track 5 allowing a maximum speed of 60 km/h across the deviated turnouts of the route. The first bogie of wagon 16 derailed as the train was passing turnout no 51 at the Neulengbach station. Maximum speed of the train while passing the station was 53 km/h. The cause of the derailment was a combination of several small faults and unfortunate circumstances: - The track at the derailment location had a twist above the specified twist but below safety limit - For the actual train speed there was an excess cant at the turnout. - The rail was dry and without any flange lubrication. The operating regulations of ÖBB specified rail flange lubrication for the track geometry and operating conditions at Neulengbach. - The derailment safety of this long car was exactly on the border of what was acceptable and hence very susceptible to wheel unloading on twisted track. - The long bogie centre distance between the outer bogies of the wagon, > 20 m, makes it susceptible to derailment if the twist stiffness is too high. International regulations are missing with regard to the acceptable twist stiffness of wagons with bogie centre distance > 20 m. - The wagon was lightly loaded on the first bogie and being in the middle of a long train it was susceptible to derailment by strong pull loads, which may occur when the train is pulled in motion after a stop. The cause the accident can be summarised to a **highly twisted track** combined with an **unfortunate wagon design** and **lack of rail flange lubrication.**	BMVIT-795.106-II/BAV/UUB/SCH /2008
AT-12	06.09.2008	Bhf Rosenbach	I 3a	KGAG 40667 (KLV Ganzgüterzug) was on route Köln-Niehl (D) towards Dobova (Slo) when a wagon derailed in front of Rosenbach station at km 22.06 approximately. The train comprised 16 wagons with a total weight of 1370 tonnes and a length of 543 m. The train derailed with the left wheel of the 3 axle of the 11th wagon in a right hand curve of radius 250 m at a speed of 24 km/h. The remaining axles of	BMVIT-795.109-II/BAV/UUB/SCH /2009

No.	Date:	Place:	Category:	Description	Reference:
				the same wagon were derailed as the wagon was dragged along for approximately 250 m before the train stopped. Significant damage to the track infrastructure at Rosenbach station occurred. The cause of the derailment was attributed to a number of factors that acted in combination: - **A track twist below safety limit** but exceeding the recommendations of ORE B55 Rp8 in the exit transition curve from a 250 m radius curve, - A wagon with long wheel base which was the same type as derailed the date of 08.04.2009 at Leithabrücke – Bhf Ebenfurth (see AT-16), - Skew loading of the wagon in empty conditions due to frame twist or suspension inequalities, - **A high actual cant (150 mm) which was above the design cant (138 mm)** in a sharp curve of 250 m radius, - A speed reduction to max 30 km/h resulted in significant excessive cant at the reduced speed, - Lack of track lubrication. Total damage cost of derailment estimated to € 1 million.	
AT-13	18.10.2008	Bhf Pöchlarn, Strecke 10102	O 1a	DG 54091 (direct freight train of RU ÔBB – Rail Cargo Austria AG) was on route from St. Valentin to Wien Zvbf. The train comprised 48 wagons with a total weight of 1430 tonne and a length of 708 m. The allowable maximum speed was 100 km/h. The weight and braking ability of the train was very uneven distributed. In the front of the train was a locomotive and 7 wagons with a combined weight of 480 tonne with a combined length of approximately 130 m. The locomotive and the 5 first wagons were placed in brake position G. Then followed a train length of 480 m comprising 32 empty and one loaded mainly 2 axle container wagons of type Lggs with an individual wagon length of 13,88 m, an axle distance of 8 m and a weight of 12 tonnes. The combined weight of this train part was approximately 450 tonnes. At the back were 8 wagons with a weight of 501 tonnes and a length of 96 m with a relatively low brake percentage (62 %) compared to the rest of the train (>85 %). At Pöchlarn station the train was routed to track 9 in order to decouple the 8 last wagons. The route involved crossing of 4-5 points in deviated position, i.e. points of 60, 59, 53, 54 and 55, involving two consecutive S-curves. The points 54 & 55 were of a type with angle 1:9 and a curve radius of 190 m. The allowable train speed of the entry route was 40 km/h. The actual entry speed of train 54091 was below 40 km/h. During entry at Pöchlarn station at the time 01:17 a sudden braking was applied by the driver possibly also involving the use of dynamic brakes of the locomotive. Wagons 15 – 17, empty 2 axle container wagons, experienced buffer locking and subsequent derailment. The main pressure brake line of the train was sheared and the train came to an immediate stop. **The cause of the derailment was the weight and brake composition of this long train in combination with the abrupt braking of the train at low speed while the train was in S-curves of the entry route**.	BMVIT-795.112-II/BAV/UUB/SCH /2008

No.	Date:	Place:	Category:	Description	Reference:
				Nobody was injured. 4 wagons and 2 turnouts were damaged.	
AT-14	22.10.2008	Wien Zvbf	O 2bi	Freight train GAG 47321, operated by RU LTE – Logistik- und Transport GmbH, was on route from Bf Voest Alpine Linz towards Hungary (Heygeshalom). The train consisted of 20 hopper wagons type Fals, a 4 axle bogie design for bulk type material. The overall train weight was 1668 tonnes with a length of 270 m, inclusive of locomotive. The wagons were loaded with iron ore fines. During entry to Wien Zvbf at the time 9.37 wagon no 13 in the train derailed with all wheels on both bogies. Buffer locking occurred towards wagon 14 that also derailed. The train main pressure line was broken and an emergency braking occurred that brought the train to an immediate stop. The general allowable line speed at the accident point between Oberlaa and Wien Zvbf is 60 km/h, but at the day of the accident an infrastructure related speed reduction to 30 km/h was signed. In the train travel direction the track descent is 12 per mille increasing up to 19 per mille for a short distance. The track geometry also involves a right curve of 226 m. The braking to the signed speed reduction was initiated somewhat late with a train speed of 42 km/h at the beginning of the line section with speed reduction. The braking was done with the dynamic brakes of the locomotive which caused a significant train compression. Due to the speed reduction a significant excess cant existed in relation to the actual speed of train 47321. Upon inspection it was obvious that all wagons of the train were significantly skew loaded towards the right side in the travelling direction. By weighing some of the wagons after the accident weight distributions of 2:1 were identified for some of the axles, which is far above the allowed 1.25:1. **The skew loading was considered to be the main cause of the accident.** The excess cant due to the speed reduction in the curve, as well the train compression due to dynamic braking by the locomotive, contributed to releasing the derailment situation. In spite of the significant skew loading the wagons did not derail during the 200 km travel from Linz to Vienna. The cause of the skew loading could have been due to one sided loading by a front loader. A similar accident happened at the station Unter Purkersdorf November 17th the same year. No persons were injured but some material damage to rolling stock and infrastructure occurred.	BMVIT-795.111-II/BAV/UUB/SCH /2008
AT-15	31.10.2008	Gummern	RS 2b	Train 45818 was on route from Villach Süd Gvbf towards München (D). The train consisted of 25 wagons with a total train weight of 1400 tonnes and a length of 490 m. Maximum allowable train speed was 100 km/h. The actual speed at derailment was 56 km/h. The initial derailment occurred at km 168.34 between Abzweigung Gummern 2 and Bf Gummern on the line toward Schwarzach - St Veit. The initial derailed axle was the mid axle of the 8th wagon, an empty autocar wagon type Laes. The train continued for 3,8 km towards the station in Gummern where further derailments occurred and	BMVIT-795.117-II/BAV/UUB/SCH /2008

No.	Date:	Place:	Category:	Description	Reference:
				the train pressure main line was broken and an emergency braking applied. In total wagons 7-10 had a total derailment of all axles, wile wagon 11 derailed with 1 axle. The remaining wagons did not derail. The initial derailment of the mid axle in wagon 8 was **caused by a broken suspension spring of trapezoidal type**. Further investigation revealed that this was due to a systematic fault in the suspension design of the wagons of this make. The damage cost of the derailment was estimated to € 5 million.	
AT-16	17.11.2008	Strecke 1010 Bf Unter Purkersdorf	O 2bi	Freight train ATGZ 47107, operated by, LTE – Logistik- und Transport GmbH, was on route from Bf Voest Alpine Linz towards Hungary (Heygeshalom). The train consisted of 20 hopper wagons type Fals, a 4 axle bogie design for bulk type material. The overall train weight was 1515 tonnes with a length of 263 m, inclusive of locomotive. The 2 first wagons were empty, the remaining 18 loaded with slag. At the station of Unter Purkersdorf the train was given a route involving 2 S-curves, first across points 59 & 58 between tracks 11 & 13 then across points 57 & 56 between tracks 13 & 15. At the time 10.23 at km 12.7 between points 56 & 57 wagon no 16 derailed with both axles of the first bogie and then overturned towards the left. All the 4 rear wagons of the same type also derailed and overturned to the left. The speed at derailment was 39 km/h. The wagons of the train were all significantly skew loaded towards the right side in the travelling direction. By weighing a not derailed wagon of the same type as the derailed a weight distribution of 1.78:1 was identified, which is far above the allowed 1.25:1. **The skew loading was considered to be the cause of the accident.** . In spite of the significant skew loading the wagons did not derail during the 180 km travel from Linz to Purkersdorf. The mixed type of sleepers in the track comprising wooden, monoblock concrete as well as duoblock concrete sleepers could have contributed to an unstable movement of the wagon that had a suspension without roll damping between bogie and wagon frame. The cause of the skew loading could have been due to one sided loading by a front loader. A similar accident happened at Wien Zvbf October 22nd the same year. No persons were injured but significant material damage occurred.	BMVIT-795.115-II/BAV/UUB/SCH/2008
AT-17	20.12.2008	Strecke 10102	RS 1ai	Freight train 44852 was on route from Wien Zvbf towards Bf Hall in Tirol. The train consisted of 17 wagons with a total train weight of 1032 tonnes and a length of 351 m. Allowable train speed 100 km/h. When passing the defect detector “HOA Seekirchen” at km 300,535 an axle box with high temperature (138^{o}C) was detected in wagon 8, and an alarm was sounded. The train was stopped at the station Hallwang Elixhausen at km 304.14 for the train staff to inspect the train. A **ruptured axle journal** was detected in wagon no 8 **caused by a hot axle box** that also fell off. In later inspections the axle box was found at km 303,440 and first traces of derailment was found at	BMVIT-795.122-II/BAV/UUB/SCH/2008

No.	Date:	Place:	Category:	Description	Reference:
				km 303,612. The cause of the hot axle box was not clearly determined. At the previous passed defect detector location "HOA Pöndorf" at km 272,585 a slightly increased temperature of 56 ^{o}C was detected in the same axle box which was below the alarm level. The damage cost was estimated to € 1 million.	
AT-18	08.04.2009	Strecke 17101 Leithabrücke – Bhf Ebenfurth	I 3a rs	Train KGAG 41186 (KLV whole train of RU ÔBB – Rail Cargo Austria AG) was on route from Sopron (Hu) towards Passau (Ger.). The train comprised 16 wagons with a total weight of 986 tonnes and a length of 523 m. In front of the station Ebenfurth the train was stopped at the entry signal at the time 15.10. The driver was informed about the derailment by an unknown external person prior to the train received a clear entry signal. The 6th wagon of the train had derailed with the first axle and a buffer locking had occurred. The derailed wagon consisted of 2 short coupled 2 axle wagon parts and was the same type of wagon that derailed at Rosenbach 06.09.2008. (see AT-10). The total length of the wagon was 31.48 m. The axle distances were 10 m + 4.98 m + 10 m. Each part of the wagon was loaded with a swap body unit. The total weight of the wagon was 49 tonnes equally divided on the 4 axles. The derailment occurred in the exit transition curve from a 265 m curve with a cant of 99 mm while the train was braked by the dynamic brakes to stop at the entry signal to Ebenfurth station. The train speed at derailment was 32 km/h. The cause of the derailment was **an excessive track twist in the transition curve from a curve that had a cant of 99 mm**, which is 22 mm above the specified maximum in the actual curve conditions according to ÔBB guidelines. At the actual the train speed of derailment a significant excessive cant existed at the derailment location. The excessive track twist above operational limit was known to ÔBB Netz and an attempt to correct it had been made, but without success. A relatively light loaded and torsionally stiff car with loose couplings may also have contributed to the derailment. Nobody was injured and the damage cost to track and rolling stock was estimated to €60 000,-	BMVIT-795.136-II/BAV/UUB/SCH /2009
AT-19	09.04.2009	St. Peter Seiten-stetten	RS 1aii	Train 45904 was en route from Wien Zvbf to Passau Hbf when a derailment occurred while the train was passing Bf St. Peter- Seitenstetten. Train 45904 comprised 20 wagons with a weight (Gesamtwicht) of 1117 tonnes and a length of 416 m. Allowable speed was 100 km/h. The initial **derailment was due to an axle shaft rupture** of the first axle in the first bogie of wagon no 18 in point no 10 of the station. This car was owned by DB Railion. Wagons no 19 & 20 also derailed and wagon 20, the last of the train overturned. The rupture occurred in the middle of the axle and **the cause was fatigue.** The initiation of the crack seems to have been at a corrosion attack. The estimated cost of the accident was € 2 300 000,-.	BMVIT-795.135-II/BAV/UUB/SCH /2009
AT-20	25.07.2009	Strecke	I 3a	Train SGAG was on route from Villach Süd towards Graz on a double track line. The train consisted of	BMVIT-795.152-

No.	Date:	Place:	Category:	Description	Reference:
		41301 Bruck a.d. Mur - Graz		14 loaded bogie tank wagons with a total weight of 1177 tonnes and a length of 230 m. At km 162.149 with a speed of 55 km/h the first wagon of the train derailed with the first bogie to the left in a right curve of radius 586 m.. Wagons 6 and 10 also derailed at the same location with their first bogies to the left. The driver noticed the situation and braked the train. Shortly before the train stopped the first wagon overturned and a small leakage of diesel oil occurred. A nearby light building was damaged by the overturned wagon. The cause of the derailment was **an excessive track twist that had developed due to ground work between the tracks.** The allowable speed at the derailment location was reduced to 60 km/h due to the ground work.	II/BAV/UUB/SCH /2009
AT-21	17.04.2010	LILO I between Wakersbach und Prambachkirchen	I 3a	Work train 71006 comprising 21 empty wagons for track ballast transport was operated at the Linzer Lokalbahn between Bf Niederspaching towards Bhf Emling. The weight of the train was 383 tonnes with a length of 223 m. The wagons of the train belonged to ÕBB Infrastruktur. Between Wakersbach and Prambachkirchen-Bad Weinberg the 13th wagon of the train derailed. The **cause of the derailment was judged to be an excessive track twist** in a curve of nominal radius 185 m and with a nominal cant of 100 mm. Measurement after the derailment found that existing curve radius and track cant deviated significantly from above values.	BMVIT-795.192/BAV/UUB/SCH/2010
AT-22	28.04.2010	Strecke 11401, Bhf Hohenau	O 6	Freight train Z 64245 was running from Hohenau station towards Wien Zvbf (shunting yard). The train comprised 40 wagons with a total weight of 1444 tonnes with a length of 658 m. The train carried no dangerous goods. While exiting Hohenau station at the time 19.25 wagon 15 of the train **derailed by the first axle in point no 5 due to a dragged along brake shoe** that got stuck in the crossing of point no 5. At point 4 180 m further along the wagon derailed with the last axle. In a tilted position the wagon was dragged along further while it damaged a catenary mast before it overturned and the train pressure main line was broken and the train came to a stop. The brake shoe was put on the track as a safety device during the composing of the train, but was not removed prior to departure.	BMVIT-795.192/BAV/UUB/SCH/2010
AT-23	16.06.2010	Braz (V), Arlbergstrecke 10105	RS 5	At June 16th freight train GAG 46676 from Curtici (Ro) nach Mullhouse (F) consisting of a locomotive and 16 French registered autocar transport wagons came out of control at the Arlberg line and derailed between the stations Hintergasse und Braz in Austria at the time 3.07. The train had a weight of 863 tonnes and a length of 548 m and was loaded with 208 autocars. Each of the 16 wagons of the train consisted of 2 permanent coupled 2 axle wagons with a permanent coupling between the 2 halves. The train pressure main between the two halves consisted of two pressure hoses extended from each wagon half and coupled together by a traditional coupling arrangement mounted on a metal plate that was supported to the mechanical coupling between the	BMVIT-795.204/BAV/UUB/SCH/2010

No.	Date:	Place:	Category:	Description	Reference:
				wagon halves by a wire loop. Suddenly along the route the driver noticed a pressure drop in the pressure main of the train. The driver applied brakes in order to assist in the stop of the train, but no real braking activity was noticed and the train speed increased in the track descent that varied in the range 25 – 34 per mille. The last 5 wagons derailed and were departed from the rest of the train in a 250 m left hand radius curve before the station Braz at a speed of 120 km/h. A little later the locomotive and the 7 first wagons derailed in a 250 m right hand curve at a speed of 125 km/h immediately in front of the station Braz. The wagons overturned and the locomotive, the rail wagons and the load of autocars were spread around in the Braz built up area. The driver was lightly injured according to the source report. No other person was injured. The total material damage is estimated to € 10 million comprising 670 m of track, 2 turnouts, signalling equipment, 5 contact line masts, 13 freight wagons and 140 autocars, damage to private property and environmental damage caused by leaking of transformer oil.	
AT-24	05.06.2010	Bf Selzhtal	RS 5	Freight train Z 48408 was operating von Spielfield Strass towards Linz Mühlbachbahnhof. The train comprised 18 loaded iron ore wagon of type Fals. The train length was 223 m with a weight of 1404 tonnes exclusive of locomotive. The train was pulled by 2 locomotives. The train was taken into track 2, a sidetrack at the station in order to perform a driver exchange. While braking for the stop the driver at a speed of 20 km/h noticed a sudden pressure drop in the pressure main and the brakes were applied at full force. The first bogie of the 9th wagon had derailed with both axles. The cause of the derailment was the loss of a brake shoe hanger and brake block due to the lost support of the brakeshoe hanger beam and a broken safety catchline. The derailment caused severe damage to the derailed wagon as well as the infrastructure of one turnout and a broken mast for the overhead lines.	BMVIT-795.201-II/BAV/UUB/SH/2010
Switzerland: Source: Untersuchungsstelle Bahnen und Schiffe http://www.uus.admin.ch/de/					
CH-1	06.05.2000	Rodi - Fiesso	RS 6?	May 5th 2000 at approximately 08.00 freight train 42338 derailed with 2 wagons when entering track 4, a sidetrack, at Rodi – Fiesso. The derailed wagons were both 4 axle container wagons located next to each other in the middle of the train. The train route was set from track 2 into track 4 across turnouts 15 &16, both located in curved track. The first of the derailed wagons were loaded with one container only in one end. The other was loaded with 2 containers and during the derailment this wagon and the containers tippled over. According to information from the reference source, no direct failure was found with the infrastructure and failure with the rolling stock was suspected to be the cause. The cost of the material damage was estimated to Sfr 200 000,- In view of the new derailment less than 4 years later, (see below), under very similar circumstances and route settings at the same location it seems more likely to believe that the cause lies with an	Schweizer Eisenbahn - Revue 6/2000

No.	Date:	Place:	Category:	Description	Reference:
				unfortunate track geometry in the entry route from the south into track 4 at the Rodi – Fiesso station. And possibly lack of lubrication	
CH-2	30.03.2004	Rodi - Fiesso	I 3a	March 30th 2004 at 22.06 freight train 54942 on route from Chiasso Smistamento to Rbhf Limmattal derailed while entering track 4 at Rodi Fiesso station. The train consisted of 2 locomotives and 25 wagons with 86 axles. Exclusive of locomotives the weight of the train was 1185 tonnes with a length of 493 m. The derailed wagon, a loaded 2 axle container wagon, was no 13 in the train. A container tippled over and fell off the wagon during the derailment. In order to be overtaken by one or more other trains the route of the train 54942 was set for track 4 at the Rodi - Fiesso station. The route into track 4 passed turnouts 20, 19, 16 and 15 in the mentioned sequence. The maximum speed for the route was 40 km/h. All above mentioned turnouts are located in curves. The main track through turnout 20 has a curve radius of 318 m with a cant of 125 mm. In deviated route the radius was 194 m. The cause is thought to be a little used **track with difficult track geometry lacking any form of lubrication.**	N° di reg. 04033001
CH-3	19.01. 2005	Chiasso Smista-mento	O 1a	Freight train 45021 was on route from Mannheim, Germany to Chiasso, Ch. The arrival time was 22.05. The train comprised 2 locomotives and 37 wagons with a total of 118 axles with a weight of 1553 tonnes and a length of 593 m, all figures exclusive of locomotives. The mass distribution of the train was very uneven. In the front of the train were 2 locomotives with a total weight of 200 tonnes divided on 10 axles with a length of 34 m. Then followed 19 empty 2 axle wagons with a total length of 268 m and a weight of 266 tonnes followed by 18 mainly loaded bogie wagons with a total length of 325 m and a weight of 1285 tonnes. The brakes of the 5 first wagons were in position G (Lange lokomotiv). The average axle load for the 19 empty 2 axle wagons in the front was 7 tonnes with an average of 7.05 m between axles (14.1 m wagon length). For the remaining part of the train the average axle load was 16 tonnes with an average of 4.06 m between axles. The train composition was within the regulations. The track entering Chiasso Smistamento station used by train 45021 has a good technical standard with a decent of 21 per mille until it changed to even track 70 m before the point of derailment in the double switch 302. The train speed was below the maximum allowable as the train had slowed down in front of a restrictive entry signal. The 10th wagon of the train derailed as it passed the double switch 302 in a deviated route setting towards the right and the following 10 wagons also derailed. The derailed wagons conflicted with a shift movement going on at the neighbouring track and 7 wagons from this shift derailed as well. The cost of the accident was estimated to Sfr 1.5 million. **The cause of the accident was attributed to the train composition** with uneven mass distribution along the train with very long empty 2-axle wagons in the front followed by heavy loaded wagons,	N° di reg. 05011901

No.	Date:	Place:	Category:	Description	Reference:
				possibly because of push from the rear part of the train in the descent when the brakes were released.	
CH-4	08.02 2006	Amsteg	O 2c	February 2nd 2006 at 22.44 freight train 40275 on route from Basel Bad (Ger) towards Desio (It) derailed with its last wagon between Erstfeld and Amsteg at km 43,688 on the Gotthardbahn. The train consisted of 2 locomotives and 18 loaded 4 axle wagons. The weight of the train exclusive of locomotives was 1511 tonnes. The train driver did not notice the derailment until the train pressure main was broken and the brakes went on when the derailed wagon passed a turnout at Amsteg – Silenen station km 46,105. Investigation showed that the first bogie of the last wagon had derailed to the left side of the track in a right hand curve. No faults were found with the track at the derailment site, neither to the rolling stock nor with the train handling. However, it was found that the load of the derailed wagon had shifted significantly to the right. The load consisted of grain type freight loaded 1 m high in sacks along the middle of the wagon without any side support. It is unclear whether that had occurred before or after the derailment, but the observed skew loading due to the shifted load was consistent with a derailing to the left. Based upon this observation the investigation concluded that the most likely cause of the derailment was **shifting of the load due to insufficient fastening or support** of the sacks. This load shift lead to unloading of the left wheels of the first bogie in the right hand curve where the derailment occurred. The material damage cost of the derailment was estimated to Sfr 550 000,-	Reg.nr.: 06020801
CH-5	24.03.2006	Cornaux	I 3e	Freight train 71625F on route from St. Triphon to Niederglatt consisted of one locomotive and 20 four-axle tank wagon each with a gross weight of 88 tonnes. Train weight exclusive of locomotive was approximately 1750 tonnes. When leaving the Cornaux station one of the tank wagons derailed and 3 more wagons followed. The train brakes were applied either by activation of a wagon installed derailment detection valve or by a rupture of the air main of the train. The train speed at the time of accident was less than 40 km/h which is maximum allowable speed in track B1. The cause of the derailment was considered to **excessive track width due to poor condition of the wooden sleepers** and the rail fastenings in the sidetrack at Cornaux station. A track width of 1505 mm was measured after the accident. The train was routed into the little used rack B1 in order to be passed by other trains.	Reg.nr.: 06032401
CH-6	09.05.2006	Olten Rbhf	O 4b	May 9th at 02.35 freight train 90331 on route from Bern to Basel derailed with the last wagon as the train was departing from Olten Rangierbahnhof (Rbhf). In Olten the train had set out and taken in some wagons at the rear. At the end of this operation the train was extended backwards beyond switch 596. The last wagon was straddling the switch tongues. At the departure the train consisted of 1 locomotive and 20 wagon with a total weight of 593 tonnes. The train was brake tested and inspected according to the rules.	Reg. nr.: 06050901

No.	Date:	Place:	Category:	Description	Reference:
				The switches at Olten Rbhf were not protected against change of position while the track was occupied. Prior to train departure, an operator in the control cabin (Rangierstellwerk switched the position of switch 596 without noticing the track occupation. When the train dispatcher gave a departure order for the train the last wagon derailed as the rear of the wagon was directed to another track than the rest of the train. The train driver did not notice the derailment but immediately stopped the train when he got a radio message about the situation. The cause of the derailment was an **untimely operation of turnout 596 while it was occupied by a train**. The cost of material damage was estimated to > Sfr 100 000,-	
CH-7	26.07.2006	Brig entry to Simplon tunnel	RS 1aii	July 26th at 10.00 freight train 48601 derailed with 8 wagons at the entry to the Simplon tunnel. The train composition was 2 locomotives and 34 loaded wagons a 90 tonnes. The total train weight exclusive of locomotives was 3048 tonnes. The length 478 m. Two rear helper locomotives were applied at the exit from Brig. At Brig station prior to the train entry to the Simplon tunnel wagon no 13 experienced rupture of the leading axle of the leading bogie. This caused a train breakage and emergency braking of the train was applied due to rupture of the air main line. This caused another 7 wagons to derail. The derailment was caused by an **axle shaft rupture due to fatigue**. The fatigue crack initiated form a damaged corrosion protection layer.	Reg. nr.: 06072601
CH-8	27.07.2006	Bresonnaz VD – Ecublens - Rue FR	I 3a	Freight train 60490 on route Payerne – Lausanne - Triage derailed with 4 wagons at the time 19.36 at km 32.6 between Bressonaz and Ecublens - Rue. The train comprised an electric locomotive type Ae 6/6 and 20 wagons (58 axles). Exclusive of locomotive the train weight was 882 tonnes with a length of 328 m. The train derailed with the wagons no 1, 5, 6 & 8 in a curve with radius 290 m where track work was ongoing. The first wagon to derail was an empty 2-axle tank wagon with a short wheel base of 4.8 m located immediately behind the locomotive. The maximum allowable speed at the accident location was 50 km/h. The train speed at accident was 48 km/h. The cause of the derailment was an excessive track twist with maximum twist of 52 mm over 4.8 m length(maximum 1:70) in a narrow curve with 290 m radius. The track cant at the accident location (190 mm) was also higher than the design value and higher than what is normally accepted. The wagon also had a skew loading due to either a frame twist or suspension failure but this was not decisive for the derailment.	Reg. nr.: 06072701
CH-9	17.08.2006	Mühlehorn	RS 1aii	Freight train 48714 was on route from Villach, AT via Buchs, CH to Biberist, CH. The train composition consisted of 1 locomotive and 16 loaded 4 axle tank wagons with chalk suspension. The weight of the train was 1368 tonnes.	Reg. nr.: 06081701

No.	Date:	Place:	Category:	Description	Reference:
				Prior to entry to the Mühlehorn station the train driver received an alarm of a hot axle box reading and a possible derailment being detected in the train control installation between Murg and Mühlehorn. As the train was on a 900 m single track stage of the line the driver did not initiate braking at once. When passing Mülehorn station an automatic emergency brake was initiated due to a train rupture. The 13th wagon of the train had derailed due to a rupture of the last axle in the last bogie. This also brought wagons 14 – 16 to derailment. A hot-axle box detector in Bludenz on the Austrian side of the border had not noticed anything wrong. Further the train was inspected in Buchs, CH. The hot axle box detector between Murg and Mühlehorn detected a high temperature reading of the 57th axle of the train, i.e. the axle in front of the derailed one. **The cause of the derailment was an axle shaft rupture due to fatigue.** The rupture was located between the wheels close to one of the wheels. The cause of the axle rupture was a material composition not meeting the requirements combined with a relatively low safety margin of the axle. The tank wagon initiating the derailment was owned by VTG.	
CH-10	30.09.2008	Meilen – Herrliberg-Feldmeilen	O 2bii I 3a	The accident train no 37672 consisted of a track maintenance machine in the front of the train followed by 10 wagons with ballast. The weight of the train was 602 tonnes exclusive of locomotive. The train was pulled by a diesel locomotive. The train was formed in Rapperswil and was on route towards Küsnacht. Between the stations Meilen and Herrliberg - Feldmeilen the last wagon of the train derailed with both axles. The derailed wagon was loaded with ballast consisting of crushed stone. It was a 2-axle wagon that was partly unloaded at Rapperswil prior to travel. As a result of the partial unloading a severe skew loading of the wagon had occurred with a load distribution of 1:1.7 between the two sides of the wagon. This skew loading is above the allowable distribution. At the derailment location a track twist of 1:100 was measured which is above the allowable twist. In addition the coupling of the derailed wagon was tightened too hard. **The combination of a skew loaded wagon and a high track twist caused the derailment**. The train speed at the time of derailment was 44 km/h.	Reg. nr: 08093001
CH-11	19.01. 2009	Rbhf Limmattal	O 5b + i	January 1st 2009 at 18.56 freight train 50834 on route from Rangierbahnhof Limmattal (RBL) to Basel derailed with wagons 11 – 13 at the exit of track 411 towards track 309 at Rangierbahnhof Limmattal. Train 50834 consisted of 4 locomotives (Type 420) and 43 wagons with 134 axles and weighed 1194 tonnes with a length of 709 m. All figures exclusive of locomotives. The train composition consisted of 17 empty or lightly loaded wagons in the front followed by 12 predominantly heavy loaded wagons in the middle and 14 empties at the end. The 4 locomotives were all in brake position G. While the train was still accelerating signal D145 indicated a stop at the next signal. The driver thought	Reg. nr.: 09011902

No.	Date:	Place:	Category:	Description	Reference:
				the route was set to north bypass (Signal F165 at a distance of 532 m) instead of the actual route for the new track 309 (Signal P 309 at a distance of 275 m) which the driver was not familiar with. The driver passed signal D145 by 100 m without initiating any braking. Once he discovered the actual route setting at switch 259 he initiated a relatively strong braking which came to force 125 m after signal D145 and 150 m in front of signal P 309. The speed was 30 km/h. Shortly after a wagon derailed in switch 229 which had a deviated position and brought 2 other wagons to derailment. 2 of the derailed wagons were long and empty 2-axle wagons. Investigations did not find anything wrong with the derailed wagons nor the track. The investigation therefore determined that the derailment was caused by the strong braking in combination with the actual train composition with several light empty 2-axle wagons in the front. The driver also acted contrary to the SBB requirement of always to initiate braking prior to passing a warning signal requiring speed reduction. **The cause of the derailment was unfortunate train handling not in accordance with regulations.** However, the investigation group made a recommendation to change the signalling installations in order to avoid any similar future misunderstandings. The material damage cost was estimated to Sfr 100 000,-	
CH-12	13.09. 2009	Basel Rangierbhf	O 4b	August 13th 2009 at 23.30 freight train 50842 on route from Rangierbahnhof Limmattal (RBL) to Basel Rbf derailed with wagons 19 – 22 upon entry to Basel Rbf. The train should operate as a shunting movement In Basel Rbf from the entrance track group E towards departure group A track 8. Train 50842 consisted of 2 locomotives and 44 wagons with 120 axles and weighed 1237 tonnes with a length of 713 m. All figures exclusive of locomotives. When the train passed switch No W 225 wagons no 19 – 22 in the train derailed. The main line of the train was broken and the train came to a stop quite soon as the speed was low. Two of the derailed wagons turned over. **The cause of the derailment was erratic operation of a control handle for) switch no W 225 while train 50842 was passing the switch.** The switch therefore changed position from a train route towards Track 8 to a train route towards Track 7 while wagon no 19 passed the switch. This caused derailment to wagons 19 – 22. Once the fault was discovered the switch was returned to the “correct” position. The marshalling yard at Basel Rbf did not have train detection device in switches with interlocking to prevent movement of switches while they were occupied by trains.	Reg. nr.: 09081303
CH-13	21.05.2010	Visp station	RS 2b	Freight train 69019 operated by SBB Cargo was running from Lausanne Triage towards Brig. The train composition was changed by setting out or taking in wagons at the stations St. Maurice and Gampel-	Reg. nr.: 10052101

No.	Date:	Place:	Category:	Description	Reference:
				Steg. Train 69019 when leaving Gampel - Steg comprised 2 locomotives type RE420 and 13 wagons with a weight of 406 tonnes and a length of 220 m exclusive of locomotives. The train derailed with wagons 8 & 9 at Visp station. Wagon 9 derailed to the left with the forward axle at point no 7 at km 136.2 at the entry to the station. The derailed axle shifted side to the right at point 29 and wagon 8 also became derailed with both axles. The train composition was broken between wagons 9 and 10 in point 33 at the exit of Visp station at km 137.5. The brakes were automatically applied and the front of the train came to stop at km 138.16. Both of the derailed wagons were empty 2axle flat wagons type Ks. The train speed at the initial derailment was approximately 95 km/h. Allowed train speed was 100 km/h. The initial derailment was **due to failure of the left hand blade spring suspension of the forward axle**. The axle box had become detached from the blade spring and the axle was running in a skewed mode. Two suspension links were lacking. The derailment of wagon 8 was due to buffer locking against the derailed wagon 9. Both of the derailed Ks wagons had circular buffer tellers of diameter 42 cm and this was considered contributory to the buffer locking. Buffer locking had also occurred between wagons 9 and 10, but wagon 10 was not derailed when the 2 parts of the train stopped. No persons were injured, but damages occurred to infrastructure and rolling stock. The derailed wagons conflicted with the free profile of the neighbouring main track but no trains arrived before the tracks were closed.	
France: Source: BEA-TT					
FR-1	18.01.2001	Montpellier station	RS 1 ai	Freight train 435671 derailed at a speed of approximately 18 km/h while entering Montpelier station. A hot axle box alarm for the 71st axle left hand wheel was detected at a hot axle box detector prior to arriving at the station. Due to the fault detection Train 435671 was directed into a side track at Montpelier station so the driver could inspect the train. During inspection it was found that an auto transport wagon type STVA had derailed due to a hot axle box and ruptured axle journal. Large wheel flats were found on the the wheels of the axle with the hot axle box. It is likely that vibrations due to the wheel flats had provoked the hot axle box.	
FR-2	13.06.2006	Ferté-sur-Chiers	I 3b + 1 3c?	The derailment occurred to freight train 72187 on route from Dunkerque to Dieulard (Meurthe et Moselle). The train consisted of 2 locomotives and 44 four axle wagons loaded with iron ore. The length of the train was approximately 500 m, and the weight was 3568 tonnes, exclusive of locomotives. The travelling speed was approximately 100 km/h. The rear wagon of the loaded iron ore train derailed at Ferté-sur-Chiers at km 190,200 while travelling at a speed of 100 km/h in a curve of 676 m radius. The front bogie of this rear carriage mounted the outside rail upon exiting the curve. The cause of the derailment appeared to be linked primarily to the condition of the track, even though its local geometry was in line with allowable values. **Dynamic coupling between track and wagon due to regular geometry deviation of the track with a long wave length seems to be the cause of the derailment.**	Affaire no BEATT-2006-06. Report date 07.09.2007

No.	Date:	Place:	Category:	Description	Reference:
FR-3	21.07.2006	St. Parres le Vaudes – Bar sur Seine	I 3d	A freight train weighing 1682 tonnes with a length of 421 m derailed with the last 4 wagons at the time 18.20 at km 191.40 between St. Parres le Vaudes and Bar sur Seine. The line is equipped with jointed track with rail lengths of 36 m. The maximum line speed at the accident location was 50 km/h. The train travelled at a speed of 44 km/h when the event occurred. The immediate cause of the derailment was **a track buckle (sun curve) that had developed due to high rail temperature** and not correctly adjusted rail joint space. The rail temperature was measured to 53^{o}C. Investigation revealed that a non-sufficient joint opening existing on the line and was known prior to the derailment, but no corrections was made. 300 m of track was damaged during the derailment.	ERA
FR-4	24.01.2007	St. Amour – Beny Aiguille-Ipcs	RS 1ai	A freight train weighing 410 tonnes with a length of 229 m derailed with 5 wagons on the line Dijon-Ville – Borg-en-Bresse between the stations St. Amour and Bény-Aiguille-Ipcs at the time 04.00. Wagons no 4, 5, 6, 7& 8 of the train derailed. The derailment was caused by **a broken axle journal at the axle bearing**. Probably due to a hot axle-box and an axle seizure. Persons were not injured and the involved wagon(s) did not contain dangerous goods. 80 m of track was damaged.	ERA
FR-5	30.10.2007	Gex – Fort l'Ecluse-Collonges	I 2a	A freight train weighing 675 tonnes with a length of 200 m derailed on the side line between Fort l'Ecluse-Collgnes and Gex due to **a rail breakage** at the time 18.00. Persons were not injured and no dangerous goods were involved. 60 m of track was damaged.	ERA
FR-6	24.11.2009	Orthez	I 3f + RS 2a	Train 84892 by FRET-SNCF operates between Bayonne and Lacq in the south of France. At the accident day the train comprised 27 bogie tank wagons mainly loaded with hazardous material. The train weight exclusive of locomotive was 1217 tonnes with a total length of 484 m. The train was stopped in front of Orthez station. After some minutes of waiting the train received a clearance from the traffic controller to proceed according to "speed of view" regulations, and the train continued its journey and accelerated to a speed of 28 km/h. Then the speed was reduced to 20 km/h. Shortly thereafter wagons 26 & 27 of the train derailed. Wagon 26 filled with liquefied gas overturned. The pressure main between wagons 25 & 26 was broken and the whole train came to a stop. The traffic was stopped immediately on both tracks. No human injury occurred. A small leakage of propane was observed and a safety zone was established around the accident scene. The initially derailed wagon was a large bogie tank wagon for transport of pressurized gas (110 m^3) which was loaded to about 75% of full volume only. This was due to axle load allowance of the line and/or the rolling stock. The relatively low loading percentage of the car left a large free liquid surface in the wagon which had two unfavourable effects on the load distribution within the wheels: 1. the point of gravity was shifted towards the inner rail at the point of derailment due to the high excess cant (160 mm) of the track caused by the low speed (20 km/h) being well below the equilibrium speed for the track cant, 2. the large free liquid surface would allow liquid to move longitudinally when exposed to	Affaire n^{o} BEATT-2009-011, décembre 2010.

No.	Date:	Place:	Category:	Description	Reference:
				accelerations and decelerations, and transversally when passing through curves with a speed different from the equilibrium speed of the track cant. At the entry to Orthez station, the line passes through an S-curve starting with a right hand curve (R=467 m) followed by a left hand curve (R=463 m). The derailment occurred in the exit transition curve of the initial right hand curve. At the end of the circle curve in the travel direction the measured maximum cant of this curve was 173 mm. This was significantly higher than the specified 159 mm, but within allowable track cant in France, but the variation between design track cant and measured track cant was higher than allowable. The design track twist in the transition curve between the opposite directed circle curves was also relatively high. However, the measured track twist was even higher than the design value with a maximum of 9 mm over a distance of 3 m (1:333) and 21 mm twist measured over a distance of 9 m. (1:430). The measured values are higher than allowable design values, but within traffic allowable tolerances. The bogie centre distance of the derailed tank wagon was 14.2 m. and over this length the maximum twist was 31 mm. The wheel climb started at km 255,994, i.e. 18 m into the exit transition curve, and the derailment occurred at km 255,987. Further, the 4 tank and bogie structure supports (lisoir & glisoir) showed different wear and resulting play on a diagonal basis due to the recent exchange of 2 of the bogie supports that were diagonally positioned. This lead to a skew loading of the bogies in the curve due to the torsion stiff tank structure. Additional to the above the contact point between wheel flange and the track lacked greasing. **The derailment is therefore caused by a combination of unfortunate track design, wagon design and loading, as well as existing deviations from design values combined with a low train speed at the point of derailment.**	
FR-7	22.05.2010	Neufchâteau	RS 1bi	The 4 last wagons of Train SNCF 58701 derailed and turned over on May 22nd 2010 in plain track in front of Gare Neufchâteau. 3 of the derailed wagons was tank wagons carrying hazardous materials of which one was carrying phenol. No human injury occurred. A small leakage of phenol was observed from one of the wagons. The cause of the derailment was due to the rupture of the forward left wheel of the most forward of the derailed wagons. Due to this derailment wheels and axles of several other wagons of the same make was inspected and cracks and fissures were found in several of them.	Affaire n° BEATT-2010-008, janvier 2011.
FR-8	29.07.2010	Bully-Grenay station	O 3b	A freight train derailed at track no 2 at Bully-Grenay station in the North of France. The cause of the derailment was **a blocked axle that had developed a wheel flat of 25 cm and was derailed on a switch** in Bully Grenay station at the time 11.10. The blocked axle was probably due to a hand brake that was not properly released prior to departure. Persons were not injured. Overall 20 wagons derailed and damaged. In addition, heavy damage to infrastructure involving: tracks, points, signals and catenary. Line interrupted for 5 days. This derailment	ERADIS FR-983

No.	Date:	Place:	Category:	Description	Reference:
				has many similarities with the derailment in UK-1 at Hatherley, near Cheltenham Spa.	
FR-9	09.03.2011	Artenay	RS 1aii	On the line between Paris and Orleans **an axle of a 2-axle freight wagon broke between the wheels**. The wagon derailed and the broken axle fell between the rails and derailed following wagon(s). Persons were not injured. Several wagons and 1000 m of track were damaged.	ERADIS FR1110
Spain: Source: Ministerio de Fomento; Comision de Investigacion de accidentes ferroviarios					
ES-1	07.12.2003	Km 426 line Valencia de Alcántara . Marvao (Portugal)	I 2a	A freight train weighing 511 tonnes with a length of 180 m derailed on open line at km 426,0 Valencia de Alcántara – Marvao (Portugal) at the time 08.00. **The cause of the derailment was a broken rail.** Persons were not injured. The train contained dangerous goods, but any leakage did not occur. The total damage cost of the derailment was estimated at €33 200. The line was closed for 38h 45 min.	ERA
ES-2	15.12.2004	Pola de Lena station	I ?	Freight train TN203 operated by RENFE was travelling on the line Leon – Gijon. The train comprised 22 wagons with a weight of 787 tonnes and a length of 280 m. At the station Pola de Lena in the province of Oviedo – Asturias the train derailed with wagons no 5 & 6 at the time 13.45 while entering Track III of the station due to a track geometry fault. The track at the derailment location was horizontal with a curve radius of 180 m. The train speed at derailment was 23 km/h. Persons were not injured. The 2 derailed wagons were empty tank wagons with rests of butane and a leakage of gas developed without further consequences. The damage cost was estimated to €10 000.	ERA + ADIF accident notification
ES-3	15.03.2006	Los Ramos Alqueiras	I 3e	A freight train weighing 1125 tonnes with a length of 315 m derailed at Los Ramos Alqueiras at the time 16.15. The derailment was due to track gauge widening due to a deteriorated sleeper screw. The main pressure pipe of the train was not broken. Persons were not injured. 102 m of track was damaged and slight damage occurred to rolling stock (€414) wagon. The train contained wagon(s) with dangerous goods, but no leakage occurred. The track was closed for 15h 18 min.	ERA
ES-4	12.12.2006	Tarragona Termino station	I 3e	A freight train weighing 883 tonnes with a length of 194 m derailed at Tarragona termino station at the time 11.50. The derailment was due to track gauge widening due to lack of a sleeper screw. The main pressure pipe of the train was not broken, but the train stopped quite fast due to a low speed. Persons were not injured. 22 m of track was damaged and one freight wagon. The train contained wagon(s) with dangerous goods, but no leakage occurred. The track was closed for 10h 50 min.	ERA
ES-5	29.03.2007	Montabliz	I 3b	A freight train weighing 799 tonnes with a length of 152 m derailed at Montabliz at the time 20.11. The derailment was due to an excess of superelevation of the track. The main pressure pipe of the train was not broken and it took 2 min before the train stopped. Persons were not injured. The train contained wagon(s) with dangerous goods, but no leakage occurred. The derailment caused heavy damage to track and rolling stock was also damaged. The total cost of the accident was €426000. The track was closed for 17 h.	ERA

No.	Date:	Place:	Category:	Description	Reference:
ES-6	25.06.2007	Venta de Baños	RS 5	A freight train weighing 638 tonnes with a length of 294 m derailed at Venta de Baños station at the time 05.30. The derailment was due to a structural failure of the braking system of a wagon. A brake triangle was falling down due to failure of rods. The main pressure pipe of the train was not broken but the train stopped within half a minute of the derailment. Persons were not injured. The train did not contain wagon(s) with dangerous goods. The derailment caused damage to track and rolling stock amounting to €74 000/€150 000. The track was closed for 18 h.	ERA
ES-7	08.01.2008	Reus station	I 3e	A freight train weighing 1233 tonnes with a length of 288 m derailed at Reus station at 13.17. The derailment was due to an excessive track gauge The main pressure pipe of the train was not broken but the train stopped within half a minute of the derailment. Persons were not injured. The train did not contain wagon(s) with dangerous goods. The derailment destroyed 640 m of track and rolling stock damage amounting to €45500 occurred. The track was closed for 13 h.	ERA
ES-8	24.10.2008	Moncófar station (Castellón), km 48,748,	RS 1bi	The freight train 50460 of RENFE-Operadora on route from Valencia to Tarragona and Bilbao derailed at the exit of Moncófar station at the time 06:28 when passing a rail switch. As a result, the locomotive and 6 of the total of 15 wagons were derailed. The locomotive and some of the wagons overturned. The derailment was caused by the **rupture of the left wheel of the third axel at the second bogie of the locomotive**. The cause of the monoblock wheel rupture was a fatigue of the wheel material initiated from scratch marks on the outer wheel surface made during turning of the wheels in a lathe. The driver of the train was slightly injured as the locomotive turned over in the derailment.	Investigacion del accidente n^{o} 0054/2008
ES-9	17.09.2009	Zumarraga station	I 3b	Freight train 93614 was on route from Hendaye to Madrid comprising 14 wagons with a weight of 762 tonnes. The train derailed at the time 16.00 at km 566,856 between the advance and main entry signal to Zumarraga station in the Province of Guipuzcoa. The derailment occurred in the clotoid transition to a circle curve with radius 285 m. The allowable speed at the derailment location was 80 km/h whereas the speed of the train was 28 km/h due to a need for slow down due to signalling status. Tha cause of the derailment was an excess of 62 mm of cant at the derailment point. The combination of excessive cant, the sharp curve and the low train speed led to the derailment. 3 wagons of the train derailed and significant damage was made to the infrastructure. No persons were injured and dangerous goods were not involved. Track 1 at Zumarraga was closed for 5½ hours whereas track 2 was closed for 39 hours.	Investigacion del accidente n^{o} 0054/2009 ocurrido el 17.09.2009
ES-10	14.06.2010	Cerdido y – Ortiguere, Coruna (ES)	O 5 aii	Freight train FR 901 belonging to Feve was on route from El Ferrol to Xove. The train derailed on the Feve line (Gauge 1000 mm) at km 43,559 - km 43,877 between Ponte Mera and Santa Maria de Mera at the time 08.32. The train comprised 2 diesel locomotives and 14 wagons of type 2SSag of which 10 were loaded with timber in containers and the last 4 empty.	Investigacion del accidente n^{o} 0028/2010 ocurrido

No.	Date:	Place:	Category:	Description	Reference:
				The derailment occurred on the line in a curve with radius 141 m with a cant of 71 mm at the initial derailment point. Allowable speed was 60 km/h, and the actual train speed was 77 km/h. Investigations revealed that the signed speed was too high accounting for the available cant. The allowable speed should not be higher than 50 km/h. The **cause of the accident was an excessive speed** in relation to track design and in relation to signed allowable speed. Containers overturned to the outer side of the curve. During derailment the train broke in two between 6th and 7th wagon and the brakes were automatically applied. 7 of the wagons (n° 5 – 11) derailed and 7 were not derailed. Several of the containers with timber overturned towards the outer curve. And 250 m of track were damaged. Humans were not injured but the material cost was severe and estimated to € 200 200,- in total.	14.06.2010
Portugal: Source: INTF					
PO-1	20.12.2006	Km 235,14 Linha do Norte	RS 1bi	A bogie tank wagon of Transfesa loaded with cement derailed in train 64311 at km 235.14 on the North line. **The cause of the derailment was rupture of the right wheel of the 1st axle** of the 2nd bogie of car no 13 of the train. The cause of the rupture was fatigue of the monoblock wheel material. The train consisted of 2 locomotives and 18 loaded bogie tank wagons for transport of cement in bulk and was on route from Souselas (south of Pampelhosa) to Aveiro. The train continued for some km after the derailment and came to a stop at km 238,412. The broken wheel was a monoblock wheel and was found in 3 large pieces along the track after the derailment. Nobody was injured.	INTF 17/2006
Italy: Source: Wikipedia & ERADIS					
IT-1	29.06. 2009	Viareggio	RS 1aiii	On 29 June 2009, at 23h48m, the train n.50325 operated by the railway company Trenitalia SpA, going southward and composed of 14 tank wagons carrying butane gas, derailed on the odd track as it entered the railway station of Viareggio. On the section of the track were the derailment occurred there are no switches. Following the derailment of the 1st wagon (wagon No. 338078182106, owned by GATX Rail Austria GmbH and registered at the DB the German network or PKP of Poland), the wagon itself hit the platform at the station and overturned. The train continued moving until the end of the station. It stopped about 200 m after the platform. The next 4 wagons also overturned. A further 2 wagons derailed but stayed upright. The last 7 wagons did not derail. 2 wagons carrying LPG developed leaks. After a few minutes there was a powerful explosion that damaged very seriously the rail infrastructure (the track, the catenary & signalling equipments) as well as surrounding housing. Totally 32 persons in the area were killed and 27 injured. An axle break is indicated as the most likely cause of the derailment, but any investigation report has not been issued.	
Hungary: Source: KBSZ: Transportation Safety Bureau (TSB)					
HU-1	08/10/2003	Budafok-Háros	RS 1bii	Freight train 83526 was operating from Zalagerseg towards Dunai Finomító. The train carried crude oil. The weight was 1765 tonnes and the length was 351 m. At the Budafok-Haros station at the time 08.57	ERA + MAV accident

No.	Date:	Place:	Category:	Description	Reference:
				wagon no 12 derailed and was followed by 7 additional wagons. The train speed of the train at the point of derailment was 55 km/h while the allowable speed was 60/70 km/h. The train pressure main was broken and the brakes applied. The **cause of the derailment was a displaced wheel tire on one of the wheels** of wagon 35 55 788 7735-7, a tnak wagon. The displaced wheel tire had caused the flange distance at the axle to widen. When passing a turnout at Budafok Haros the axle derailed in a point crossing. Inspections after the accident showed indications of this fault at more than 100 km prior to the derailment. No persons were injured in the derailment. The line was closed for 15 hours. Minor amounts of crude oil leaked out without any consequences. 193 m of track was damaged and the total cost was estimated to €160 000,-	report
HU-2	09/15/2004	Fényeslitke	RS 1aii	Freight train 68441/68411 was operating from Budapest towards Zahony at the Ukrainean border. The train comprised 27 wagons of which 26 were tank wagons loaded with petroleum products and one was acting as safety wagon between the locomotive and the loaded tank wagons. The train weight was 1885 tonnes and the train length 341 m. When the train was passing the station of Fényeslitke at the time 09.29 wagon no 13 of the train, a tank wagon with light petroleum, derailed in turnout no 3 at the entry to the station. 4 more tank wagons, no 14, 15, 16 & 17, derailed at turnouts in the exit and of the station. The train main pressure line was broken. The brakes were applied and the train came to a stop. Several of the wagons overturned and leaked. The **cause of the derailment was a broken axle shaft due to fatigue** of one of the axles of the initially derailed wagon. The rupture was initiated from a small mark in the axle protective coating. The infrastructure damage was severe comprising 1200 m of track 4 points, track catenary masts, and Strail elements of a level crossing 1200 m of track were damaged. A net amount of 106 tonnes of petroleum products were released to the ground. The railway traffic on the line was disrupted for 62 hours. The total cost of the accident was estimated to €1 280 000.	ERA + MAV accident report
HU-3	06/08/2006	Line 1, Komárom station	O 6	Freight train 45552 was operated by BRKS (a Slovak railway) when leaving Komarom station with a Slovak locomotive and staff. The train consisted of 25 wagons with a weight of 554 tonnes and a length of 375 metres with a destination in the Czech republic. When leaving Komarom marshalling yard the train derailed with the first two wagons in switch no 428 at the Komarom station. The first wagon derailed with 4 axles and the second wagon with 2 axles. The cause of the derailment was a brake shoe positioned in front of the left wheel of the first axle of the first wagon that was not removed prior to the train departure. The brake shoe was pushed along until it reached point no 428 where it was stuck in the point crossing and caused the derailment of the left wheel of the first axle as it moved over the brake shoe. The speed at the derailment was 15 km/h and the brakes were swiftly applied. The direct costs were minor and estimated to 1 000 000 HUF (4000	TSB HU-253 Final report:: http://www.kbsz.hu/images/Vasuti_zarojelentesek/2006-0048-7.pdf

No.	Date:	Place:	Category:	Description	Reference:
				EUR). The cause of the derailment was an **operational error by not removing a brake shoe left under the train prior to the train departure.**	
HU-4	28/10/2006	Line 120: Between Mende and Sülysap stations - open line	RS 1ai	The first bogie of the fifth unit of freight train 96340, which was a special track maintenance machine, derailed and caused damage to sleepers along 600 m of the track and diesel oil was leaked out from the tank of the special vehicle. The cause of the derailment was a **hot axle box and a rupture of the axle journal** with a total damage of the bearing housing. The train operated at 60 km/h at the time of the derailment which also was maximum speed allowed for the maintenance machine. The technical certificate of the maintenance machine had expired September 2006 and hence it should have been recalled for maintenance at the time of accident. Infrastructure: 1 000 000 HUF (4 000 EUR) Rolling stock: 1 000 000 HUF (4 000 EUR) Environment: 100 000 HUF (400 EUR)	TSB HU-380 Final report:: http://www.kbsz.hu/images/Vasuti_zarojelentesek/2006-0103-5.pdf
HU-5	07/12/2006	Line 100: Between Debrecen and Ebes stations	O 7 + RS 6	Freight train nr 63202 was on route from Zahony marshalling yard toward Budapest Ferencvaros. When departing Debrecen the train consisted of 1 locomotive and 28 wagons with a total train weight of 1077 tonnes and train length of 525 m, all inclusive of locomotive. At 02.18 between Debrecen and Ebes one of the lower emptying hatches of the 23rd wagon (empty hopper wagon for grain) fell of the train on to the track and landed under the first bogie of the 24th wagon which was lifted off the rails. The train continued for 7 km with the derailed bogie running on the side of the rails. When entering the Ebes station 6 more wagons of the train (all empty hopper grain wagons) were derailed and the train separated between wagons 23 and 24 which also overturned. The train brakes were automatically applied and the train stopped. The wagons 22 – 28 were derailed The track was severely damaged. The train speed during the event was approximately 70 km/h. The lower hopper emptying hatch consists of a steel plate 800x900x10 mm to which two 30 mm racks are located with a small stop block in the end of the rack. The hatches are moved by a rack and pinion arrangement. The hatches were left open after unloading of the wagons and some of the hatches had lost the stop block. During movement of the train they were wriggled loose. During investigation after the accident it was found that out of a total of 30 hatches of the 10 wagons 20 hatches was found open, 5 were completely missed. 3 were found half open and 2 were found in closed position. **The cause of the accident was judged to be by hatches left open after emptying of the wagons.** Some of the hatches were without stop blocks to avoid over-opening and once they wriggled loose during train journey they were lost underneath the train and hence caused derailment. Recommendations were made to check existence of the stop blocks and to ensure closing of hatches after unloading.	TSB HU-381 Final report: http://www.kbsz.hu/images/Vasuti_zarojelentesek/2006-0151-5_2006_14.pdf

No.	Date:	Place:	Category:	Description	Reference:
				Infrastructure: 100 000 000 HUF (400 000 EUR), Rolling stock: Appr. 20 000 000 HUF (80 000 EUR)	
HU-6	27/12/2006	Line 1: Between Lebeny-Mosonszent miklos and Kimle stations	RS 1ai	Freight train 47182 consisted of 21 wagons fully loaded with corn. The train weight inclusive of locomotive was 1742 tonnes with a length of 328 m. Locomotive nr. V63046. Between the stations Lebeny-Monszentmiklos and Kimle at approximately 19.00 hours wagon no 5 of train 47182 derailed on the open track with one axle. The train continued with one derailed axle for 2000 m with a speed of approximately 50 km/h. When passing a level crossing the wagon toppled over and blocked the neighbouring track. 3 other wagons derailed maybe due to a Strail element of the level crossing road surface that came loose. The cause of the initial derailment was an **overheated axle box of the fifth wagon and a broken axle journal**. The accident train had been observed by railway staff along the track with an axle making noise and producing sparks without anybody taking action to stop the train. The track received substantial damages for a length of 2000 m. The cost of the accident was estimated as follows: Infrastructure: 80 000 000 HUF (320 000 EUR) Rolling stock: 40 000 000 (160 000 EUR) Safety recommendation: Better training of the staff to evaluate train danger indications and possible consequences.	TSB HU-383 Final report:: http://www.kbsz.hu/images/Vasuti_zarojelentesek/2006-0175-5_2006_16.pdf
HU-7	25/01/2007	Line 100: station Szolnok	O 7	On 25 January 2007 at 11:37 hours, one empty four-axle tank-wagon of train no. 63000 derailed before points no.84 on a straight track section when approaching Szolnok station. The tank of the wagon was self supporting and when it collapsed due to internal vacuum it also derailed the wagon. In the derailment another tank-wagon in front also derailed with two axles. The cause of the tank collapse and derailment was due to a closure of tank valves/openings while the tank was hot. Steam had been used to assist during emptying of the wagon and when the valves/openings to the tank were closed a vacuum developed as the tank cooled and steam condensed. **The accident cause was tank collapse due the vacuum created as the temperature dropped after emptying the wagon with steam.** This occurred during train passage. Damage: Infrastructure: The track (ca 150 m) slightly damaged, a signal post fell over the rolling stock. The tank of one of the derailed wagons completely damaged. Other wagons slightly damaged. Safety recommendation: Regulate the tank refrigeration after steam has been used for emptying of molasses.	TSB HU-466 Final report: http://www.kbsz.hu/images/Vasuti_zarojelentesek/2007-0034-5.pdf
HU-8	07/02/2008	Line 40: Budafok-Haros station	I 3e	Train 83521 was on rote from Dunai Finomito toward Budapest Ferencvaros Nyugati. The train consisted of 19 four axle wagons (tank wagons) with a total train weight of 1363 tonnes and a train length of 282 m. The locomotive was V43-1208. When train 83521 was leaving a sidetrack at the Budafok-Haros station at approximately 08.50 the 6th wagon, a tank wagon laden with gasoline,	TSB HU-473 Final report: http://www.kbsz.h

No.	Date:	Place:	Category:	Description	Reference:
		Locomotive: V43-1203		derailed and overturned. The speed of the train at the time of derailment was approximately 10 km/h. There was no leaking of dangerous goods or no human injury. **The derailment was caused by the general poor condition of the track.** The old wooden sleepers were scheduled for replacement in 2007 but the work had been postponed. After the accident the unloaded track width was measured to 1475 mm at some places. The maximum speed was reduced to 10 km/h in many of the tracks. The accident investigation concluded that a major renovation was necessary. Accident cost: Infrastructure: 120 000 EUR RS: the derailed tank wagon was seriously damaged. .	u/dokumentumok/2008-052-5_zj_.pdf
HU-9	26/03/2008	Line 80: station Kobanya-felso Locomotive nr. 1047-001	I 2c + o	Freight train no 44405-2 was on route from Sopron to Curtici, Romania. The weight of the train was 1352 tonnes and the length was 584 m. At 1:18 a car-carrier wagon of train no. 44405-2 derailed at point Nr 22 at the Kobanya-felso station as the train was arriving to the station. The first and the last bogie of wagon no 16 ran on different tracks and the rear part of the wagon collided with a parked disused freight wagon. This also caused wagon no 15 to derail. The speed at the derailment location was 17 km/h. The point rail moved away from the stock rail as the train passed the switch and the last bogie of wagon 16 was directed to a different track than the front part of the train. The rear part of the wagon 16 collided with a parked disused wagon at the track. The **cause of the derailment was a faulty switch probably due to insufficient maintenance or operational failure.** The KBSZ stated that the reason of the accident was staff lacking knowledge or bad working routines. Infrastructure damage was 15 000 EUR in addition the derailed freight wagon was damaged slightly.	TSB HU-476 http://www.kbsz.hu/dokumentumok/2008-136-5_Zj.pdf
HU-10	22/07/2008	Line 80: Rakos station Loc. Nr. V43-1108	O 4b	Freight train no 53612 comprised 38 wagons with a total weight of 1253 tonnes and a length of 590 m. On approaching Rákos station, freight train no. 53612 derailed at point no 6 due to the fact that the point was switched from one track to another while wagon 14 or 15 occupied the switch. The 15th wagon derailed with 4 axles and three further wagons sustained damage. Points no 12, 18 and 20 as well as the rail track between points no 6 and 20 sustained damage. The train speed at the time of derailment was 12-13 km/h. The cause of the derailment seemed to be several faulty actions at the control centre of the Rakos station: A train route had been set for train no 53612 arriving from Köbanya felsö. The train route included a secured position for point 74 b giving flank protection to the secured train route for train 53612. Prior to arrival of the train point 74 b was being sheared open by a shunting move without anybody noticing this was the reason why the J entry signal for train 53612 changed to a stop aspect. Regardless of that the train was given a oral radio authority from the control centre to proceed with care.	TSB HU-711 http://www.kbsz.hu/images/Vasuti_zarojelentesek/2008-315-5.pdf

No.	Date:	Place:	Category:	Description	Reference:
				While train 53612 slowly was entering the station persons at the control centre was working to set and secure a train route for train 5205 towards Köbanya felsö via another track. During this work **point no 6 changed position while train no 53612 was passing it, most likely due to an operational fault from the control centre,** or a fault in the interlocking. Switches as well as the track between points No.6 and 20 sustained damage. Four derailed wagons were slightly damaged.	
HU-11	09/09/2008	Line 30: Szekesfehervar station Loc: V63-040	I 3a	Train No 42011-2 was on route from Szolnok to Hodos, Slovenia. The train consisted of 27 wagons with a total weight of 662 tonnes and a length of 506 m. The locomotive was V63 040. The 11th wagon of train No. 42011-2 derailed with two axles as the train was leaving Székesfehérvár station on track XII at the time 12:53. The temperature at the day of the derailment was very high 35^{o}C. The train speed at the derailment was 17 km/h while allowable speed in the track was 10 km/h due to the poor track condition. KBSZ analysis of the situation after the accident revealed: 1. Slight assymetric loading of the derailed wagon but not by itself sufficient to cause derailment. 2. Poor track condition comprising: a. excessive track widths of 1465 and 1466 were measured b. track twist of 1:62 measured on bogie wheel basis of 1,8 m which is far above the allowable 1:300 c. unsupported track sleepers over a distance of ~ 4 - 5m. 3. High air temperature of 35^{o}C was increasing the seriousness of above condition.. The main cause of the accident was **poor track condition with a track twist far above acceptable values.** The KBSZ accident report stated that the speed reduction was far from sufficient to avoid derailment but was only to reduce consequences.	TSB HU-715 http://www.kbsz.hu/dokumentumok/2008-408-5_zj.pdf
HU-12	04/02/2009	Line 1: Rajka station Locomotive: 240024-0	I 3e + I 3a	Train no 45213 consisted of 5 bogie wagons with a weight of 217 tonnes and a length of 74m, exclusive of locomotive. At Rajka station, the border station towards Slovakia, the last wagon of train no. 45213 derailed with 4 axles when approaching track X of the station at the time of 08:45 4th of February 2009. The weight of the car was 77.9 tonnes. The cause of the accident was **worn track with track width and track twist above allowable values**. The train speed at the accident location was 9 km/h. The derailed wagon and the track were slightly damaged. There was no injuries The KBSZ accident report stated that the speed reduction was far from sufficient to avoid derailment	TSB HU-717 http://www.kbsz.hu/dokumentumok/2009-052-5-%20ZJ.pdf

No.	Date:	Place:	Category:	Description	Reference:
				but was only to reduce consequences.	
HU-13	23/03/2009	Line 40: Pusztaszabolcs station Locomotive: V63-029	I 3a+ O 2bi	Freight train no 58141-2 originating in Vac consisted of 23 wagons with a total load of 1138 tonnes of cement clinker. The train weight was 1762 tonnes with a length of 311 m, all exclusive of the V63 locomotive. When departing from track VIII of Pusztaszabolcs station at 4:49 am the first wagon of train 58141-2 overturned. The speed was only about 5 km/h. Later wagons 3 & 4 also derailed at the same location, but stayed upright. Wagon no 12 also derailed when trying to move the non-derailed part of the train after the initial derailments. The wagons were loaded at the DDC cement works in Vac by a front loader from one of the wagon sides. This had caused a significant skew loading of the wagons. The total load was approximately 40 % higher on the right wheels than on the left wheels. This was significantly above the allowable skew loading of 1:1.25 but was not considered enough to cause derailment by itself. The train had travelled at least 75 km in this load condition without derailing. There was nothing wrong with the rolling stock itself. The derailment occurred in a right curve. Measurement of the track at the derailment location showed a track twist of 1:140 – 150 measured on the wheel basis of the bogie. Allowable value without requiring maintenance action was 1:300. **The combination of a significant skew loading of the wagons to the right, the right hand curve and the excessive track twist was the cause of the derailment.** The derailed wagon and the track were slightly damaged. Total cost: €120 000?	TSB HU-718 http://www.kbsz.hu/dokumentumok/2009-113-5_zarojel.pdf
HU-14	21/04/2009	Line 80: Vamosgyork station Locomotive: 91550450001-7	O 6	Train 53401 consisted of 2 locomotives (1 electric and 1 diesel locomotive) and 9 empty tank wagons. The gross weight inclusive of locomotives was 378 tonnes with a train length of 134 m. The first and second wagon of the train No. 53041 derailed as it was leaving the Vamosgyork station, because **a brake shoe was left under the first bogie of the first wagon**. The train dragged the brake shoe along until it jammed in a turnout of double switch type. This caused the wagons to derail as the wheel jumped the brake shoe. There was no injury. The 2 train drivers claim to have checked the train prior to departure, but the train dossier is not correct in relation to train composition, and there is no signatures and time for execution of brake test. The accident investigation report of Kbsz therefore indicates that a proper brake test and train visitation might not have been carried out. The report recommends MAV to improve its routines for written documentation of train visitation and brake test and final notification to train dispatcher/traffic controller that such routines have been carried out. The derailed wagon and the track were slightly damaged.	TSB HU-720 http://www.kbsz.hu/dokumentumok/2009-0157-5_zj.pdf

No.	Date:	Place:	Category:	Description	Reference:
HU-15	15/03/2010	Line 92: Miskolc Station	RS 1ai	At Miskolc-Rendező station on 15th of March, 2010 at 9:30 freight train Nr. 53410 derailed with 3 wagons when departing from Miskolc marshalling yard. The derailment was caused by damage of bearing no.6 of the wagon Nr. 33 51 795 2507-6 (Zas type) and the wagon derailed with 4 axles before points no. 520. **The axle journal ruptured and the axle box fell off**. The broken parts were found on the track. As a consequence of this derailment, the wagon in front of and the one behind wagon no.33 51 795 2507-6 also derailed. The derailed tank wagons were dangerous goods transporter wagons - RID 33/1294 - (toluene) but empty at the moment of the derailment). Points no. 520 and 521 sustained serious damages. Nobody was injured.	TSB HU-878
Romania: Source: ERADIS & AFER (Ministry of Transport and Infrastructure Romanian Railway Investigation Report					
RO-1	22.02.2007 04:10	Dej Triaj station	I 2e	The freight train no 42612 formed of 32 Ukrainian loaded tank wagons transposed from Ukrainian gauge (1524 mm) into normal gauge (1435 mm) was on the route from Halmeu to Dej Triaj. Before the arrival on line no 4A, in Dej Triaj station the train passed over the switch no 47 A where 8 wagons derailed, beginning with the 6th wagon after locomotive (wagon no 57653776, 57586463, 57653461, 57653230, 51226074, 57655482, 57653420 and 57585952). The accident started with the derailment of the first axle of the 6th wagon no. 57653776 caused by unloading of the left hand wheel due to failure in the support of the track. The ballast supporting the turnout has subsided into the ground without any attempt to re-ballast the track or improve the entire track foundation at the location. Many of **the sleepers of the track in the turnout were unsupported**, neither were their structural condition good. The cause of the derailment is considered to be **neglect of track maintenance in general**.	ERADIS RO-70
RO-2	22.02.2007 18.30	Cricov station	RS 1bii	The freight train of empty stock no. 60373 formed of 27 open wagons was travelling from Ploiesti Triaj to Catusa. Twenty kilometres north of Ploiesti Triaj, in Cricov intermediate station, the train dispatcher at the station observed that the last but one wagon, no. 88536657717-3, was derailed. The train dispatcher announced the train driver through radio contact to stop the train. At the same time the engine driver heard the radio message he noticed the loss of air pressure in the train mainline. The train was stopped on the line Cricov - Inotesti, at km 77+100 on section 034. As the train passed over the switches the last wagon no 88536656880-0 also derailed. **The wheel tyre of the 2nd axle of the last but one wagon was found peeled away from the wheel rim.** The loosening of the wheel tyre no. 5 of the wagon no. 88536657717-3 having as result its rotation on the wheel rim and the grinding of the rails. In the technical inspections it was noted that the wheels did not comply with the regulations in force with regard to markings so that any relative displacement between wheel tyre and wheel rim could be detected. Further, the wagon was not removed from service as the Ploiesti works was not equipped as	ERADIS RO-69

No.	Date:	Place:	Category:	Description	Reference:
				appropriate.	
RO-3	15.12.2007	Km 538,16 between Milova and Conop	RS 1bii	The freight train no. 50366, formed of 25 empty wagons, 365 m length, was on the route from Episcopia Bihor (west of the Romanian railway network, cross border with Hungarian railway network) to Plopsoru (center of the Romanian railway network). On the main line Arad-Simeria, between Milova and Conop stations, the 9th empty freight wagon derailed with the second axle of the second bogie. The engine driver of train no. 50369 meeting the accident train on the neighbouring track observed that one of the wagons of the train no. 50366 was derailed (one axle). He announced by radio station the engine driver of the train no. 50366 who stopped his train. The 9th wagon was found with the wheel tyre displaced from the wheel rim. **The change of the pair of wheels gauge, following the displacement of the tyre of the wheel** no. 2 belonging to the wagon no. 8853 6656 718-2,led to the respective axle derailment between the railway stations Milova and Conop, at the km 586+310 The loosening of the tire of the wheel no. 2 at the wagon no. 8853 6656 718-2 (the 9th wagon after the locomotive) led to its turning round the wheel rim and to the grinding of the fastening ring	ERADIS RO 413
RO-4	13.03.2008	Zavideni station	RS 1ai	The freight train no. 41651, formed of 25 wagons, was on route from Piatra Olt Station to Babeni Station. The service official from Zavideni Station observed sparks at the 6-th wagon and informed the driver to stop the train. The driver stopped the train and found that the **axle journal of the 6-th wagon was broken** and the axle box was hot and damaged. The wagon was loaded with iron oxide. The rupture of the axle journal was due to fatigue. The cause of the fatigue was partly blamed by wrong metallurgical composition of the material used for fabrication of the axle. In the investigation report it was mentioned that 5 identical axle journal breaks had occurred in Romania for the same reason in the period 2004 – 2005.	ERADIS RO 438
RO-5	28.05.2010	Halmeu station	RS 2c + I 3e	Block freight train no 70728 loaded with coal operated by SC Group Ferroviar Roman Sa was running from Halmeu towards Minita. The origin of the train was the Ukranian station of Eseni. The train had changed bogies due to the difference in track gauges at the Ukranian border station Diacovo. The train consisted of 28 wagons (112 axles) of which 26 loaded with coal. The total train weight was 2149 tonnes exclusive of locomotive with a length of 455 m. The train had central couplers. As train 70728 departed track 5 at Halmeu station it derailed with the first bogie of the 5th wagon (no 67573287) in switch no 23 at the time of 17.15 with a speed of 12 km/h. The first axle of the wagon was the first to derail. The main line of the train was broken and the brakes applied automatically and the train stopped within a short distance. The derailment was caused by climbing of the left wheel of the first axle of the said wagon when passing the trailing point that was correctly set for the deviated track position. The switch had a tangent deviation of 1:9 with a curve radius of 300 m for the deviated track. The switch track was without any design cant.	ERADIS RO-920 & AFER Romanian Investigation Body

No.	Date:	Place:	Category:	Description	Reference:
				Investigations after the accident found that the loading of the wagon and the train speed was within allowable limits. Further, the nominal track width was exceeded by 40 mm at the point of derailment. The breadth of the wheel tread and the distance between the wheels on the initially derailed axle was slightly below allowable minimum. There was also a slight cant and twist of the track leading up to the derailment point. The above factors could have been contributory causes to the derailment. The main cause of the derailment was thought to be an ungreased centre pivot of the derailed bogie of the wagon. The centre plate was completely dry and rust had developed on the casting surfaces. **The ungreased centre pivot caused a significant increased guiding force of the left wheel to steer the wagon through the curve. The guiding force exceeded the stability limit of the wheel which climbed the rail.** No human injury occurred and the material damage was small. The total accident cost was estimated to 2200 lei. The investigation also revealed that the agreement between the Ukrainian Railway Transport (UZ) and the Romanian operator did not stipulate the need for lubrication of the centre plate of the bogies during the shift of bogies, nor who should be responsible for this action. This was considered the root cause.	
RO-6	18.07.2010	Aiud station	RS 1bii	The freight train in question, no 60133-2 at the accident location, was operating from Zalau Nord in the northwest of Romania to Constanta Port at the Black Sea. The train was operated by SC Group Transport Ferroviar SA. The train comprised 33 bogie wagons of which 30 were loaded with pipes with a total of 132 axles. The train was hauled by the locomotive EA 444 assisted by the banking locomotive DA 581. The train weight exclusive of locomotives was 2073 tons and the length 510 m. Due to the weight, the train had been split and reassembled during the journey. At the time 08.30 July 18th 2010 in switch no 6 when entering Aiud station the 19th wagon of the train, wagon no 8435451255-8, derailed with the last bogie in the travelling direction. The train speed at derailment was 15 – 20 km/h due to a speed reduction in the track. The train brake main pipe was broken due to the derailment and the train brakes applied automatically. The train came to a stop 61 m after the derailment. No human injury occurred and the total accident cost was estimated to 71926 lei. The direct cause of the derailment was the **displacement of the tire on the wheel rim of wheel no 6** leading to the derailment of axle 3 in the travelling direction of the above mentioned wagon. The loosening of the tire was most likely due to uncontrolled brake action while running on the accident wagon as brake blocks on most of the wheels were missing. Further the wheel profile was severly worn in the middle close to developing a false flange. The wheel set was 43 years old.	ERADIS RO-AFER Railway Investigating body
Czech republic: Source: Drazni inspekce (The Rail Safety Inspection Office)					
CZ-1	22.02.2008	Km 45,892 between Zabreh na Morave and	RS + I 2e + i 3a	Freight train Nex 1.nsl 47315 consisted of a locomotive type HDV and 30 wagons (102 axles) including several empty wagons for auto transport type Laaers. The train weight was 1002 tonnes with a train length of 628 m. Empty auto transport wagon Laaers 23 87 436 3634-9, running as wagon no 20 of the train, derailed on open line between the stations Zabreh na Morave and Lukavice na Morave at the	C.j: 6-525/ 2008/DI

No.	Date:	Place:	Category:	Description	Reference:
		Lukavice na Morave stations		time 11.40. The derailment was not immediately noticed, and the train continued until Lukavice station where the wagon no 21 (Laaers 43 87 427 2699-7) also derailed in switch no 10. The train pressure main line was broken and the train came to a stop. Both the derailed wagons were empty auto transport wagons. Laaers 23 87 436 3634-9, the initial derailed wagon consist of 2 short coupled 2 axle wagon elements with a long wheel base and long overhangs with an overall wagon length of 31 m. The tare weight of the wagon assembly is 38.8 tonnes. Laaers 43 87 427 2699-7 is an articulated 3 axle wagon with a wheel base in excess of 10 m and an overall wagon length of 26.5 m. The tare weight of the wagon is 27 tonnes. From pictures in the Czech investigation report it was obvious that the track superstructure was unsupported by the substructure on at least one rail for approximately 8 sleepers. A track twist is likely to have occurred. Further, the accident investigation found faults of the wagon Laaers 23 87 436 3643-9 which claimed to be causing vibrations. This was considered the main derailment cause. Accident cost was estimated to CZK 9 449 727 exclusive of wagon damage. During the run from the derailment location to the station Lukavice, the derailed wagon threw ballast at fast train no EC 108.	
CZ-2	24.04.2009	Cercany station	O 2bi	Block freight train no. 1 nsl 69911 consisted of a locomotive type HDV and 24 loaded 4 axle bogie wagons of type Ua and Uas. From pictures in the investigation report in the Czech language it seems that the load of the train consists of some form of bulk minerals. The wagons have a very elevated load compartment, maybe because the wagons are equipped for side tipping. The train weight, exclusive of locomotive, was 1920 tonnes, and the length 355 m. At the time 04.10 while entering track 2a at Cercany station the train derailed with wagons 19 – 22. The direct cause of the accident was stated to be an **improperly loaded and unbalanced wagon** in combination with insufficient routines by the train operator to detect, identify and rectify such situations. No human deaths or injuries occurred. The total cost of the accident was estimated to € 58 000,-	C.j: 6-1342/ 2009/DI
CZ-3	21.01.2010	Přerov - Prosenice	RS 2c	Freight train Nex 46723 operates between Villa S.Lucia-Aquin Piedmonte, Italy) and Tychy FIAT (Polen) comprised 19 mainly empty car carrier wagons belonging to SITFA (Societa Italiana Transporti Ferroviari Autoveicoli SpA). The train weight was 616 tonnes and the length 548 m. The 13th wagon of the train derailed at 23.55 at the Bohumin – Přerov line between the stations Přerov and Prosenice. The derailed wagon 43 83 4254 362-8 was of type Laekks with 3 axles and had an overall length of 26,24 m with a centre articulation. The total cost of the accident was estimated to €165 611. The cause of the derailment seems to be a skewed wagon support on the intally derailed axle of the wagon no 13 of the train.	Č.j.:6-289/ 2010/DI
Slovak republic: Source:					

No.	Date:	Place:	Category:	Description	Reference:
SK-1	07.10.2003	Ruskov km 76,288 – 77,415	RS 2a	A freight train weighing 2000 tonne with a length of 320 m derailed at the time 09.45 with 2 wagons near Ruskov between km 76,288 and 77,415. The cause of the derailment was that one of the bogies had limited rotation possibilities, either due to high friction or mechanical obstructions. The main pressure brake line of the train was not broken and the train continued for 4 min before it was stopped. No human fatalities or injuries occurred. The line was closed for 9 hours and the total cost of the derailment was € 9400,-. The train carried dangerous goods in the form of chlorine, but no leakage occurred.	ERA
SK-2	13.04.2004	Velke Kostol'any – Piest'any	RS 1ai	A freight train weighing 1200 tonne with a length of 320 m derailed at the time 12.06 at km 74,964 on the line Velke Kostol'any – Piest'any due to a damaged axle bearing resulting in a broken axle journal and a lost axle box. The snap ring came loose and the axle box housing got lost. The main pressure line of the train was not broken and the train continued for 10 min before it was stopped. No human fatalities or injuries occurred. The line was closed for 12 hours and the total cost of the derailment was € 28000,-. No dangerous goods were involved.	ERA
SK-3	27.12.2005	Bratislava Vychod station	I 2c	A freight train weighing 1500 tonne with a length of 420 m derailed at the time 13.50 at the Bratislava East station due to a broken point switch rail. The switch rail was broken at multiple places. The main pressure line of the train was broken and the train came to a standstill. No human fatalities or injuries occurred. The line was closed for 21 hours and the total cost of the derailment was € 85000,-. No dangerous goods were involved.	ERA
SK-4	30.032006	Trnava – Kuty km 39,362	I 1c + E	A freight train weighing 200 tonne with a length of 120 m derailed at the time 03.20 at km 39,262 on the line Trnava – Kutny due a destruction of the railway superstructure due to flooding. The river Myjava had swollen due to a broken dam. Ballast of the railway superstructure had been swept away and the geometry location of the track had failed. The driver applied brakes as soon he was aware of the situation but it was not possible to stop the train prior to the damaged track where the train derailed. No human fatalities or injuries occurred. The line was closed for 54 hours and the total cost of the event was € 57 000,-. Most of the damage was caused by the flood. No dangerous goods were involved.	ERA
SK-5	15.09.2006	Zvolen - Plesivec	RS 3	A freight train weighing 640 tonnes with a length of 210 m derailed at Hajnacka at the turnout for Urbanka on the line Zvolen – Plesivec at the time 0.35 due to a break of the beam side sill of a freight wagon loaded with coiled steel sheets. The train main brake pressure line was broken and the train was stopped. No fatalities and human injuries occurred. No dangerous goods were involved. The line was closed for 1 hours and the total estimated cost for the accident was € 102 000,-.	ERA
SK-6	27.07.2007	Zohor – Plavecky Mikulas	I 3d + RS 1biii	A freight train weighing 1068 tonnes with a length of 388 m derailed on the line Zohor - Plavecky Mikulas at km 6.71 at the time 11.50 due to a track buckle (probably sun curve). At the same time there was a failure of a wheel set with different diameter wheels. The train main pressure brake line was broken and the train came to a standstill. No fatalities and human injuries occurred. No dangerous goods were involved. The line was closed for 7 days and 7 hours. The total estimated cost for the accident was € 213 000,-.	ERA
SK-7	06.09.2007	Lucenec – Zvolen	RS 2b	A freight train weighing 700 tonnes with a length of 280 m derailed on the line Lucenec – Zvolen km 176.51 – km 189.712 at the time 0.28 due to a break of a suspension leaf in a blade spring of 2 axle	ERA

No.	Date:	Place:	Category:	Description	Reference:
				wagon. The train main pressure brake line was not broken and the train continued for 5 min before it was stopped. No fatalities and human injuries occurred. No dangerous goods were involved. The line was closed for 54 hours and the total estimated cost for the accident was € 81 000,-.	
SK-8	04.12.2007	Ziar nad Hronom	O 6	A freight train derailed in turnout 18 while leaving the station Ziar nad Hronom on the line Nove Zamsky – Zvolen at the time 17.55 due to a braking shoe left under the train. The braking shoe was dragged along until it was stopped at turnout no 18 where the train derailed. The train main pressure brake line was broken and the train was stopped. No fatalities and human injuries occurred. No dangerous goods were involved. The line was closed for 5 hours and the total estimated cost for the accident was € 41 000,-.	ERA
Poland: Source: State Commission on Rail Accident Investigation					
PL-1	10.08.2007	Line no 274 Walbryzch Fabrycny – Walbryzch Glowny	I 3e	A freight train weighing 1898 tonnes with a length of 339 m derailed with 5 wagons at km 76.688 at the time 18.30 due to an excessive track width (+60 mm wider at derailment location). The main pressure pipe of the train was not broken but the driver noticed the derailment and stopped the train. No human fatalities or injuries occurred and dangerous goods were not involved. The traffic was disrupted for 24 hours and the infrastructure damage cost was estimated to € 29 000.	ERA
PL-2	23.10.2007	Line 7 Lublin station	I 3e	A freight train weighing 1690 tonnes with a length of 309 m derailed at the time 03.35 with the 3 last wagons in a turnout due to an excessive track width (+60 mm wider at derailment location). The main pressure pipe of the train was not broken but the driver noticed the derailment and stopped the train. No human fatalities or injuries occurred and dangerous goods were not involved. The traffic passed the accident location was disrupted for 13 hours and the total damage cost was estimated to € 40 000.	ERA
PL-3	17.11.2007	Kalisz station	RS 2b	A freight train weighing 769 tonnes with a length of 392 m derailed with 3 wagons at km 76.688 at the time 16.15 due to a broken spring of the wagon bogie and general substandard condition of the freight wagon. The main pressure pipe of the train was broken and the train came to a standstill. No human fatalities or injuries occurred and dangerous goods were not involved. The traffic passed the accident location was disrupted for 24 hours and the total damage cost was estimated to € 15 000.	ERA
PL-4	25.11.2007	Line 91 Zurawica station	RS 1bii	A freight train loaded with coal consisting of locomotive and 37 bogie wagons with a total weight of 2266 tonnes and a length of 520 m derailed with 3 wagons at Zurawica station at the time 15.49 due to a broken wheel tire of one of the cars. The main pressure pipe of the train was not broken but the derailment was observed by a person on the station. The driver was noticed and the train stopped. No human fatalities or injuries occurred and dangerous goods were not involved. The traffic passed the accident location was disrupted for 22 hours and the total damage cost was estimated to € 26 600.	ERA
PL-5	16.06.2008	Km 57,578 Radziwillow - Miedniewice	RS 1ai	Line no 1 double-track km. 57,578 section Radziwiłłów - Miedniewice track no. 1 The freight train No TP14261 operated by PKP Cargo comprising ET22 type locomotive and 32 loaded coal wagons was on route Tarnowskie Góry - Warszawa Praga. The length of the train was 470 m and the gross mass was 1629 tonnes. Said train had a derailment of 4 coal wagons type Eaos. The owner of the wagons was PKP Cargo. **The basic cause of the accident was a broken axle journal that was wrenched off the car**. The axle box of the right wheel of the front axle came off and wagon no	ERADIS PL-576

No.	Date:	Place:	Category:	Description	Reference:
				8251535358523-7 was derailed. Derailment of the above mentioned wagon caused derailment of 3 other coal wagons. The speed of the train was 75 km/h while the maximum permitted on the line for the train was 80 km/h. 400 m after the derailment the train stopped due to a broken main line of the train The gauge of the track No 2 was blocked as a result of the accident. Total cost of the accident is estimated to 1.59 m. PLN (approx. 353 k. Euro) comprising RS-damage - Wagons - Wheel/axle/bogies - Equipment failure. Underlying causes was claimed to be Insufficient planning and organisation of maintenance, corrosion of fatigue-friction as the result of variable tensions during the work of the wheel set, and the structural inhomogenity of the material of the axle.	
PL-6	10.09.2008	Line no 65 (1520 mm gauge)	O 1a + RS 1 biii	A freight train weighing 1662 tonnes with a length of 680 m derailed with wagon no 23 of 51 at the time 21.05 due to unfortunate train composition (empties before loaded) and worn wheel and track. The driver noticed the derailment and stopped the train. No human fatalities or injuries occurred. The train contained dangerous but no leakage occurred. The traffic was disrupted for 5 hours and the damage cost was relatively low involving 40 broken sleepers.	ERA
Estonia: Source: Ministry of Economic AffaiRS and Communications; Emergency Management Department					
EE-1	04.12.2008	Rakvere - Kunda	I 1a	6 wagons of the train derailed. The rail was broken and sleepers fractured in the accident. The six derailed wagons were damaged in terms of wheel-sets, brakes and mechanical coupling systems. The railway infrastructure damages amounted to 138 metres. The road bed was sinking under the railway superstructure, induced by the excessive moisture in the swamp during autumn rain period, and the fact that the freight train ran on the insufficiently maintained embankment at the speed of 38 km/h instead of the allowed limit of 25 km/h. No injuries or loss of life and neither any environmental damage. 1. **The direct cause of the accident was subsidence of the road bed under the railway superstructure,** induced by the excessive moisture in the swamp during autumn rain period combined with excessive speed of the freight train of 38 km/per hour instead of the allowed limit of 25 km/h. The vibrations generated by the train passage on the insufficiently maintained embankment caused the soil under the rail track to slide and move. 2. The factor instrumental to derailing of wagons was the rail break and fracture of sleepers of the track under the train, caused by the joint impact of the train weight and the landslide. 3. The six derailed wagons suffered damage to wheel sets, brakes and mechanical couplings. 4. The railway infrastructure was totally damaged for 138 meters, and it was necessary to dismantle broken rails and replace sleepers on the railway for a length of 1 km. 5. 340 tonnes of cargo from the 5 wagons was discharged during restoration work 6. The line was closed for more than 4 days.	Rauteeliiklu-sõnnetuse Uurimaisar-uanne

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Det Norske Veritas

Assessment of freight train derailment risk reduction measures:

B3 – Top ten ranking of safety measures

Report for European Railway Agency
Report No: BA000777/08
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21 September 2011

MANAGING RISK

Assessment of derailment risk reduction measures:
B3 –Top ten ranking of Safety Measures Rev 3
for

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0.0 Executive Summary

0.1 Introduction

In 2009 the European Railway Agency (the Agency) issued a recommendation (ERA/REC/01-2009/SAF) on a specific proposal, made by the RID Committee of Experts, for a new harmonised rule aimed at reducing the consequences of freight train derailments, potentially involving dangerous goods (DGs). The recommendation concerned the potential use of a Derailment Detection Devices (DDD[1]). This device automatically applies the brakes on a freight train when a derailment of a wagon equipped with that device is suspected.

Although the Agency's recommendation was that the DDD should not be adopted in the RID it was agreed that alternative prevention based measures should be further explored before deciding on imposing, by law, measures based on derailment detection.

Therefore recognising that freight train derailments remain a safety and operational concern, and following a request made by the European Commission, the Agency has commissioned further work with the objective of which is to carry out an exhaustive analysis of all prevention and mitigation measures which could reduce the risks related to freight train derailments.

Det Norske Veritas (DNV) was selected by the Agency to contribute to this work, the results of which are presented in this and related documents.

0.2 Project Scope and Objectives

The study is divided into two distinct research stages: Parts A and B.

Part A has the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be voluntarily applied or to be introduced in EU regulation within 5 to 10 years).

Part B has the objective of analysing the measures identified in Part A with a view to identifying those that are the most efficient. Part B is scoped to include all prevention measures but is limited to mitigation measures based on derailment detection.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries (Turkey, Macedonia and Croatia), Norway and Switzerland (hereafter called the target countries). In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term.

0.3 Methodology

0.3.1 Part A: Measure Identification

Part A work sought to identify the existing use of freight train derailment risk reduction measures (technical, procedural or organisational) through a range of activities. These included:

- Direct consultation with a large number of Infrastructure Managers, Railway Undertakings, Wagon Owners, supplier organisations, industry bodies and other actors.
- In-house knowledge, literature and internet research.

[1] DDD is an acronym used to refer to a type of detector which automatically activates train brakes when a derailment is detected based on detection of wagon acceleration. Device type EDT-101 is an example of such a device.

Activity in this work package also included the identification of the existing application scope of identified measures, and also the collection of market and performance data for these measures.

0.3.2 Part B: Measures Assessment

Part B considered the problem of freight train derailment and its causes, and then how the measures identified in Part A could be used to improve the situation. This room for potential improvement can be achieved either through the wider use of existing measures, or the application of new measures.

These objectives were achieved through a series of tasks that included the following:

- Comprehensive review of freight train derailment accidents to establish their causes and consequences.
- The development of risk models to quantify the causes and consequences of freight train derailment accidents.
- The development of cost-benefit models to enable economic indicators of each measure's efficiency to be established.
- The identification of other advantages or drawbacks for each measure thus allowing a final consideration of the most promising measures to be made.

0.4 Study Conclusions

0.4.1 Opening Remarks and Context

It is important to clarify that this report looks at the ***potential for improvement***, and is not an absolute assessment of the efficiency of all measures that are applied today. Therefore it follows that if a measure is applied extensively already there is little room for improvement through the further application of that measure. For this reason some measures that are extensively applied already are not considered in this work. Their omission should not be considered as suggesting such measures are not efficient.

In this context the measures listed in this section can be seen as efficient in addressing the potential reduction in risks associated with freight train derailments and providing the detailed background against which public policy can be formulated.

The assessment of measures does not consider the way or the order in which these interventions should be pursued, for example it is not considered whether these interventions should be introduced in a mandatory or voluntary way or whether the measure should be introduced as an EU harmonised measures or only within certain member states or only certain companies.

0.4.2 Efficiency Assessment of Measures

0.4.2.1 Technical Preventative Measures

We consider the following technical measures as being efficient (they have a positive or unity benefit / cost ratio in our reference case and all sensitivity studies):

- P13-Wheel Load Impact Detectors / Weighing In Motion (a measure that addresses a number of common freight train derailment causes such as wheel defects, loading anomalies).
- P28-Replacement of Brass for Polyamide Roller Cages (a measure that addresses hot axle box caused freight train derailments).

- P15-Bogie Hunting Detectors (a measure that addresses problems associated with lateral instability, caused by wheel or other defects).
- P11-Bearing Acoustic Monitoring (a measure that addresses hot axle box caused freight train derailments).

Considering measure P28, we have considered an immediate replacement of brass for polyamide roller cages. We have also discussed an alternative option which is for the replacement of brass for polyamide roller cages at the next scheduled maintenance interval for axles / axle boxes. This is almost a zero cost option, although the benefits would take longer to materialise, and be a function of the maintenance cycle for freight wagons.

Potential drawbacks to the use of these measures (excluding measure P28) relate to the rate of false alarms. To some extent these can be overcome by the use of good alarm management processes. Further false alarms from those technical measures that are based on early defect detection are unlikely to have an immediate operational impact.

In addition the following two measures are efficient based on the parameters in our reference case:

- F7-Sliding Wheel Detectors (a measure that addresses problems associated with handbrakes which may be left on, seized axles and similar events).
- P16-Wheel Profile Detectors (a measure that addresses problems associated with wheel defects).

Potential drawbacks include false alarms as reported above. Finally, measure F7 is to the best of our knowledge a market with only a small number of suppliers. This may give rise to market advantage to existing suppliers of these systems if they were to form the basis of formal recommendation.

0.4.3 Technical Mitigation Measures

We consider the following mitigation measure as potentially efficient if the significant identified drawbacks could be solved:

- M1a-Derailment Detection (with automatic brake application) applied to All Freight Trains

This present assessment is fully in line with the previous assessment made by the Agency [4]. The significant drawback previously identified is confirmed by the present study and the related accident analysis. A false alarm of such a device may lead to train compression which is a contributory cause of freight train derailments (and also a significant operational disruption). In this respect we note that CSM Regulation, Annex I, point 2.5.4 states:

For technical systems where a functional failure has credible direct potential for a catastrophic consequence, the associated risk does not have to be reduced further if the rate of that failure is less than or equal to 10^{-9} per operating hour.

(Measure P1: Check rail has similar disadvantages, although this is not considered efficient by our assessment.)

Finally, we acknowledge an alternative type of derailment detection device which provides an alarm to the train driver when a derailment is suspected, but without an automatic brake application (type M1b). We are however not aware of these being available on the market (for freight application). We consider that an assessment of these devices, considering the human factors issues involved and their costs would be required before these could be formally assessed.

0.4.4 Organisational Measures

We note that the measures above are technical measures that are aimed at addressing, in some cases, organisational problems. Therefore we would add the following organisational and supervision items:

- F-2: Awareness Programme for Rolling Stock Maintenance. This measure may serve to address the problem of poor maintenance standards of rolling stock. This may include training that sought to concentrate on main rolling stock maintenance derailment causes (which can be extracted from our task report, [3]) and best practice. This measure may be followed by increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.
- P-18: Track Geometry (all tracks). Although the case for improvements in this area are not conclusively made from a quantified perspective, the problem of poor track geometry (in particular track twist), and the possible requirement to improve this aspect just to maintain current performance levels (see Section 9.3.1) should be considered. This is of course an area for each IMs own management system. However a specific measure in this regard must be concerned with increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.

The two measures above represent significant contributors to the derailment problem and organisational failures of individual IMs and RUs in fulfilling their obligations.

Contents

1.0 Introduction

1.1 Background

In 2009 the European Railway Agency (the Agency) issued a recommendation (ERA/REC/01-2009/SAF) on a specific proposal, made by the RID Committee of Experts, for a new harmonised rule aimed at reducing the consequences of freight train derailments, potentially involving dangerous goods (DGs). The recommendation concerned the potential use of a Derailment Detection Devices (DDD[2]). This device automatically applies the brakes on a freight train when a derailment of a wagon equipped with that device is suspected.

Although the Agency's recommendation was that the DDD should not be adopted in the RID, the joint meeting of RISC and Inland TDG EU regulatory committees agreed that considering the low potential benefit in terms of avoided fatalities and injuries expected with DDD type devices, as well as some other problems related to the operation of trains equipped with these types of detectors, more efficient prevention measures should be further explored before deciding on imposing, by law, measures based on derailment detection.

Therefore recognising that freight train derailments remain a safety and operational concern, and following a request made by the above mentioned EU Committees, the Agency has commissioned further work the objective of which is to carry out an exhaustive analysis of all prevention and mitigation measures which could reduce the risks related to freight train derailments.

Det Norske Veritas (DNV) was selected to deliver this work, the results of which are presented in this and related documents.

1.2 Overall Project Scope and Objectives

The study is divided into two distinct research stages: Parts A and B.

Part A had the objective of identifying all prevention and mitigation measures that exist today or could be implemented within the short term (before 1st of January 2013) or medium term (ready to be applied or to be introduced in EU regulation within 5 to 10 years). This has been achieved through the following schedule of activities:

- Task A.1 - identification of existing operational and technical measures.
- Task A.2 - description of the markets and technologies covered by the devices/systems in use or which may be used at the short or medium term.
- Task A.3 - description of the rules (including specific devices/systems used) in generic functional and performance terms.
- Task A.4 - advice on innovative longer term measures (unlikely to be available within 10 years) which might be considered in a future R&D project.

Part B had the objective of analysing the measures identified in Part A (excluding those identified in Task A.4) with a view to identifying those that are the most efficient. Part B was scoped to include all prevention measures but limited to mitigation measures based on derailment detection.

[2] DDD is an acronym used to refer to a type of detector which automatically activates train brakes when a derailment is detected based on detection of wagon acceleration. Device type EDT-101 is an example of such a device.

Part B objectives have been achieved through the following schedule of activities:

- Task B.1 – construction of detailed fault and event trees[3] describing freight train derailments and showing which derailment cause or impact the identified safety functions act on.
- Task B.2 - semi-quantitative assessment of benefits and drawbacks of existing safety rules, and of new or improved measures at short and medium terms, using data on actual/targeted performance as well as conservative assumptions.
- Task B.3 - top ten ranking of potentially efficient new safety measures or improvements at short and medium terms, including practical and legal implementation aspects.

The geographical scope for this work is the EU-27 countries plus the 3 candidate countries, Norway and Switzerland (hereafter called the target countries). In addition, the USA and Japan are considered in the scope of safety measure identification, but limited to the most commonly used safety measures and to the foreseeable innovations at medium term. For Part B however, our measures are assessed on the basis of their potential implementation in the EU railway system only.

[3] The technical scope excludes intentional acts and derailments during civil works. Marshalling operation incidents are also excluded as the impacts arising from such events are normally more limited than from train operation. Collisions leading to derailment are also excluded from the study scope; however consequences of collisions that occur pursuant to a derailment are included.

2.0 Project Abbreviations and Definitions Used

Term	Description
(the) Agency	European Railway Agency
CSI	Common Safety Indicator
CSM	Common Safety Method
CST	Common Safety Target
DDD	Derailment Detection Device of a type similar to EDT 101
DG	Dangerous Goods
DNV	Det Norske Veritas
Effectiveness	The extent to which options (measures) achieve the objectives of the proposal
Efficiency	The extent to which objectives can be achieved for a given level of resources/at least cost (cost-effectiveness)
EVIC	European Visual Inspection Catalogue
HS	High speed (>40km/h)
IM	Infrastructure Manager
Immediately Severe	A derailment with a mechanical impact that may cause a leak or material from a Dangerous Goods wagon.
JSSG	Joint Sector Support Group
Long Term	Measures that are unlikely to able to be introduced before 10 years
LS	Low speed (40km/h or less)
Measure	A control that may be put in place to either reduce the likelihood or minimise the consequence of a freight train derailment
Medium Term	Measures that could be introduced within 5 to 10 years
NDT	Non Destructive Testing
NSA	National Safety Authority
RAM	Reliability, Availability and Maintainability
RID	Regulations Concerning the International Carriage of Dangerous Goods by Rail
RIV	Regolamento Internazionale Veicoli
RU	Railway Undertaking
Short Term	Measures that could be introduced before 1st of January 2013
SMS	Safety Management System
Target countries	EU-27 countries plus the 3 candidate countries (Turkey, Macedonia and Croatia), Norway and Switzerland
TDG	Transport of Dangerous Good Regulations
TSI	Technical Specification for Interoperability
UIC	International Union of Railways

3.0 Methodology and Preparatory Work

3.1 Summary

A fuller specification for task B.3, [1], is provided below:

> *"The task B.3 will propose a justified list of top ten potentially most efficient[4] new or improved measures on the basis of the task B.2 (efficiency assessment), the legal feasibility and the implementation costs. Both, possibilities for new or improved harmonized EU regulation, or improvements at National level (regulatory) or at Company level (voluntary) should be considered."*

The achievement of the objectives of this task represents the culmination of previous work completed in Parts A.1 to A.3 and Parts B.1 and B.2, together with some targeted and specific new work to enable the "top ten" measures to be identified.

We report on the former in Section 3.2, and the new work completed for this task in Section 3.3 and onwards within this document. We have summarised the linkages and task activities in the figure below.

3.2 Key Activities from Previous Project Tasks

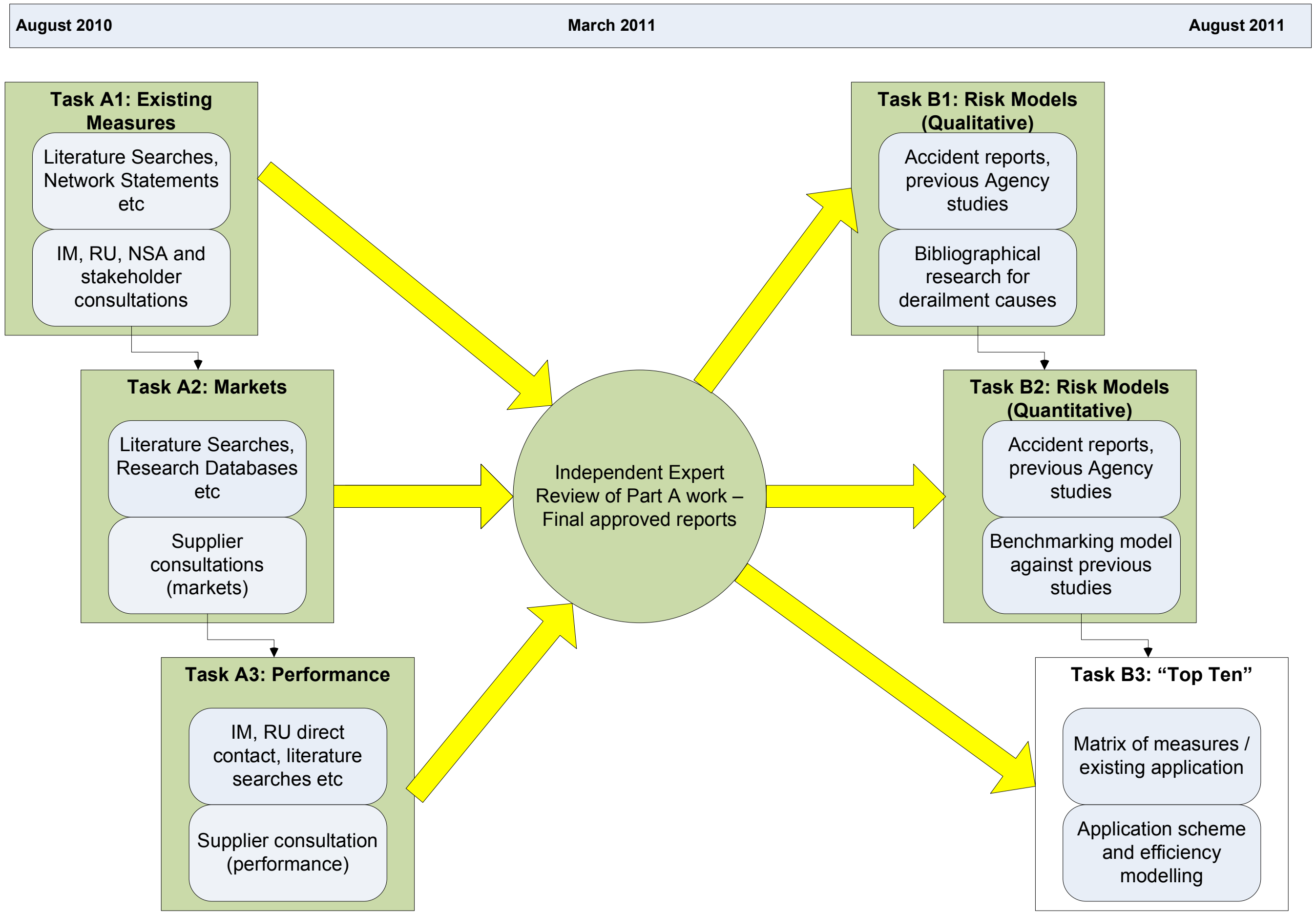
The following represents a brief summary of some of the completed key project activities:

1. For task A.1 an extensive series of consultations with Infrastructure Managers (IMs), Railway Undertakings (RUs) and other actors [2] was conducted with the objective of establishing the range of existing measures (and potentially new measures) used as controls against freight train derailments.
2. For tasks A.2 and A.3 an extensive series of consultations with suppliers was conducted regarding existing technical measures (and potentially new measures), market share, costs and benefits, [2].
3. For Task B.1 and B.2 a comprehensive accident analysis and research activity was completed to enable a risk model to be developed linking together freight train derailment causes, consequences and impacts [3].
4. A benchmarking activity was completed [3, Section 7] to compare the results of our analytical models with previous model outputs, to provide validity to our findings.

Work completed is shown shaded green in Figure 1 below. In Section 6.0 we take the opportunity to summarise the main components of these activities in relation to the cost model, although the reader is referred to the referenced documentation for more comprehensive discussion of these tasks:

[4] Efficiency refers to the consideration of costs and benefits

Figure 1 Task Linkages[5]



[5] IM = Infrastructure Manager; RU = Railway Undertaking; NSA = National Safety Authority

3.3 Task B.3 Research

Specific activities for this final project task has included:

1. An activity to sort our measures into assessment categories; namely those that can be assessed quantitatively (through the use of cost / benefit modelling techniques), those that can be assessed on a qualitative basis and those that can be rejected without any form of further detailed analysis.
2. Research to provide a more complete understanding of the extent to which existing measures are used within the target countries and therefore a potential application scope for new measures, or for the increased coverage of existing measures.
3. Collection of remaining information to enable each measure's efficiency to be calculated.
4. Establishing the most efficient "top ten" with consideration to both quantitatively and qualitatively assessed measures.
5. The consideration of other factors that may influence the selection of these measures, including[6]:
    - Market considerations and whether the potential recommendation of a measure may give a supplier(s) a competitive advantage.
    - Potential drawbacks with the measure.
    - Any other issues identified during the analysis.

[6] Implementation costs are considered in the cost benefit analysis or in the qualitative assessment as documented for that measure.

4.0 Assessment Categorisation

The measures we have identified as part of our Part A activities are assessed as described in Table 1 (for preventative measures) and Table 2 (for mitigation measures). For these we have applied the following general scheme to determine our assessment methodology:

- Measures which have previously been ***discarded or are out of scope*** are referenced in the table below with a reference to that part of our analysis where this was agreed.
- For measures that are not discarded, we have considered how best to assess them.
  - We have used ***qualitative basis*** for assessment if the following applies:
    - They generally offer only small benefit in comparison with other measures, and / or;
    - They form part of a suite or measures that can be integrated together (for example a number of measures identified associated with rolling stock maintenance which can be integrated into a single measure), and / or;
    - There is insufficient data to enable a more detailed assessment and therefore there would be significant uncertainty in the results.
- Otherwise, measures are assessed on a ***quantified basis***.

Table 1 Assessment Method for Preventative Measures

Measure Number	Description	Time Category	Efficiency Assessment?
P-1	Check rail in sharp curves (radius less than 250 metres)	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 5.2.1
P-2	Track and flange lubrication (installed on track)	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 5.2.2
P-3 to P-5	Measure number no longer used.		These measures are related to collision events, where derailment is a secondary consequence. They have not been considered further
P-6	Geo radars	Medium	This measure was considered to have a commercial benefit rather than a direct derailment reduction benefit and has not been considered further. Ref [3].
P-7	Rolling stock mounted equipment for monitoring of rail profile conditions.	Medium	This measure was considered to have a commercial benefit rather than a direct derailment reduction benefit and has not been considered further. Ref [3].
P-8	Track circuit	Medium	This measure is primarily for train detection purposes and has not been considered further. Ref [3].
P-9	Interlocking of points operation while track is occupied.	Medium	This is a relatively low frequency / low severity contributor to freight train derailments. We have undertaken a qualitative assessment for this measure in Section 9.1.1
P-10 P-12	Hot axle box (hot bearing) detectors. Hot wheel and hot brake detectors.	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 5.2.3 These devices are assessed together as they are often part of the same detection system.
P-11	Acoustic bearing monitoring equipment	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 5.2.4
P-13	Wheel load and wheel impact load detectors	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 5.2.5

Measure Number	Description	Time Category	Efficiency Assessment?
P-14	Dragging object and derailment detectors	Medium	Dragging objects are a low contributor to freight train derailment. Derailment detectors are assessed at M1. Not considered further, Ref [3].
P-15	Bogie performance monitoring / Bogie lateral instability detection (bogie hunting)	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 5.2.6
P-16	Wheel profile measurement system / Wheel profile monitoring unit	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 5.2.7
P-17	Measure number no longer used.		These measures related to collision events, where derailment is a secondary consequence. They have not been considered further
P-18	Sufficient availability of maintenance resources (for Infrastructure maintenance)	Short	We have established parameters to enable a quantified assessment. This is reported in Section 5.4.2
P-19	Clearance of obstructions from flange groove (particularly at level crossings)	Short	We have established parameters to enable a quantified assessment. This is reported in Section 5.4.1
P-20	Ultrasonic rail inspection	Short	Rail brakes/ruptures are relatively low frequency contributors to freight train derailments. We have undertaken a qualitative assessment / discussion for this measure in Section 9.1.2
P-21	Track geometry measurement of all tracks	Short	Addressed with P-18 above.
P-22	EU-wide intervention/action limits for track twist	Medium	We have undertaken a qualitative assessment for these measures in Section 9.3.1
P-23	EU-wide intervention/action limits for track gauge variations	Medium	
P-24	EU-wide intervention/action limits for cant variations	Medium	
P-25	EU-wide intervention/action limits for height variations and cyclic tops	Medium	
P-26	Flange lubrication - locomotives	Medium	This measure is primarily for wear reduction purposes and has not been considered further. Ref [3].
P-27	Replace composite wheels with monoblock wheels	Medium	Insufficient data to enable the measure to be quantified. Ref [3].
P-28	Replace metal roller cages in axle bearings by polyamide roller cages.	Medium	We have established parameters to enable a quantified assessment. This is reported in Section 5.3.1
P-29	Replace existing axles for stronger axles or axles with improved material properties with regard to crack initiation and crack propagation	Medium	Currently the subject of an on-going work programme (EURAXLES). Not assessed by this project. Ref [3].

Measure Number	Description	Time Category	Efficiency Assessment?
P-30	Increase the use of central couplers between wagons in fixed whole train operation	Long	Probably limited to bulk material block train on set routes. Cost of this measure significant compared to benefit. Not assessed by this project. Ref [3].
P-31	Increase the use of bogie wagons instead of multiple single axle wagons with a long wheel basis.	Medium	Potential benefit considered relatively small compared to the cost of implementation. Significant commercial issues. Not assessed by this project. Ref [3].
P-32	Install disc brakes instead of wheel tread brakes for new wagons.	Medium	The primary objective for this measure is likely to be in relation to the Noise TSI. Whilst it may have secondary benefits in terms of reduced heat activation of wheels, potentially reducing wheel failure rates, it is not considered there is a strong enough correlation between this measure and a reduced derailment rate to justify its consideration as a freight train derailment measure. Also, other measures are in place, or could be put in place, which would be more effective against this potential derailment hazard.
P-33	Rolling stock design for track twists (for new wagons)	Long	The time for this measure to be implemented is governed by the renewal rate of wagons. Not likely to be possible before the long term, and hence not considered by this project. Ref [3].
P-34	Secure underframe brake gear from falling down	Medium	Brake gear or other wagon underframe gear that can fall down and cause derailment is in many countries prevented by the use of safety slings. Although a wider application of this measure may have potential benefit, we note that this a relatively low frequency contributor to freight train derailments. We have undertaken a qualitative assessment for this measure in Section 9.1.3
P-35	Regular greasing and checks of rolling stock buffers.	Short	This is assessed on a qualitative basis in conjunction with measure F-2 in Section 9.3.2
P-36	Wheel set integrity inspection (ultrasonic) programs.	Short	This is assessed on a qualitative basis in conjunction with measure F-2 in Section 9.3.2
P-37	Derating of allowable axle loads	Short	Currently the subject of an on-going work programme of the Joint Sector Service group. Not assessed by this project. Ref [3].
P-38	EVIC (European Visual Inspection Catalogue)-based inspection of freight train rolling stock axles	Short	Currently the subject of an on-going work programme through EVIC. Not assessed by this project. Ref [3].
P-39	Double check and signing of safety-classified maintenance operations	Short	This is assessed on a qualitative basis in conjunction with measure F-2 in Section 9.3.2
P-40	Qualified and registered person responsible for loading	Medium	This is assessed on a qualitative basis in conjunction with measure F-2 in Section 9.2.1
P-41	Locomotive and first wagons of long freight trains in brake position G	Short	This is assessed on a qualitative basis in Section 9.2.2
P-42	Limitations on use of brake action in difficult track geometry	Short	This is assessed on a qualitative basis in Section 9.2.2
P-43	Dynamic brake test on the route	Medium	This is assessed on a qualitative basis in Section 9.2.3.
P-44	Saw tooth braking to limit heat exposure to wheels	Short	This measure is assumed to be applied where it is required and is not assessed by this project. Ref [3].

Measure Number	Description	Time Category	Efficiency Assessment?
P-45	Initiation of braking or speed reduction prior to passing signal showing reduced speed	Short	We consider this to be part of existing driver practice and therefore implemented where required and is not assessed by this project. Ref [3].
P-46	Not allowing traffic controllers and drivers to override detector alarms	Short	This is assessed on a qualitative basis in Section 9.2.4.
P-47	Wagons equipped with a balance to detect overload in visual inspection.	Medium	This is assessed on a qualitative basis in Section 9.2.5.
F-1	End of train device (brakes)	Medium	Not considered to have substantial benefit for existing freight train lengths. Not assessed by this project. Ref [3].
F-2	Awareness program and improved maintenance for Rolling Stock	Short	This is assessed on a qualitative basis in Section 9.3.2
F-3	Heat sensitive material to reveal hot axle box conditions	Short	Not considered further, [3]. However we note that this measure could have a role to play to aid in separating false alarms from genuine alarms.
F-4	Machine Vision Devices	Medium	We do not believe we can make an assessment of systems of this type when solely deployed as a freight train derailment prevention system. Systems of this type are built around a core module with options that may include: • 3D Profiling (for out-of-gauge loads) • Fire detection functions • Pantograph defects detection • Wheel load measurement • Thermographic mapping In the context of a holistic accident prevention system, this technology may prove cost-effective. However, the functionality in relation to derailment prevention (wheel load, hot axle box detection etc) is already addressed. Systems of this type may detect potential derailment causes that are not covered by the systems studied to date – such as open hatches or covers that may become detached and pose a derailment risk – however it is inconceivable that a network of machine vision devices consisting of a core module and profile measurement module would be deployed for this purpose. We have not considered this further.
F-5	Telematics	Medium	This measure does not have a direct impact on derailment rate. Not assessed by this project. Ref [3].
F-6	Anti-lock devices	Medium	Quantified assessment
F-7	Sliding wheel detectors.	Medium	Quantified assessment
F-8	Handbrake interlock.	Medium	We consider this to be similar F-6 and F-7. This measure is not assessed.

Table 2 Assessment Method for Mitigation Measures

Measure Number	Description	Time Category	Efficiency Assessment Method
M-1a		Medium	Quantified assessment
M-1b		Medium	Quantified assessment
M-2	Equip tank wagons with impact shielding to protect against penetration		No. This is outside the scope of work covered by this project.
M-3	Install emergency warning lights on locomotive to warn train on neighbouring track going in opposite direction of derailment		No. This is outside the scope of work covered by this project.
M-4	Attach mechanical guides to the bogie structure or on wagon at an appropriate position so that is more likely that the derailed wagon is kept on the track and does not overturn.		No. This is outside the scope of work covered by this project.
M-5	Install safety rails (guard rails) at bridges and in tunnels		No. This is outside the scope of work covered by this project.
M-6	Install battering rams in front of safety critical pillar supports of roof structures and overbridges in order to prevent derailed rolling stock damaging such safety critical structures		No. This is outside the scope of work covered by this project.
M-7	Installation of dragging object and derailment detectors		No. This is outside the scope of work covered by this project.
M-8	Installation of deviation points leading to a safe derailment place in strongly descending tracks from marshalling yards and train formation stations		No. This is outside the scope of work covered by this project.
M-9	Radio or cell phone communication installations like GSM-R in order to transfer emergency stop orders to trains		No. This is outside the scope of work covered by this project.
M-10	Separate passenger and freight traffic to separate lines to a larger degree (which is also EU-policy)		No. This is outside the scope of work covered by this project.
M-11	Restrictions on freight traffic in general or hazardous materials transport in special through certain busy passenger terminals and/or underground stations to restrict traffic and limit the consequences of a derailment.		No. This is outside the scope of work covered by this project.
M-12	Develop and apply a checklist for dangerous goods transport as the Swiss checklist for dangerous goods transport by freight trains		No. This is outside the scope of work covered by this project.
F-9	Harmless infrastructure		No. This is outside the scope of work covered by this project.

5.0 Quantified Assessment Parameters and the Cost Model

5.1 General Assumptions and Clarifications

The following assumptions apply to the measures discussed below:

1. Some technical measures discussed in this section may benefit from trending. This trending can increase the effectiveness of such measures. These types of measures work on single inspection / pass-by, but their effectiveness is generally lower in this set-up. The trending function requires each wagon to be fitted with some form of telematics or wagon "tagging". The costs of such technology are not included in the assessment of derailment prevention measures.
2. The application scopes we discuss below are indicative based on suppliers' recommendations and other information. In practice, each IM or RU would need to consider an application scope that best achieved the objectives.
3. We note that some countries have invested heavily in some of the measures, whilst others may have chosen different options. We have not considered a per-country application scope taking this into account. Our analysis is therefore to be taken as a European average picture.
4. We consider each measure in isolation on its individual merits in terms of preventing or mitigating freight train derailments. Combinational measures are not considered. We have provided some commentary on combinational issues at Section 10.2.
5. Non-safety benefits (such as reduced maintenance costs, increased asset lifetime) are not considered.
6. Track length in the EU-27 is approximately 340,000 km (extracted from Eurostat, "Railway transport – Length of Tracks" and from DNV consultation), 85% of which is open for freight traffic (estimated from DNV consultation). Freight traffic therefore operates on approximately 289,000 km of track.
7. We have assumed an additional 10% for side-tracks in stations and yards, hence 34,000 km (all of which we assume can be operated by freight traffic).
8. We are aware that recent developments directed towards specific derailment causes (such as hot axle box derailments) will reduce the future benefit available, compared with the historical average. We discuss this in the relevant sections below.

5.2 Infrastructure Measures

5.2.1 Measure P-1: Check Rails

5.2.1.1 Measure Objective

Check rails are installed to guide the wheels in rigid crossings and point crossings. Check rails may also be installed in sharp curves to prevent derailments as it will hinder flange climbing on the outer rail in sharp curves. In some countries check rails may also be used to give additional safety against derailment when the track is passing safety critical installations such as overhead bridge supports. It is the application in sharp curves we consider here.

5.2.1.2 Measure Installation Scope

For this measure to be effective check rails would be installed in curves of radius less than 250 metres on all routes where freight may be carried (where not currently fitted). Information regarding the quantity of such locations within the European rail community is not available to the project team, and would require each IM to survey their network to determine suitable locations. In the absence of this information we have made the following assumptions:

- Applicable total track length for this measure is assumed to be (289,000 + 34,000) = 323,000 km.
- Our knowledge of track layout in Norway (as a reference example) indicates that in the region of 1% to 2% of the network open for freight traffic is made up of curves of this type. However, Norway has a “curvy” network and the average in the EU-27 is likely to be less than this. Further, some curves are fitted with check-rails, although not a significant number. Taking these factors into consideration we have chosen a reference value of 0.5% for track length satisfying our criteria. Applying these factors, we use a value of 323,000 km * 0.5% = 1,615 km.
- A more limited application scope may be possible. This may be for high usage freight routes on curvy lines or other “at-risk” sections, where alternative approaches (such as track lubrication or cant adjustment) are not feasible. However, detail on the extent of the EU-27 network that satisfies this requirement is not known and therefore not assessed.

5.2.1.3 Measure Effectiveness

In terms of a maximum potential benefit we reported 25 avoided derailments [3] to be possible and achievable with a comprehensive application scope (similar to that described above), if the measure could be 100% effective.

In [2] we assigned this measure an effectiveness of 90% which we would consider to be an appropriate reference value.

5.2.2 Measure P-2: Track Lubrication

5.2.2.1 Measure Objective

Lubrication of the flange and track contact point is an important measure in reducing the friction between rail and wheel flange and hence reduce the risk of derailment in difficult track geometries, i.e. in narrow curves or track sections with high cant and/or high twist. The reduced lateral track force in narrow curves should cause less wear, less noise and less risk of derailment.

5.2.2.2 Measure Installation Scope

In many countries traction unit based flange lubrication is an applied measure addressing this problem for regularly used routes. The major benefit from track lubrication units is in countries where flange lubrication measures are not frequently used, and for parts of the network that are not regularly operated (e.g. side-tracks which are common derailment locations).

Knowledge of each IMs network and the proliferation of side-tracks and their usage pattern is not available to the project team. In the absence of this information we have made the following assumptions:

- Side-tracks are installed approximately every 15 km of track length.
- 50% of side-tracks are infrequently used (and may have dry rails) or are otherwise at a lower level of repair than main-line routes.
- One or two lubrication units are required per side-track, depending on conditions. We have used an average of 1.5 per side-track.
- The required number of units is estimated at (289,000 / 15) * 1.5 * 50% = 14,450.

5.2.2.3 Measure Effectiveness

The effectiveness for this measure is somewhat difficult to estimate. In this respect we are not aware of any study that has been performed that quantifies lubrication effectiveness as a derailment mitigation option (we have contacted many suppliers on this subject, and they are also not aware of such studies). However, it is frequently referenced as a “good measure” and often recommended in accident reports as a measure that should be applied.

We have made a working assumption that it may be up to 50% effective in cases where dry rail has been a contributory derailment cause. This is applied to the maximum number of potentially avoided derailments for this measure, which we reported to be 25 [3].

5.2.3 Measure P-10 and P-12: Hot Axle Box / Hot Wheel and Brake Detectors (HABD/HWD)

5.2.3.1 Measure Objective

Hot axle boxes leading to axle journal seizures and ruptures are amongst the most frequent cause of freight train derailments, and also have a tendency to occur at high speeds, [3]. In response to this many IMs have taken steps to install hot axle box detectors, with recent activity to increase the coverage and replace older designs with newer technical solutions. Further, some countries that currently have no such devices are embarking on an implementation strategy [4]. In this context we estimated in our market assessment [2] approximately 1,500 units currently in use; a number which we believe to be increasing.

5.2.3.2 Measure Installation Scope

In terms of current installations, of the 1500 units we estimated to be in use, some will be “double units” covering adjacent lines. For the basis of our assessment we have assumed 50% to be double units, therefore:

- Coverage = 289,000[7] km / (1,500 * 1.5 * 85%[8]) = 151 km between installations.
- Coverage of one per 50 km (a typical installation density, although we do note that hot axle box derailments can occur less than 50 km from the last operational hot axle box detector) would require approximately 5,780 units installed in total, therefore a further 3,530 units.

5.2.3.3 Measure Effectiveness

The recent developments in terms of increased installation density and improved technology discussed in Section 5.2.3.1 is likely to make significant in-roads towards reducing derailments caused by hot axle boxes and related causes. (One IM has stated that they have reduced to almost zero the incidence of derailments caused by hot axle boxes / broken axles and broken wheels, partly as a result of implementing this technology – of course with suitable supporting arrangements such as the availability of side-tracks and a robust alarm management process.)

We therefore need to address the fact that solutions currently being implemented are likely to return benefits in future years, regardless of any additional action that may be taken. In this regard we have made the following working assumptions:

- The data used for our accident analysis is an average assessment based on previous years’ accident figures. In this regard our accident data is “lagging” current figures and does not take into the developments discussed above. In particular the increasing use of HABD/HWD in recent years will have the effect of reducing the available benefit for measures directed towards derailments from that cause. In this respect we have assumed our data is lagging by at least 1.5 years, and that by 2013 will be a further 1.5 years behind.

[7] We exclude side-tracks from the installation scope for these measures
[8] We have assumed that of the total HABD installations, they are equally distributed on mixed, freight only and passenger lines. Hence the 85% of them will be installed on freight carrying routes.

To compensate for this we have applied the assumption (used in [3]) that a 6% year-on-year reduction of derailment rate and therefore the available benefit, should be applied[9]. Starting from our maximum risk reduction potential of 80 avoided derailments per year [3]; we arrive at a revised maximum potential benefit of 67 avoided derailments per year.

- We note from our accident analysis [3] that at least 10% of hot axle box derailments occur despite the incident train having previously passed a HABD/HWD. This is an underestimate of the true position since we only count cases where this has been explicitly stated. (In Germany, where the most HABD/HWD are installed, we observe the highest proportion of derailments due to hot axle boxes.) We assume 10% of such failures will continue to evade detection, even with a comprehensive application scope.
- Applying this we deduce that a revised maximum risk reduction potential is 60 avoided derailments.

5.2.4 Measure P-11: Acoustic Bearing Monitoring (Bearing Acoustic Monitoring; BAM)

5.2.4.1 Measure Objective

Acoustic bearing detectors are, like HABD, used to detect developing mechanical structural defects associated with wheel bearings. They are however based on the analysis of sound as wheel sets pass by. The major advantage over HABD is that acoustic bearing detectors are able to detect developing defects much earlier as such defects will result in increased noise. It is stated by one supplier that defects can be detected 10,000's of km before a failure occurs. Trending over time allows early identification of defects before they lead to failures.

5.2.4.2 Measure Installation Scope

We use the following assumptions:

- Suppliers' recommended 30 units per 50,000 km of track are installed. Hence a density of (289,000 / 50,000 * 30) = 173 units would be required. However, we note that this is mainly in relation to long haul routes in the USA and Australia. For short / medium haul routes (of say 100 km to 300 km) it is possible that a BAM would not be encountered very frequently / at all if installed at this density. (Although the significant advance warning stated for this measure does not require a freight train to pass a detector site very frequently.) We have calculated that one detector installation per 500 km or track would be necessary in Norway to cover approximately 95% of freight train operations, and consider this would be a suitable indicative installation density for European application, hence about 578 units. There are few installations existing in the EU (other than test locations), hence these would be new.

5.2.4.3 Measure Effectiveness

In terms of benefit and effectiveness:

- Maximum available benefit 63 avoided derailments per year [3] reduced by 6% per year as reported for HABD. This suggests a maximum achievable benefit of 53 avoided derailments per year.
- It is stated by one supplier that BAM are 90% effective in detecting the early on-set of bearing problems on a single pass-by, and that this increases to 95% when trended. It is also stated that the technology can detect defects in brass or polyamide roller cages equally as reliably[10].

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[9] We have applied the 6% factor to the derailment causes that we believe to be reducing; this does not apply to all derailment causes so it is not applied to all measures.
[10] These are supplier claims which we are unable to validate due to lack of EU experience.

5.2.5 Measure P-13: Wheel Load and Wheel Load Impact Detectors (WLID) / Weighing In Motion (WIM)

5.2.5.1 Measure Objective

Devices of this type typically monitor rail vehicle wheels for rolling wheel surface defects such as flats and spalls, together with wheel out of roundness and vehicle weight imbalances. They may help to detect wheel defects and also identify conditions that may, if left un-rectified, lead to wheel-set failures.

5.2.5.2 Measure Installation Scope

Considering the information we have assembled:

- An installation density of approximately one unit per 1000 km is suggested, thereby indicating a fully covered installed base in the EU of (289,000 km / 1000 km) = 289 units. (Installation locations are likely to be where a freight train can be inspected and removed from service, or denied access to the network.) However, as we have reported for BAM, this is unlikely to provide full coverage for all freight traffic and we note that the Netherlands has an average installation density of about one unit per 170 track km (in the Netherlands this technology is used for track access charging in addition to derailment mitigation). We have assumed a targeted and planned installation density of one unit per 500 track km would provide a reasonably comprehensive coverage for most freight traffic, hence about 578 units.
- We estimated a total of 150 current installations [2], with 85% on freight traffic routes, hence 128 units. A further 450 units would therefore be required for a comprehensive coverage.

5.2.5.3 Measure Effectiveness

In terms of potential benefits and effectiveness, the following may be summarised:

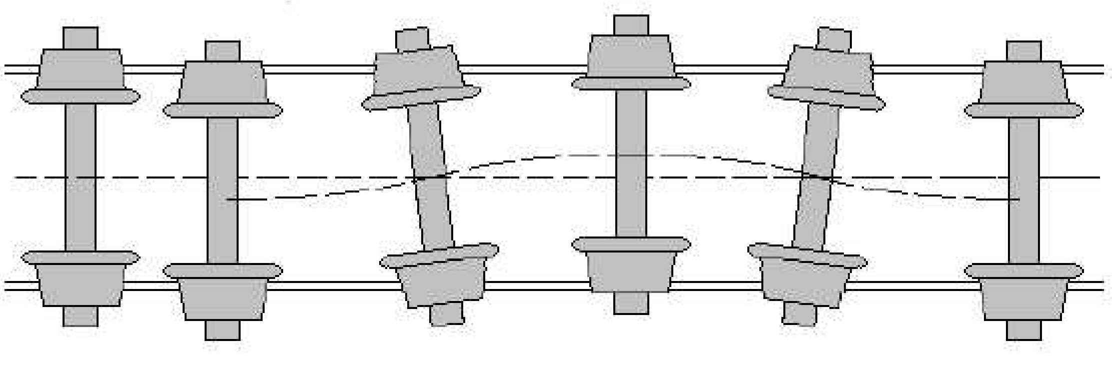
- We indicated a maximum potential benefit of 120 avoided derailments. This is modified by the observed 6% year-on-year reported for HABD, hence 100 avoided derailments.
- We note that the Netherlands [4] is quoted as indicating a 90% reduction in hot axle box failures, as well as significant reductions in derailments by other causes (for example broken primary suspension reduced by almost 100%), following the application of this technology. Although the Netherlands uses relatively few HABD, it is considered likely that the combinational effect of these two technologies (as well as other factors) has resulted in this dramatic reduction in reducing hot axle box and other derailments. For the purpose of our modelling activity, we have assumed 75% effectiveness for this measure in isolation.

5.2.6 P-15: Bogie Performance Monitoring / Bogie Lateral Instability Detection (bogie hunting)

5.2.6.1 Measure Objective

This wayside defect detection system is capable of detecting and identifying wagon bogies that exhibit poor steering performance, an example of which is shown below. Bogie hunting is likely to occur when the rail profile is worn outside of allowable conditions; a wheel profile detector is likely to offer similar functionality.

Figure 2: Lateral Instability



This system monitors safety performance in several dimensions such as: potential of flange climb derailment, gauge spreading, and rail over. Like BAM, devices of this type often rely on trending to enable defects to be identified and early maintenance action scheduled to correct the defect.

5.2.6.2 Measure Installation Scope

In terms of application:

- We have assumed that a similar coverage as BAM, hence a density of 578 units. There are few installations existing in the EU (other than test locations) therefore these would mostly be new installations.

5.2.6.3 Measure Effectiveness

In terms of benefit and effectiveness:

- We estimated a maximum available benefit of 47 avoided derailments per year [3]. This is not modified by our 6% reduction factor as derailments from this cause are not considered to be addressed by the recent programmes to reduce the frequency of hot axle box derailments.
- Little data exists in the countries that are within the scope of this study relating to the effectiveness of these measures, because they are not installed to any great extent. By virtue of the fact that they are installed in the USA, Australia and other geographies, we assume they are effective. We have used a 90% effectiveness rating for this measure.

5.2.7 P-16: Wheel Profile Monitoring System / Wheel Profile Monitoring Unit

5.2.7.1 Measure Objective

Damage to the wheel profile may be a contributing cause to derailments. Whereas wheel load impact detectors can detect some wheel profile problems, wheel profile measurement systems provide a more complete picture. They are also based on other technology: analysis of wayside digital camera images highlighting the profile using lasers or strobe light. A number of wheel profile parameters are captured, e.g. flange height, flange width, flange slope, tread hollow and rim thickness. Some measurement systems can operate with trains passing at high speeds (e.g. up to 140 km/h).

5.2.7.2 Measure Installation Scope

This type of unit would be installed where the widest coverage could be secured; this may include at major depots and selected freight routes across the network. It would not be required that freight trains / wagons were required to pass a detector site frequently, as defects evolve over time and are unlikely to be immediately catastrophic.

Considering the information we have assembled and our comparison of this technology with bogie hunting detectors:

- An installation density of one unit per 500 km, hence about 578 units.
- For the purpose of our assessment we estimate 30 current installations [2], with 85% on freight traffic routes, hence 26 units. A further 548 units would be required using this as a basis. (Installation locations are likely to be where a freight train can be inspected and removed from service, or denied access to the network.)

5.2.7.3 Measure Effectiveness

In terms of potential benefits and effectiveness, the following may be summarised:

- We indicated a maximum potential benefit of 23 avoided derailments. This is modified by the observed 6% year-on-year derailment reduction factor, hence 19 avoided derailments.
- We assume the effectiveness of this measure to be similar to other technical measures. An effectiveness of 90% is used.

5.2.8 F-7: Sliding Wheel Detectors

5.2.8.1 Measure Objective

The sliding wheel detector is a mechanical device that compares wheel rotation rates between wheel sets to detect locked wheels. It may detect issues such as handbrakes that are not released, jammed wagon brakes or seized axle box bearings.

5.2.8.2 Measure Installation Scope

The system is normally installed in depots and sidings on departure roads and possibly other strategic locations. Suppliers' recommendation for application in Great Britain (GB) would be for 100 units (and GB accounts for about 9% of European track length) hence about 1,100 units would be required to cover the European rail network. We are not aware of many that are currently installed; hence we consider these "new". We do consider this optimistic, and that it would probably not cover all freight origin points and strategic places en-route where locked wheels may be likely. We have increased our scope estimates by 20% to cover additional strategic points. Hence we use 1,320 units.

5.2.8.3 Measure Effectiveness

Our assessment of the measures potential effectiveness is as follows:

- We indicated a maximum potential benefit of around 27 avoided derailments. On further of this this measure we conclude that it cannot be as effective as, say measure P-6: Anti-Lock devices as it cannot detect locked wheels between detection sites. Hence to provide a realistic assessment of the potential effectiveness of this measure we have undertaken a detailed review of our accident database [2, Annex 1] to specifically identify freight train derailments that can be directly attributed to this cause (UK-1 and NL-8 are examples). Through this research we consider that approximately 1% to 2% of freight train derailments have this as a cause and we have used 8 avoided derailments as our reference case.

- This measure is not applied in the EU and therefore we have no specific effectiveness data. However this is used in other countries, such as Australia. We assume that as it an existing and mature measure it is at least 90% effective.[11]

5.3 Rolling Stock Measures

5.3.1 Measure P-28: Replace Metal Roller Cages in Axle Bearings by Polyamide Roller Cages

5.3.1.1 Measure Objective

Polyamide roller cages are stated to offer safety improvements compared with brass roller cages, decreasing the incidence of overheating and axle box failures. Manufacturers' claims[12] include:

- Reduced friction and wear and reduced operating temperatures.
- Safe failure mode without seizing.
- Can operate for longer periods without lubrication (testing is stated to have shown that polymer cages can operate for more than 500 km when all lubrications is removed. This is well beyond that which steel based cages can safely operate), [5].
- Compared with machined brass cages they are substantially lighter, which minimizes dynamic adverse conditions in bearings. Two sliding elements steel - polyamide have better sliding properties as compared with steel - brass. In addition to that polyamide better damps vibrations and noise. Thanks to technologic abilities the cage design has been solved to permit optimum passage of lubricant to rolling elements. Another advantage of bearings is self-lubricating capacity of polyamide. In case of lubrication deficiency the wheel set seizure does not occur so instantly as in case of brass cage bearings, [6]

It is important to note that these are suppliers' claims. However in many derailment accident reports where a hot axle box has been the cause it is specified that the bearing had a brass roller cage; in none of the accidents has it been specified that there was a polyamide roller cage. We are aware that programmes to replace brass roller cages with polyamide roller cages have been introduced by several RUs, among those:

- CargoNet in Norway in 2000
- VR in Finland pre 2003.

The replacement appears to have been effective resulting in a reduced number of hot axle box derailments although sufficient data for quantification does not exist.

Similar programmes are applied by other RUs. Since the normal maintenance interval for freight wagon roller bearings are 12 years (for brass or polyamide to the best of our knowledge) the last brass roller cage in the CargoNet owned rolling stock fleet should be removed by 2012.

5.3.1.2 Measure Installation Scope

Currently a number of RUs are requiring the replacement of brass with polyamide roller cages on an opportunistic basis, to combat the significant problem of hot axle box derailments. We believe there to be little cost difference between brass and polyamide variants and hence this

[11] To be effective the wheel must be locked and skid. It may not be effective in cases where the handbrake is only partly applied as the wheel may continue to rotate.

[12] We note many manufacturers' claim benefits from the use of these roller cages, and that it also a common recommendation arising from accident reports to replace brass for polyamide roller cages. However, we have not seen any independent validation of such claims.

is a minimal cost option. We are however unable to assess this in any reasonable manner as there is no appreciable cost.

A second option would be to change all remaining brass roller cages with polyamide. We are unaware of the total number of bearings of each type in use, but we assume the following:

- 50% of the existing freight fleet are fitted with brass roller cages. There are about 720,000 freight wagons [7] with a mix of single axle and bogie wagons (equal mix assumed). This equates to upwards of 2,000,000 roller bearings requiring replacement.

5.3.1.3 Measure Effectiveness

- We estimated a maximum available benefit of 53 avoided derailments per year [3] as for HABD. This is modified by the observed 6% year-on-year derailment reduction factor, hence 44 avoided derailments.
- If we are able to take the suppliers' claims at face value, then the ability to operate for lengthy distances without lubrication and excessive heat build-up (up to 500 km) and also be more tolerant of vibrations is likely to be significant. On this basis we have assumed this measure to be 75% effective[13].

(Additional benefits could be for example requiring a lesser density of installation of HABD.)

5.3.2 F-6: Anti-lock Devices

5.3.2.1 Measure Objective

Devices of this type act to reduce locking of the wheels and associated wheel damage during braking on railway freight cars. In turn this may reduce maintenance costs of re-profiling wheel sets, increase safety with reduced risk of wheel cracking or major tread damage that could increase derailment risk, reduce impact forces to track and reduce noise.

5.3.2.2 Measure Installation Scope

The large retro-fit time (up to 12 days per wagon), coupled with the limited derailment safety benefit estimated for these types of product [3], would lead us to consider this measure will be applicable to new wagons only. Therefore to consider this measure we have modelled it as if it were fitted to the entire fleet but considering only the acquisition and on-going maintenance cost (not the fitting cost).

5.3.2.3 Measure Effectiveness

This measure addresses wheel failures and other derailment causes where these are caused by braking failures (including handbrakes not released, brakes remain stuck on after application etc). We predicted up to 27 derailments from this cause [3]. This measure is not modified by our 6% reduction factor as derailments from this cause are not addressed by the recent programmes to reduce the frequency of hot axle box derailments.

The device has no measured effectiveness or reliability claims, since it is new to the market. We have assumed that it will be 75% effective in preventing derailments from the causes that it seeks to mitigate.

5.3.3 M-1: Derailment Detection

5.3.3.1 Measure Objective

There are two devices of this type: those that act directly on the brake pipe invoking a immediate and automatic full application of the brake (M-1a); those that provide a clear

[13] We would consider it prudent for independent substantiation of suppliers claims to be performed in advance of any recommendation.

indication to the train driver of a suspected derailment (M-1b) but without automatic brake application. The objective is to prevent a derailed axle causing further damage, and/or the initial derailment escalating in severity.

5.3.3.2 Measure Installation Scope

Two devices are fitted per wagon within the following scope:

- All freight wagons (approximately 720,000).
- All freight wagons carrying dangerous goods (DG) (approximately 100,000).
- A sub-set of DG wagons, as proposed by RID 2013 provision (approximately 17,000).

We consider these options in our analysis. We also consider that there are about 2,000 wagons fitted with devices of this type. These are largely fitted to DG tank wagons, and we assume that 75% are fitted to tank wagons carrying the most hazardous materials as covered by the proposed RID 2013 provision (hence 1,500).

5.3.3.3 Measure Effectiveness

We have studied the accident database we have assembled and are able to report the following[14]:

- There are five accidents that appear to have been initially non-severe, but the application of emergency brakes is stated to have been a contributory factor in the derailment escalating. We cannot know the outcome had emergency brakes not been applied. (Comparable with M-1a.)
- There are 62 accounts of cases where the application of emergency brakes (either through the brake pipe being severed or driver emergency braking) has occurred, and the train has been brought to a safe stop. We cannot know the outcome had emergency brakes not been applied; it is possible that the train would not have been brought to a safe stop.
- There are four cases where the driver has known or suspected a derailment but has not taken appropriate action leading to further wagons derailing. It is not known whether this further derailment led to an escalation of severity. (Comparable with M-1a.)

Given these data, it is not possible for us to conclude or differentiate between these two measures in terms of which may be the best option from a safety point of view. In the absence of information to separate the measures from an effectiveness perspective, the only parameter that we re-model (with reference to our event tree, [3]) is the detection probability. We assume that for wagons fitted with a device of this type (M-1a, M-1b) that 95% of derailments will be detected as soon as they occur.

5.4 Organisational Measures

5.4.1 Measure P-19: Clearance of Obstructions from Flange Groove (particularly at level crossings)

5.4.1.1 Measure Objective

Obstructions in the flange groove may lead to freight derailments, albeit few in number. Inspection and clearance of obstructions is a measure that may address this issue.

[14] Not all accident report provide information to establish whether emergency braking was initiated, hence we are not able to include those in this analysis

5.4.1.2 Measure Installation Scope

The European Level Crossing Forum report 125,000 level crossings in Europe. If we assume that 85% of these are on lines that freight traffic may use, then there are about 106,000 level crossings that fit within the scope of this study.

Some level crossings are more exposed to this hazard than others; for example urban locations where level crossings are surrounded by tarmac are perhaps less likely to get stones obstructing them, compared with rural locations. For the purposes of our assessment we have considered that most level crossings are in urban areas or are otherwise not significantly exposed to this hazard to the same extent. We have used an assumption that 25% of level crossings are exposed hence 26,500 level crossings would require additional inspection effort.

For this measure to be effective, inspections over and above the existing inspection interval would be necessary. In this regard we have assumed the following:

- That an inspection would be required after inclement weather. This would include wet weather / daytime thaw followed by freezing conditions. Strong winds that could move debris are another potential cause.
- Optimistically we have assumed that these weather conditions may occur 10 days per year, therefore additional inspections of 10 * 26,500 level crossings = 265,000 additional inspections.
- Each inspection takes 30 minutes.
- This is required on-going cost requirement.

5.4.1.3 Measure Effectiveness

We have assumed this measure will be 90% effective in removing all derailments attributable to this cause.

This measure is not modified by our 6% reduction factor as derailments from this cause are not addressed by the recent programmes to reduce the frequency of hot axle box derailments.

5.4.2 Infrastructure Track Geometry Measures

5.4.2.1 Measure Objective

Track geometry defects are one of the most common causes of freight train derailments. We have also noted that there is an increasing use of single axle wagons with a very long wheel base which makes the derailment risk in twisted track even larger and with an increased containerization as well as loading by bulk material by front wheel loader the control of skew loading is more of a challenge.

We consider this problem in relation to secondary lines predominately for freight operations, as well as side-track at stations:

We consider here the following:

- P-18: Sufficient availability of maintenance resources to maintain lines and tracks at stations and side tracks to minimum safety requirements.
- P-21: Track geometry measurement of all tracks.

Other issues such as

- P-22: EU-wide intervention/action limits for track twist.
- P-23: EU-wide intervention/action limits for track gauge variations.

- P-24: EU-wide intervention/action limits for cant variations.
- P-25: EU-wide intervention/action limits for height variations and cyclic tops.

are addressed elsewhere in our report.

5.4.2.2 Cost and Application Data

There is some difficulty making a quantified assessment of measures of this type, due to data shortages and also the insistence of many IMs that they both have sufficient resources and apply appropriate standards to all their assets. This is not always borne out by accident reports. Further there are national differences in accident rates and also criteria which pose a problem for a “European average study” such as this.

We have established from [8] an average railway maintenance cost of about €25,000 per track kilometre. Further, approximately 40% of this figure is for permanent way maintenance and about 50% for track work. Hence this equates to about €5,000 (€25,000 *40% * 50%) per track kilometre. We assume this is for track geometry testing and rectification work. This figure applies to main-track.

We assume secondary lines and side-track accounts for 34,000 km. We have further assumed that a partial inspection of these is already undertaken, perhaps at an expenditure of 50% of that applied to main-track. This has two consequences:

- An annual increased maintenance cost of €2,500 per secondary line / side-track kilometre would be required to maintain to a similar level to main-track.
- In addition to the cost above, it is likely that there would likely be an initial one-off spend required to upgrade secondary line / side-track to bring it up to specification. We have made an assumption here that in year one this would amount to double the annual maintenance cost, hence €5,000 per side-track kilometre.

5.4.2.3 Effectiveness Data

In our accident data we have identified that approximately 50% of derailments occur in stations / side-tracks, despite these locations accounting for 10+% or total track length. Using these approximate figures, we can postulate that:

- From the number of derailments predicted as a result of track geometry failures (129 [3]), it is theoretically possible that a 45% reduction could be achieved, to 58.
- This measure is not modified by our 6% reduction factor as derailments from this cause are not addressed by the recent programmes to reduce the frequency of hot axle box derailments.

6.0 The Cost Model and Parameters

6.1 Cost Model Summary

The cost model brings together all the facets that apply to the measures we have identified.

These are on the one hand costs associated with each measure and on the other hand the benefits that the measure may secure.

Costs of a measure include:

- The quantity (number of units, deployment rate, resource requirement etc.) for the measure.
- The costs per unit for the measure.
- Annual maintenance and upkeep other costs for measure.

Benefits include:

- The number of avoided derailments (or reduced number of severe derailments for "M" measures), each of which has benefits that include:
    - o Reduction in the number of fatalities and injuries associated with freight train derailments.
    - o Reduction in the quantity of damaged tracks, damaged wagons, operational disruption and environmental contamination.

It is the purpose of the cost model to weigh these factors such that the most efficient measures can be selected. To achieve this both the costs and benefits need to be monetised. The details of how this is achieved are provided in our reports [9], [3], although we recap these below.

The benefits of implementing a measure in terms of avoided derailments are monetised using the information shown below.

Table 3 Railway System and Operational Costs[15]

	Track Damage		Wagon Damage		Disruption Costs	
Scenario	Average Km	Cost (E/km)	# wagons	Cost/wagon (E/wagon)	Hours disruption	Cost/hour (E/hour)
Immediate severe, DG involvement	0.5	427746	7	23526	50	16040
Not immediate severe, DG involvement	5	160405	7	23526	50	16040
Immediate severe, no DG involvement	0.5	427746	7	12832	50	16040
Not immediate severe, no DG involvement	5	160405	7	12832	50	16040
Not severe derailment, safe stop	0.5	32081	2	5347	12	8020

In addition, the cost model assigns monetised benefits associated with the value of preventing a fatality or injury of €1,500,000 and €200,000 respectively.

Therefore, preventing an immediately severe DG derailment that leads to loss of three lives has a cost (at today's values) of:

- (3 * €1,500,000) + 0.5 * (€427,746) + 7 * (€23,256) + 50 * (€16,040) = €5,678,665.

An event of this type is predicted to occur at a rate that is calculated by our frequency assessment model. For example, if this is predicted to be once every ten years, then the annual cost is:

[15] A severe derailment is defined as an event with a mechanical impact that may cause a leak of material from a DG tank / wagon, or for a contents spill of a normal freight wagon.

- 0.1 * €5,678,665 = €567,866.

The costs of the measures themselves are unique to each measure, and we summarise the key cost components in Table 4.

6.2 Economic Indicators

Of course a measure will have an investment cost that is made today (or at the time that the measure is implemented) and returns benefits over a period of time. In these cases it is practice to consider this in the economic assessment. This is normally achieved by the use of the following economic indicators:

1. **Net Present Value** – the difference between the present value of cash inflows and the present value of cash outflows.
2. **Benefit / Cost Ratio** – the ratio of benefits to costs (a ratio greater than 1 indicates that the benefit outweighs the cost).
3. **Internal Rate of Return** - can be defined as the break-even interest rate which equates the Net Present of a projects cash flow in and out.

Our assumptions / clarifications regarding the use of these indicators are:

- We apply a discount rate of 4%.
- We assume that the measure is fully implemented at Year 1 and will return benefits in the same year.
- We have applied today's costs and benefits regardless of when the measure is implemented. We believe this to be a reasonable assumption as costs and benefits are likely to be stable within the periods defined as short and medium term.
- We have assumed that any investment is made by the EU Railway actors, for the benefit of EU Railway actors. This means that the economic analysis will focus entirely on costs and benefits within the EU without consideration that some benefits may in fact be transferred to stakeholders outside EU, or that there may be an inequitable share of costs and benefits between actors.

Table 4 Cost and Benefits for Reference Case

Measure	Purchase / Installation Costs	Annual Maintenance Cost	Max Potential Benefit[16]	Measure Effectiveness / Other Considerations	Net benefit[17]
P-1: Check Rail	€500 / metre[18]. **Total installation cost for 1,615 km = €807.5 million**	Additional maintenance cost of €5 / metre [2]. **Annual additional maintenance cost €8 million**	25 avoided derailments	Assumed 90% effective where fitted [2]	**23 avoided derailments (6 HSD, 17 LSD)**
P-2: Track Lubrication	€3250 / installation[19]. **Total installation cost for 14,450 units = €47 million**	€3000 / installation (lubricant top-up) **Annual additional maintenance cost €43 million**	25 avoided derailments	Assumed 50% effective	**13 avoided derailments (10 LSD, 3 HSD)**
P-10 & P-12: HABD/HWD	€250k / installation **Total installation cost for 3,530 €882.5 million**	Approx. 30 hours per year (supplier info) **Annual additional maintenance cost €5.3 million**	60 avoided derailments	60 * 90% * 99% (99% being the availability figures for devices of this type, [2l])	**53 avoided derailments (12 LSD, 41 HSD)**
P-11: BAM	€550k / installation **Total installation cost for 578 units = €318 million**	12 hours per year (supplier info) **Annual additional maintenance cost €347,000**	53 avoided derailments	53 * 90% * 98% % (98% being the availability figures for devices of this type, [2l])	**47 avoided derailments (11 LSD, 36 HSD)**
P-13: Wheel Load / Impact Detectors	€400k / installation **Total installation cost for 450 units = €180 million**	12 hours per year (supplier info) **Annual additional maintenance cost €270,000**	100 avoided derailments	100 * 75% * 98% (98% being the availability figures for devices of this type, [2])	**74 avoided derailments (33 LSD, 41 HSD)**

16 Refers to avoided derailments and related reduction of impacts
17 Refers to avoided derailments and related reduction of impacts
18 This is increased from the value used in our report [2]. Installation of check rails is likely to require change of sleepers or additional fixings for their attachment.
19 This is a typical cost for a mechanical lubrication system installed and initially topped up with lubricant (supplier information)

Measure	Purchase / Installation Costs	Annual Maintenance Cost	Max Potential Benefit[16]	Measure Effectiveness / Other Considerations	Net benefit[17]
P-15: Bogie Hunting Detectors	€385k / installation **Total installation cost for 578 units = €222.5 million**	15 hours per year (supplier info) **Annual additional maintenance cost €433,500**	Max: 47 avoided derailments	47 * 90% * 99% (99% being the availability figures for devices of this type, [2])	**42 avoided derailments (30 LSD, 12 HSD)**
P-16: Wheel Profile Monitoring	€300k / installation **Total installation cost for 548 units = €164 million**	140 hours per year (supplier info). However, the regular pass-by check will be on opportunistic basis (100 hours). 40 hours of specific maintenance assumed. **Annual additional maintenance cost €1 million**	Max: 23 avoided derailments	23 * 90% * 95% (95% being the availability figures for devices of this type, [2])	**20 avoided derailments (14 LSD, 6 HSD)**
P-18 & P-21 Track Geometry	**€170 million to upgrade 34,000 km side-track and secondary lines**	**Annual additional maintenance cost €85 million**			**58 avoided derailments (35 LSD, 23 HSD)**
P-19: Clearance of Flange Groove	**€6.7 million to perform 132,500 hours per year inspections (circa €50 / hour)**	**€6.7 million to perform 132,500 hours per year inspections (circa €50 / hour)**	5 avoided derailments	5 * 90%	**4.5 avoided derailments (0.5 LSD, 4 HSD)**
P-28: Polyamide Roller Cages	Assumed 1 hour per bearing at cost of €75 (including purchase) **Total installation cost to replace 2 million brass roller cages = €150 million**	None	44 avoided derailments	44 * 75%	**33 avoided derailments (7 LSD, 26 HSD)**
F-6: Anti-lock Devices	€5,000 per wagon set **Total installation cost for 720,000 units (all freight wagons) = €3600 million**	30 mins / wagon per year **Annual additional maintenance cost €18 million**	27 avoided derailments	27 * 75%	**20 avoided derailments (8 LSD, 12 HSD)**

Measure	Purchase / Installation Costs	Annual Maintenance Cost	Max Potential Benefit[16]	Measure Effectiveness / Other Considerations	Net benefit[17]
F-7: Sliding Wheel Detectors	€40,000 per installation **Total installation cost for 1,320 units = €53 million**	Negligible, but has a life limited item that is replaced at 3 years (€250 assumed) **Three yearly additional maintenance cost €330,000**	8 avoided derailments	8 * 90% *99% (99% being the availability figures for devices of this type)	**7 avoided derailments (3 LSD, 4 HSD)**
M1- Derailment Detection	€2000 per wagon **All Freight: Total installation cost for 718,000 wagons = €1436 million** **All DG: Total installation cost for 98,000 wagons = €196 million** **RID scope: Total installation cost for 15,500 wagons = €31 million**	Negligible, but has 6 year maintenance requirement (1 hour per wagon assumed) **All freight (6 year) : €36 million** **All DG (6 year) : €5 million** **RID Scope (6 year) : €775,000**	N/A	95% effective in detecting a derailment	**All freight: 76 derailments prevented from becoming severe** **All DG: 10 derailments prevented from becoming severe** **RID scope: 2 derailments prevented from becoming severe**

7.0 Assessment Results – Reference Case

7.1 Quantitative Results Presentation

For the parameters established in this report, we show the results for our reference case.

Table 5 Quantitative Analysis (Sorted by Measure Number)

	Net Present Values			Benefit / Cost Ratio			Internal Rate of Return		
Measure	10 years	20 years	40 years	10 Years	20 Years	40 Years	10 years	20 years	40 years
P1-Check Rail	-701	-635	-559	0.2	0.3	0.4	-31%	-14%	-6%
P2-Track Lubrication	-276	-459	-667	0.3	0.3	0.3	N/A	N/A	N/A
P10&12-HABD/HWD	-507	-257	27	0.5	0.7	1.0	-16%	-4%	0%
P11-BAM	47	294	572	1.1	1.9	2.8	3%	10%	11%
P13-WLID/WIM	379	756	1,183	3.1	5.1	7.4	51%	52%	52%
P15 Bogie Hunting Detector	80	283	514	1.4	2.2	3.2	8%	14%	15%
P16-Wheel Profile	-27	65	170	0.8	1.4	1.9	-4%	5%	7%
P18-Track Geometry	-373	-568	-788	0.5	0.6	0.6	N/A	N/A	N/A
P19-Clearance Flange Groove	-20	-34	-49	0.6	0.6	0.6	N/A	N/A	N/A
P28-Roller Cages	109	284	482	1.7	2.9	4.2	16%	21%	21%
F6-Anti Lock Device	-3,581	-3,581	-3,580	0.0	0.1	0.1	N/A	N/A	N/A
F7-Sliding Wheel Detector	-0	35	75	1.0	1.6	2.4	0%	7%	9%
M1a-Derail Det All Freight	-385	303	1,094	0.7	1.2	1.7	-7%	3%	5%
M1a-Derail Det All DG	-44	56	170	0.8	1.3	1.8	-6%	3%	6%
M1a-Derail Det RID	-2	17	39	0.9	1.5	2.2	-2%	6%	8%

Table 6 Quantitative Analysis (Sorted by Benefit / Cost ratio)[20]

		Net Present Values			Benefit / Cost Ratio			Internal Rate of Return		
Rank	Measure	10 years	20 years	40 years	10 Years	20 Years	40 Years	10 years	20 years	40 years
1	P13-WLID/WIM	379	756	1,183	3.1	**5.1**	7.4	51%	52%	52%
2	P28-Roller Cages	109	284	482	1.7	**2.9**	4.2	16%	21%	21%
3	P15 Bogie Hunting Detector	80	283	514	1.4	**2.2**	3.2	8%	14%	15%
4	P11-BAM	47	294	572	1.1	**1.9**	2.8	3%	10%	11%
5	F7-Sliding Wheel Detector	-0	35	75	1.0	**1.6**	2.4	0%	7%	9%
6	M1a-Derail Det RID	-2	17	39	0.9	**1.5**	2.2	-2%	6%	8%
7	P16-Wheel Profile	-27	65	170	0.8	**1.4**	1.9	-4%	5%	7%
8	M1a-Derail Det All DG	-44	56	170	0.8	**1.3**	1.8	-6%	3%	6%
9	M1a-Derail Det All Freight	-385	303	1,094	0.7	**1.2**	1.7	-7%	3%	5%
10	P10&12-HABD/HWD	-507	-257	27	0.5	**0.7**	1.0	-16%	-4%	0%
11	P19-Clearance Flange Groove	-20	-34	-49	0.6	**0.6**	0.6	N/A	N/A	N/A
12	P18-Track Geometry	-373	-568	-788	0.5	**0.6**	0.6	N/A	N/A	N/A
13	P1-Check Rail	-701	-635	-559	0.2	**0.3**	0.4	-31%	-14%	-6%
14	P2-Track Lubrication	-276	-459	-667	0.3	**0.3**	0.3	N/A	N/A	N/A
15	F6-Anti Lock Device	-3,581	-3,581	-3,580	0.0	**0.1**	0.1	N/A	N/A	N/A

The top nine measures (Wheel Load Impact Detectors to Wheel Profile Detectors) show a positive NPV and therefore greater than unity benefit to cost ratio at Year 20, whilst the tenth best measure, Hot Axle Box / Hot Wheel Detectors is unable to show overall benefit at this point.

[20] Note that IRR cannot compute measures where, for example, the cost exceeds the benefit beyond Year 1. We therefore rank our measures based on B/C ratio. We also use the results at year 20, as these are the likely lifecycles for each measure considered.

7.2 Qualitative Results Presentation

An alternative non-financial presentation is provided below.

Table 7 Qualitative Analysis (Sorted by Measure Number)

Measure	Fats	Track (km)	Wagons (number)	Opeartions (hrs)	Environmental events	Derails prevented
P1-Check Rail	0.16	35	109	751	3	23
P2-Track Lubrication	0.09	20	61	422	2	13
P10&12-HABD/HWD	0.47	70	270	1889	8	53
P11-BAM	0.41	63	240	1673	7	47
P13-WLID/WIM	0.59	104	366	2542	10	74
P15-Bogie Hunting Detector	0.29	63	199	1377	5	42
P16-Wheel Profile	0.14	30	95	657	2	20
P18-Track Geometry	0.36	85	280	1941	7	58
P19-Clearance Flange Groove	0.04	6	23	164	1	4.5
P28-Roller Cages	0.29	44	169	1180	6	33
F6-Anti Lock Device	0.17	28	99	693	3	20
F7-Sliding Wheel Detector	0.06	10	35	241	1	7
						Severe derailments saved
M1a-Derail Det All Freight	0.96	341	379	2881	17	76
M1a-Derail Det All DG	0.85	45	50	380	4	10
M1a-Derail Det RID	0.12	9	10	76	1	2

In this table it is of course not surprising to see that the measures with the best economic performance secure the largest benefit.

It is interesting to note however that "M" measures show the largest absolute benefit. This is because they are intended to prevent the escalation of consequences, and therefore target only the most serious outcomes.

To illustrate this point we consider measure M1 applied to all DG trains (M1a-Derail All Freight and P13- WLID/WIM detectors. We can see that M1a-Derail Det All Freight prevents 76 derailments from becoming severe whilst P13 prevents 74 derailments from occurring at all. On first consideration it may seem that preventing 74 derailments is the better outcome. However, of these 74, a number will be safely managed and not escalate in consequence, therefore only a proportion of these prevented derailments are severe. Further, since it is only severe derailments that lead to loss of life, preventing severe derailments has significant advantages in this respect.

7.3 Additional Measures and Discussion Points

7.3.1 Measure P28-(Polyamide) Roller Cages

An alternative opportunity exists for this measure, as introduced earlier in our report. That is the replacement of brass for polyamide roller cages at the next appropriate maintenance interval. We are not able to assess this in an economic sense as it has almost no cost.

The benefit will accrue over time, as a function of the maintenance intervals for wagons.

7.3.2 Measure M1-Derailment Detection

We have assessed only those measures that invoke an emergency braking (M-1a), not those that provide an alarm to the train driver (M-1b). The latter would require the train driver to take appropriate action although it is difficult to envisage an appropriate action that does not involve bringing the train to the prompt stop.

We have not identified any measures of type M-1b on the market, although we have to conclude that these would be more expensive that the "simple" M-1a measures. Additional technology would be required, possibly involving the provision of power, transmitting and receiving technology or some other form of alarm transfer. There is also likely to be a substantial training requirement to instruct the train driver how to react in an alarm situation.

Considering M-1b measures we therefore cannot conclude that these measures bring the same benefit as M-1a measures as new failure modes are introduced, including human error.

8.0 Sensitivity Analysis

8.1 Motivation

It is necessary for a study of this complexity to make certain assumptions regarding modelling parameters; this work is no different in that respect.

Whilst we have endeavoured to research and validate our assumptions, it is prudent to test the key assumptions to determine if the results are robust when subject to reasonable variance.

This is the purpose of our sensitivity analysis.

8.2 Method and Results

We considered two cases:

1. A minimising set of parameters; these present what we consider to the reasonable "worst case" in minimising the interests of each measure. These concentrate on:
    a. The assessed reasonable minimum effectiveness of the measure (leading to a reduced number of derailments avoided / detected and hence reduced benefit).
    b. The assessed reasonable increased application scope for the measure (leading to an increased quantity of that measure and hence an increased cost).
2. A maximising set of parameters; these present what we consider to the reasonable "best case" in maximising the interests of each measure.
    a. The assessed reasonable maximum effectiveness of the measure (leading to an increased number of derailments avoided / detected and hence increased benefit).
    b. The assessed reasonable reduced application scope for the measure (leading to a reduced quantity of that measure and hence a reduced cost).

We have limited our attention to application scope and effectiveness. Our set of minimising and maximising parameters is presented at Appendix I of this report and the results below.

Table 8 Quantitative Analysis (Sorted by Benefit / Cost ratio) – Minimising Parameters

		Net Present Values			Benefit / Cost Ratio			Internal Rate of Return		
Rank	**Measure**	**10 years**	**20 years**	**40 years**	**10 Years**	**20 Years**	**40 Years**	**10 years**	**20 years**	**40 years**
1	P13-WLID/WIM	171	511	896	1.5	**2.5**	3.6	12%	17%	17%
2	P28-Roller Cages	-60	56	188	0.7	**1.2**	1.8	-7%	3%	5%
3	P15 Bogie Hunting Detector	-121	47	237	0.7	**1.1**	1.6	-8%	2%	4%
4	P11-BAM	-188	42	301	0.6	**1.1**	1.6	-9%	1%	4%
5	M1a-Derail Det All Freight	-601	-59	567	0.6	**1.0**	1.4	-11%	-1%	3%
6	M1a-Derail Det RID	-16	-6	5	0.5	**0.8**	1.1	-14%	-3%	1%
7	M1a-Derail Det All DG	-103	-42	27	0.5	**0.8**	1.1	-14%	-3%	1%
8	F7-Sliding Wheel Detector	-42	-17	11	0.5	**0.8**	1.1	-15%	-3%	1%
9	P10&12-HABD/HWD	-530	-295	-30	0.4	**0.7**	1.0	-17%	-4%	0%
10	P16-Wheel Profile	-170	-97	-15	0.4	**0.7**	1.0	-17%	-5%	0%
11	P18-Track Geometry	-453	-697	-972	0.5	**0.5**	0.5	N/A	N/A	N/A
12	P1-Check Rail	-1,597	-1,597	-1,595	0.1	**0.1**	0.2	N/A	N/A	N/A
13	P2-Track Lubrication	-446	-743	-1,080	0.1	**0.1**	0.1	N/A	N/A	N/A
	P19-Clearance Flange Groove	Not modelled								
	F6-Anti Lock Device	Not modelled								

Table 9 Quantitative Analysis (Sorted by Benefit / Cost ratio) – Maximising Parameters

		Net Present Values			Benefit / Cost Ratio			Internal Rate of Return		
Rank	Measure	10 years	20 years	40 years	10 Years	20 Years	40 Years	10 years	20 years	40 years
1	P13-WLID/WIM	409	806	1,257	3.2	**5.4**	7.8	56%	57%	57%
2	P28-Roller Cages	190	386	608	2.9	**4.9**	7.1	45%	47%	47%
3	P15-Bogie Hunting Detector	93	307	548	1.4	**2.3**	3.4	10%	15%	16%
4	M1a-Derail Det RID	12.45	41.34	74.30	1.39	**2.3**	3.23	0.09	0.15	0.15
5	P11-BAM	78	346	649	1.2	**2.1**	3.0	6%	12%	13%
6	F7-Sliding Wheel Detector	7	47	92	1.1	**1.9**	2.7	3%	10%	11%
7	M1a-Derail Det All DG	-15	105	242	1	**1.5**	2	-0	0	0
8	P16-Wheel Profile	-19	79	189	0.9	**1.4**	2.0	-3%	5%	7%
9	M1a-Derail Det All Freight	-212	593	1,516	0.9	**1.4**	2.0	-4%	5%	7%
10	P10&12-HABD/HWD	-484	-218	83	0.5	**0.8**	1.1	-15%	-3%	1%
11	P18-Track Geometry	-293	-439	-605	0.6	**0.6**	0.6	N/A	N/A	N/A
12	P1-Check Rail	-267	-178	-76	0.4	**0.6**	0.8	-20%	-6%	-1%
13	P2-Track Lubrication	-110	-182	-264	0.6	**0.6**	0.6	N/A	N/A	N/A
14	P19-Clearance Flange Groove	Not modelled								
15	F6-Anti Lock Device	Not modelled								

We have not modelled F6-Anti lock device as it considered clear from our reference case that it cannot be cost-effective. Further, we have eliminated P19-Clerance of Flange Groove as we believe our reference case already shows this measure in its best possible light and it still remains outside the top ten when compared with other measures (and this is a measure that we do not consider the Agency would be minded to make a specific recommendation on as it should be part of each IM's SMS).

We note here that although there is some re-ordering of priority our list of top ten measures remains unchanged.

8.3 Summary and Results Discussion

We were surprised to note measure F-7 appearing towards the top of the ranking (reference and sensitivity), however we do acknowledge that in our consultation exercise at least one IM did state this to be a known problem. Although the quantity of avoided derailments is relatively low, the cost of the measure is also relatively low, with low maintenance and upkeep costs.

Also measure P-28 has been assessed on the basis of fitting polyamide roller cages with immediate effect. We have also discussed an alternative option which is for the replacement of brass for polyamide roller cages at the next scheduled maintenance interval for axles / axle boxes. This is almost a zero cost option, although the benefits would take longer to materialise, and be a function of the maintenance cycle for freight wagons.

Measure P-11 would involve a radical departure from the existing means of addressing hot axle box derailments, which are controlled in the EU through other means. If these other means can be successful in reducing this as a derailment cause then the benefit of BAM will diminish also.

9.0 Qualitative Assessment

9.1 Technical Measures

9.1.1 Measure P-9: Interlocking Of Points Operation While Track Occupied

Our analysis [3] of accidents associated with points movement under a train indicates a small number of derailments from this cause mostly resulting from a lack of train detection / interlocking protection. These accidents usually occur at station entrances and exits. We estimated [3] 11 per annum, mostly low speed. (We have not considered shunting operations derailments, of which there are many.) Due to the relatively low number of derailments, and the relatively low consequence of such derailments, we have not researched data for a quantitative analysis.

Whilst this is the case, some locations could be addressed by a relatively low cost “fix”. In particular, if the point is electrically operated centrally from a signal box then the cost to implement a solution could be relatively small (we estimated a cost of €10,000 [2] for an additional track circuit (plus installation costs)). Also, we are able to assume that interlocking protection is very effective, as this is a high integrity system (although the possibility for human error exists).

We feel that is unlikely that the Agency would consider a specific recommendation for this measure on the basis of its low risk and also that such interlocking is not fitted in higher risk locations. Whilst we therefore do not offer this as a recommendation, it may prove cost-effective in mitigating a number of lower consequence freight (and passenger) train derailments and could form the basis of an advisory notice.

9.1.2 P-20: Ultrasonic Rail Inspection

Our analysis [3] of accidents associated with rail failures indicated up to 18 derailments per year annually potentially resulting from this cause. We also recognise that ultrasonic rail inspection is an effective technique to combat this problem.

However, whilst this is the case we note that this measure is extensively applied already. We therefore conclude that it is not the technical measure that requires strengthening; rather it is the frequency of its usage and also the analysis and implementation of findings that should be addressed which we consider an organisational issue.

9.1.3 Measure P-34: Secure Brake Gear Underframe

Our analysis [3] of accidents associated with braking components becoming loose and falling from a train indicated a small number of derailments potentially resulting from this cause (approximately 7 freight train derailments annually).

We consider that the cost of applying this measure to all freight wagons currently not equipped with a safety sling or appropriate containment system is likely to prove expensive as it will require an engineered solution bespoke to the wagon type. It is also possible that the measure may introduce its own risks, with the possibility that the safety sling itself becomes a derailment risk if not properly maintained.

We therefore have concluded that this measure would not be suitable for recommendation by the Agency.

9.2 Operational Measures

9.2.1 P-40: Qualified and Registered Person Responsible for Loading

Loading errors can contribute significantly to freight train derailments, usually in combination with other defects such as poor train handling or adverse track geometry. Control of such events is covered by national and local rules, which in some cases include the use of externally qualified loading personnel.

To strengthen this control through the EU, it could be considered to require the qualification and registration of loading personnel. However, although the problem of train loading is an issue of importance, we question how effective a measure like this may be. In particular:

- Freight train loading rules and controls are already in place, and allocated to persons through each RU's safety management system. An external qualification is unlikely, in our opinion, to have a significant impact in reducing the incidence of such events.
- The costs associated with designing and maintaining a qualification system is likely to be expensive as well as time consuming to implement.

We consider that better enforcement of existing controls is likely to be a more fruitful approach and therefore do not consider this measure further.

9.2.2 P-41: Locomotive and First Wagons of Long Freight Trains in Brake Position G; P-42: Limitations of Brake Action

We identified these as examples of existing measures that are currently applied in many countries, where required. There are potential drawbacks also with these measures in that they may reduce the braking effort available to the operator and therefore may contribute to derailments and other accidents or incidents.

On the basis that measures of this type are based on local operating conditions, it would not be appropriate or possible to propose an EU wide rule covering the intent. It is therefore a matter for national and company attention and we do not consider this further.

9.2.3 P-43: Dynamic Brake Test On-route

Some countries, such as Sweden, Finland and Norway support this functionality. However, we consider [3] that the potential in terms of derailment avoidance is relatively small and is unlikely to support making this a special provision.

It would be considered that a decision on this topic is best placed at the National level. We do not consider this further.

9.2.4 P-46 Not Allowing Traffic Controllers and Drivers to Override Detector Alarms

We have reported [3] a number of accidents that have occurred despite a warning being provided to the traffic controller and the incident train being allowed to continue. In this regard we consider that the use of the use of more modern integrated monitoring detection stations will go some way to eliminating this problem.

This is also conditioned by local operating constraints such as the location of detection stations and the availability of inspection locations.

All national "rule books" and operating instructions deal with operating in degraded conditions, and this we believe should continue to the case for alarm management.

9.2.5 P-47: Wagons Equipped with a Balance to Detect Overload in Visual Inspection

This is an interesting measure that has a role on a voluntary basis. It may provide partial protection against loading errors, in particular skew loading. Such a measure may be useful when a load is containerised and cannot easily be inspected.

Whilst we cannot consider that an EU regulation may be developed for this specific measure, it may be put forward as an advisory note for the voluntary consideration of wagon owners.

9.3 Organisational Measures

9.3.1 P22 to P-25: EU Intervention Limits

We have considered the issue of general maintenance for side-tracks at measures P-18 and P-21. As a separate issue we address the issue of intervention limits. This would apply to the main-line network.

It is clear that derailments, particularly those which are attributable to track twist, are a major concern. We estimated between 34 and 50 per annum; these include cases where track twist (for example) are within existing safety limits, but due to unfortunate freight train composition and loading (which may also be within relevant criteria) combine to cause a derailment. It may be the case that future possible changes in freight traffic, more containerisation and increased use of single axle wagons may require these parameters to be addressed just to maintain the status-quo. Further, for an interoperable and open railway, track parameters should be as consistent as possible so that freight train can pass safely through each country. A system of common and stricter safety limits and intervention limits would be a step forward.

Whilst we have estimated the potential benefit we cannot estimate the effort and expense that would be required to bring the EU railway up to a similar standard. We therefore are unable to perform a quantified analysis for this group of measures.

We also note that there would be some significant hurdles to cross regarding what a revised set of safety and intervention limits might be, the capture of these in a revised Infrastructure TSI for and then the implementation of these through the EU railway system.

We have therefore not considered this group of measures beyond this discussion.

9.3.2 F-2: Awareness Programme for Rolling Stock Maintenance

During our consultation exercise it was reported by IMs that some rolling stock operating on their networks was of a poor standard / poorly maintained. Also, we have identified a number of specific measures related to this issue, these being:

- P-35: Regular greasing and checks of rolling stock buffers.
- P-36: Wheel-set integrity inspection.
- P-39: Double check and signing of safety-classified maintenance operations.

If we can include hot axle box derailments and axle failures in the category of rolling stock maintenance related problems, then the benefit in terms of avoided derailments is very significant indeed. We are however unable to estimate the expense that may be required, in terms of increased maintenance, that would make significant in-roads into this problem.

On the basis of their being more than 100+ freight train derailments associated with wheel-set and axle failures, and with an average cost that may approach €1,000,000 per derailment [3] would suggest a substantial investment could be justified.

We may consider two options:

1. Initially the development of an awareness training programme, that sought to concentrate on main rolling stock maintenance derailment causes, and best practice (which could include measures P-38 in addition to those listed above). This could possibly be developed through the Agency, and rolled out to RUs and Entities in Charge of Maintenance (ECMs).
2. A second set of measures directed towards NSAs and concerned with Supervision of this aspect.

10.0 Other Issues

10.1 Identified Drawbacks

We have not so far considered potential drawbacks associated with our quantified and qualitative assessments of measures.

10.1.1 Provoking Derailments

We consider that measures P1-Check Rail and M1-Derailment Detection (types that apply full emergency train braking) have a common drawback. That is that they each may provoke derailments (albeit not very frequently).

For example an accident in Finland on 09 March 2009 had as a cause "***ice packed in the flange way between the crossing frog and the check rail in a turnout***". Poor alignment and maintenance of check rails may also contribute to derailments.

Similarly, train compression under heavy braking is also a known cause of derailments and hence a false alarm of some M1 devices may lead to this outcome. In this respect we note that CSM Regulation, Annex I, point 2.5.4 states:

For technical systems where a functional failure has credible direct potential for a catastrophic consequence, the associated risk does not have to be reduced further if the rate of that failure is less than or equal to 10^{-9} per operating hour.

It is possible that these measures may require to be demonstrated to meet this stipulation prior to any further recommendation being made.

10.1.2 False Alarms

False alarms are a potential issue with the majority of technical measures discussed in this report although some may have more direct impacts than others.

Measures based on trending or to detect early defects are less likely to have a service affecting consequence. We consider technical measures ***P11-BAM; P13-WLID; P15-Bogie Hunting; P16-Wheel Profile*** fall into this category. Alarms or warnings are likely to be dealt with at a convenient time without undue impact on the operational railway.

Measure ***P10/12-HABD/HWD and F7-Sliding Wheel Detectors*** are, in our opinion, more likely to have operational impacts as they may need more immediate attention which could involve bringing the incident train to an immediate stop (although in the case of the latter this is likely to be in at a location where an inspection is relatively straightforward and not service affecting).

10.1.3 Market Competition / Advantage

Measure F-7-Sliding Wheel Detectors are as far as we are able to establish a technology (in the form that we have considered) that is provided by a small number of suppliers.

10.2 Potential Combinations

A number of measures address the same issues (which is not surprising since there are a relatively small number of high likelihood derailment causes).

Detection of hot axle box conditions is covered by ***P10/12-HABD/HWD; P11-BAM; P13-WLID*** (indirectly through the detection of leading indicators). Measure ***P28-Roller Cages*** also addresses the same problem.

The measures are not mutually exclusive however, and could be applied in combination. For example ***P11-BAM*** could be applied to long distance freight routes to provide optimum coverage at minimum cost (compared to other measures that require a much denser population of detection sites). This could be supplemented by the use of measure ***P10/12-HABD/HWD*** for shorter freight routes and strategic points of the network at critical locations.

Further, to the best of our knowledge, measure ***P28-(Polyamide) Roller Cages*** does not impinge on the effectiveness of existing detection systems, although this may need to be tested to confirm this manufacturer's claim. Further, it could be postulated that polyamide roller cages offer improved performance under emergency running and may allow an extension of the distance between detection sites thus allowing a lower density level for measure ***P10/12-HABD/HWD.***

11.0 Conclusions and Recommendations

11.1 Important Remarks

It is important to clarify that this report looks at the ***potential for improvement***, and is not an absolute assessment of the efficiency of all measures that are applied today. Therefore it follows that if a measure is applied extensively already there is little room for improvement through the further application of that measure. For this reason some measures that are extensively applied already are not considered in this work. Their omission should not be considered as suggesting such measures are not efficient.

In this context the measures listed in this section can be seen as efficient in addressing the potential reduction in risks associated with freight train derailments and providing the detailed background against which public policy can be formulated.

The assessment of measures does not consider the way or the order in which these interventions should be pursued, for example it is not considered whether these interventions should be introduced in a mandatory or voluntary way or whether the measure should be introduced as an EU harmonised measure or only within certain member states or only certain companies.

11.2 Efficiency Assessment of Measures

11.2.1 Technical Preventative Measures

We consider the following technical measures as being efficient (they have a positive or unity benefit / cost ratio in our reference case and all sensitivity studies):

- P13-Wheel Load Impact Detectors / Weighing In Motion
- P28-Replacement of Brass for Polyamide Roller Cages
- P15-Bogie Hunting Detectors
- P11-Bearing Acoustic Monitoring

Considering measure P28, we have considered an immediate replacement of brass for polyamide roller cages. We have also discussed an alternative option which is for the replacement of brass for polyamide roller cages at the next scheduled maintenance interval for axles / axle boxes. This is almost a zero cost option, although the benefits would take longer to materialise, and be a function of the maintenance cycle for freight wagons.

Potential drawbacks to the use of these measures (excluding measure P28) relate to the rate of false alarms. To some extent these can be overcome by the use of good alarm management processes. Further false alarms from those technical measures that are based on early defect detection are unlikely to have an immediate operational impact.

In addition the following two measures are efficient based on the parameters in our reference case:

- F7-Sliding Wheel Detectors
- P16-Wheel Profile Detectors

Potential drawbacks include false alarms as reported above. Finally, measure F7 is to the best of our knowledge a market with only a small number of suppliers. This may give rise to market advantage to existing suppliers of these systems if they were to form the basis of formal recommendation.

11.2.2 Technical Mitigation Measures

We consider the following mitigation measure as potentially efficient if the significant identified drawbacks could be solved:

- M1a-Derailment Detection (with automatic brake application) applied to All Freight Trains

This present assessment is fully in line with the previous assessment made by the Agency [7]. The significant drawback previously identified is confirmed by the present study and the related accident analysis. A false alarm of such a device may lead to train compression which is a contributory cause of freight train derailments (and also a significant operational disruption). In this respect we note that CSM Regulation, Annex I, point 2.5.4 states:

For technical systems where a functional failure has credible direct potential for a catastrophic consequence, the associated risk does not have to be reduced further if the rate of that failure is less than or equal to 10^{-9} *per operating hour.*

(Measure P1: Check rail has similar disadvantages, although this is not considered efficient by our assessment.)

Finally, we acknowledge an alternative type of derailment detection device which provides an alarm to the train driver when a derailment is suspected, but without an automatic brake application (type M1b). We are however not aware of these being available on the market (for freight application). We consider that an assessment of these devices, considering the human factors issues involved and their costs would be required before these could be formally assessed.

11.2.3 Organisational Measures

We note that the measures above are technical measures that are aimed at addressing, in some cases, organisational problems. Therefore we would add the following organisational and supervision items:

- F-2: Awareness Programme for Rolling Stock Maintenance. This measure may serve to address the problem of poor maintenance standards of rolling stock. This may include training that sought to concentrate on main rolling stock maintenance derailment causes (which can be extracted from our task report, [3]) and best practice. This measure may be followed by increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.

- P-18: Track Geometry (all tracks). Although the case for improvements in this area are not conclusively made from a quantified perspective, the problem of poor track geometry (in particular track twist), and the possible requirement to improve this aspect just to maintain current performance levels (see Section 9.3.1) should be considered. This is of course an area for each IMs own management system. However a specific measure in this regard must be concerned with increased supervision of these parameters by NSAs to ensure that practicable risk reduction objectives are being applied.

The two measures above represent significant contributors to the derailment problem and organisational failures of individual IMs and RUs in fulfilling their obligations.

12.0 References

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13.0 Appendix I: Sensitivity Parameters

Table 10 Sensitivity Parameters (Minimising Parameters)

Measure	Max Potential Benefit (Ref)	Net benefit (Ref)	Sensitivity (Eff.min)	Sensitivity (App.min)	Justification / Comment
P-1: Check Rail	25 avoided derailments	23 avoided derailments	Measure effectiveness reduced to 75%. New net benefit = 19 avoided derailments.	Application scope doubled. (Hence 3,230 km.)	Existing measure well proven. Effectiveness considered to be quite tightly constrained around reference value. Small negative variation applied. Application scope estimated, and could have high variance.
P-2: Track Lubrication	25 avoided derailments	13 avoided derailments	Measure effectiveness reduced to 25%. New net benefit = 6 avoided derailments.	Two lubrication units per side track required. (Hence 19,266 units.)	Derailment prevention is a secondary benefit of this measure. Effectiveness as a derailment prevention measure difficult to establish, which is reflected in the selection of sensitivity parameters.
P-10 & P-12: HABD/HWD	60 avoided derailments	53 avoided derailments	Measure effectiveness reduced to 85%. New net benefit = 50 avoided derailments.	No change	Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small negative variation applied Application scope – no significant variation likely
P-11: BAM	53 avoided derailments	47 avoided derailments	Measure effectiveness reduced to 85%. New net benefit = 44 avoided derailments.	One unit per 300 km, hence 960 units.	Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small negative variation applied Application scope - shorter routes in Europe compared with existing installed base may require more units.
P-13: Wheel Load / Impact Detectors	100 avoided derailments	74 avoided derailments	Measure effectiveness reduced to 70%. New net benefit = 67 avoided derailments.	One unit per 300 km, hence additional 832 units.	Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small negative variation applied Application scope – to adequately cover short-haul routes more units may be required (assumed as BAM)
P-15: Bogie Hunting Detectors	Max: 47 avoided derailments	42 avoided derailments	Measure effectiveness reduced to 75%. New net benefit = 35 avoided derailments.	One unit per 300 km, hence 960 units.	Not significantly installed in Europe. Sensitivity value selected to reflect unproven in Europe. Application scope - shorter routes in Europe compared with existing installed base may require more units.

Measure	Max Potential Benefit (Ref)	Net benefit (Ref)	Sensitivity (Eff.min)	Sensitivity (App.min)	Justification / Comment
P-16: Wheel Profile Monitoring	Max: 23 avoided derailments	20 avoided derailments	Measure effectiveness reduced to 80%. New net benefit = 17 avoided derailments.	One unit per 300 km, hence 934 additional units.	Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small negative variation applied Application scope – to adequately cover short-haul routes more units may be required (assumed as BAM)
P-18 & P-21 Track Geometry	Max: 129 avoided derailments	58 avoided derailments	No change	10% cost increase in year 1, and subsequent years. Hence €187 mill and €93 mill respectively.	Effectiveness no change from reference value. Application scope – amount of track requiring additional attention estimated.
P-19: Clearance of Flange Groove	Not modelled. We consider that we have already applied optimistic parameters and shown this measure to be able to be discarded without further consideration.				
P-28: Polyamide Roller Cages	44 avoided derailments	33 avoided derailments	Measure effectiveness reduced to 50%. New net benefit = 22 avoided derailments.	50% increase in brass roller cages (3 million)	Effectiveness unproven scientifically, reflected in reduction in this parameter. Application – increase in quantity of brass roller cages
F-6: Anti-lock Devices	Not modelled. No further negative assumptions applicable.				
F-7: Sliding Wheel Detectors	8 avoided derailments	7 avoided derailments	Measure effectiveness reduced to 75%. New net benefit = 5 avoided derailments.	50% increase in density, hence 1980 units.	Existing measure well proven (although not in Europe). Sensitivity value selected to reflect unproven in Europe. Application scope – we consider there to be some uncertainty around the density required to achieve the assigned benefit. A 50% increase in density is modelled for this measure
M1- Derailment Detection	N/A	N/A	Measure effectiveness reduced to 90%.	No change	We believe the measure is effective with little variance. Small negative variation applied. Application scope – unchanged.

Table 11 Sensitivity Parameters (Maximising Parameters)

Measure	Max Potential Benefit (Ref)	Net benefit (Ref)	Sensitivity (Eff.min)	Sensitivity (App.min)	Justification / Comment
P-1: Check Rail	25 avoided derailments	23 avoided derailments	No change	Application scope halved to 800 km.	Effectiveness not considered to significantly exceed reference value. Application scope estimated, and could have high variance.
P-2: Track Lubrication	25 avoided derailments	13 avoided derailments	Measure effectiveness increased to 75%. New net benefit = 19 avoided derailments.	One lubrication units per side track required. (Hence 9,633 units.)	Derailment prevention is a secondary benefit of this measure. Effectiveness as a derailment prevention measure difficult to establish, which is reflected in the selection of sensitivity parameters. Small positive variation applied.
P-10 & P-12: HABD/HWD	60 avoided derailments	53 avoided derailments	Measure effectiveness increased to 95%. New net benefit = 56 avoided derailments.	No change	Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small positive variation applied. Application scope – no significant variation likely
P-11: BAM	53 avoided derailments	47 avoided derailments	Measure effectiveness increased to 95%. New net benefit = 50 avoided derailments.	No change	Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small positive variation applied Application scope – no significant variation likely
P-13: Wheel Load / Impact Detectors	100 avoided derailments	74 avoided derailments	Measure effectiveness increased to 80%. New net benefit = 78 avoided derailments.	No change	Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small positive variation applied Application scope – no significant variation likely
P-15: Bogie Hunting Detectors	Max: 47 avoided derailments	42 avoided derailments	Measure effectiveness increased to 95%. New net benefit = 44 avoided derailments.	No change	Effectiveness: Small positive variation applied Application scope – no significant variation likely
P-16: Wheel Profile Monitoring	Max: 23 avoided derailments	20 avoided derailments	Measure effectiveness increased to 95%. New net benefit = 21 avoided derailments.	No change	Existing measure well proven. Effectiveness considered to very tightly constrained around reference value. Small positive variation applied Application scope – no significant variation likely

Measure	Max Potential Benefit (Ref)	Net benefit (Ref)	Sensitivity (Eff.min)	Sensitivity (App.min)	Justification / Comment
P-18 & P-21 Track Geometry	Max: 129 avoided derailments	58 avoided derailments	No change	10% cost decrease in year 1, and subsequent years. Hence €153 mill and €76 mill respectively.	Effectiveness no change from reference value. Application scope – amount of track requiring additional attention estimated.
P-19: Clearance of Flange Groove	Not modelled. We consider that we have already applied optimistic parameters and shown this measure to be able to be discarded without further consideration.				
P-28: Polyamide Roller Cages	44 avoided derailments	33 avoided derailments	Measure effectiveness increased to 85%. New net benefit = 37 avoided derailments.	50% decrease in brass roller cages (1.3 million)	Effectiveness unproven scientifically, reflected in reduction in this parameter. Application –decrease in quantity of brass roller cages
F-6: Anti-lock Devices	Not modelled. We consider that we have already applied optimistic parameters and shown this measure to be able to be discarded without further consideration.				
F-7: Sliding Wheel Detectors	8 avoide8d derailments	7 avoided derailments	Measure effectiveness reduced to 95%. New net benefit = 8 avoided derailments.	No change	Existing measure well proven (although not in Europe). Sensitivity value selected to reflect unproven in Europe. Application scope – no significant variation likely
M1- Derailment Detection	N/A	N/A	Measure effectiveness increased to 95%.	No change	We believe the measure is effective with little variance. Small positive variation applied. Application scope – unchanged.

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