DNV·GL

RESEARCH ON RISK MODELS AT THE EUROPEAN LEVEL

Final Report

European Railway Agency

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Objective: To provide a short screening review of existing railway risk models.

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1 EXECUTIVE SUMMARY

The European Railway Agency (the Agency) has commissioned DNV GL to undertake a short screening exercise to review relevant risk models used in the railway domain and in the oil/gas and aviation sectors. The focus of this screening exercise is on quantitative risk models although information on qualitative approaches has been collected as well where possible.

The primary means of identifying information on risk models was a short survey of National Safety Authorities undertaken in July 2015. This identified eight Member States that reported using a quantitative risk model and a further five using a qualitative risk model. Details of these quantitative models and publically available qualitative models were then captured in a standard template agreed with the Agency, where possible, noting that all the models were confidential and not available for public examination. Five Member States reported having neither a qualitative nor a quantitative risk model.

A review of the risk modelling used in the oil and gas and in the aviation sectors was additionally made to explore if these sectors used any different techniques that might form a technique relevant for railway risk modelling.

2 INTRODUCTION

The definition of risk model and risk profile used in this screening exercise is:

- **Risk Model:** Tool designed to draft the risk profile of an entity which could be a railway organisation or a Member State.
- **Risk Profile:** List of risks or unwanted events to which the entity is exposed at a given point in time and which may lead to an accident.

Risk models are used in a number of industrial sectors ranging from nuclear to oil/gas. They are used for a variety of purposes which can govern the way the model is structured and populated with data. The commonly used purposes for a risk model are:

- For low frequency high consequence events in which accidents can occur only once every few years a model can be used to provide an indication of underlying risk, so that years with no accident are not viewed as overly safe and years with an accident as overly dangerous.
- To provide a prediction of future risk by extrapolating the existing risk picture into the future.
- To identify areas of the overall risk profile that should be subject to greater supervisory or management attention.
- To assess the impact of changes in technology or operational practise on the risk profile and additionally support a case for investment in these changes.

The Agency is aware that a number of railway risk models are used in differing EU Member States and wishes to understand further the basis of these models in terms of what they model, what data input is necessary and the principles behind the modelling. The Agency is further interested in whether these models could be adapted to the EU level.

The screening exercise then seeks to further the Agency's understanding in this area by preparing an overview of the differing theoretical techniques that are available to support risk modelling, providing an overview of the main risk modelling techniques used in the oil/gas and aviation sectors, and by surveying the National Safety Authorities in the European Union plus Norway, Switzerland and the Channel Tunnel for their existing use of railway risk models.

3 THEORETICAL APPROACHES TO RISK MODELLING

3.1 Objective

This section outlines various ways in which risk models can be constructed, and considers which approach would be most appropriate for European railways. It is based on the review of existing models in the aviation, oil & gas and railways industries. It also considers other approaches that have been proposed in the literature. It is written from DNV GL's existing knowledge, based on practical experience of model development in different fields.

3.1.1 Definition of Risk Models

In general, risks refer to the likelihood and consequences of events with uncertain impacts on people, property, business or the environment. In principle, risks may include beneficial impacts, but in most cases they refer to negative impacts, i.e. harm. This project has a particular focus on risks of accidents to passengers. This is equivalent to what in other industries would be described as major accident safety.

Therefore the review concentrates on quantitative safety risk models.

3.2 Types of Risk Models

Risk models come in many different and overlapping forms. Nevertheless, the following broad categories of construction can be distinguished:

- Statistical models, based on analysis of accident data. Some industries (such as the maritime industry) have sufficient data to base a risk model entirely on statistical analyses of previous accidents. Typically this requires a large database of previous accidents, broken down by causes and consequences. If complete, this dataset represents historical societal risks, and a statistical breakdown of it shows the accident contributors. Typically such an analysis must also allow for trends and incomplete reporting. To turn it into a model of individual risks merely requires corresponding activity data. Such an analysis is only a "model" in a loose sense, and could better be described as a database. However, some applications are able to make predictions for individual installations by the use of modification factors or regression analyses to represent the effects of key risk controls.

- Fault tree/event tree models. Many industries (including the aviation and nuclear industries) have extensive incident data and more limited data on major accidents, and combine this through fault trees and event trees, showing how incidents can escalate to accidents, and develop with different consequences. The base events of the fault tree may be quantified using incident experience and activity data, or by using expert judgement, or generic data from other industries. Such models can make predictions for individual installations by adjusting the probabilities of appropriate branches of the trees. They provide a visual representation of how different factors combine to give the overall risk. They are appropriate when the risk controls are mainly hardware that naturally falls into discrete "failed" or "working" states. Some applications condense these models into qualitative "bow-ties", showing how the main risk controls prevent accident occurrence and development.

- Safety management models. In many industries (such as mining and healthcare), safety management activities have a greater influence on the risk than hardware. The factors that underlie good safety management have been identified, and some audit techniques are able to quantify the performance of an individual organisation using scoring techniques. The overall safety management scoring system is in effect a type of risk model, as it shows how performance in individual areas affects the overall risk.

- Influence models. A few research models (notably in the aviation industry) have attempted to represent the contribution of human and organisational factors in accident causation through the use of influence models. These factors can vary continuously between "very good" and "very poor" performance. This approach can integrate measures of safety management performance with fault tree/event tree models. Some such models are implemented as Bayesian Belief Nets (BBN), which comprise a fully probabilistic representation of the possible states of each causal factor and the linkages between them. Some analysts see these as the future direction of risk modelling, as they follow a rigorous theoretical framework, compared to the approximations involved in fault tree/event tree models. However, data and computational limitations mean that these are at present also very simplified representations of reality.
- Summed failure case models. Some industries (such as the oil & gas industry) make extensive use of consequence models for the release of hazardous materials, representing their discharge, dispersion and ignition, and consequent fire, smoke, explosive and toxic impacts. These consequence models are based on theoretical calculations calibrated against practical experiments. Risk models are formed by weighting the consequences according to the historical frequencies of releases. The risks are calculated for individual failure cases, and the discrete cases are summed to obtain the total risks for each installation.
- Pathway models. Some industries (such as the food and chemicals industry) are concerned with the risks of accidental product pollution or ingestion along specific pathways from source to receptor. These make use of probabilistic transport models for the source and fate of hazardous materials in the food chain or natural environment. These consequence models may be based on laboratory or field experiments. Such models make predictions for individual installations by using site-specific data at each step. They provide a probabilistic model of how successive factors combine to give the overall risk.
- Simulation models. Some industries (such as the oil & gas and railway industries) also make use of simulation models to manage operational reliability, and such models provide an alternative way of quantifying the accident sequences represented in fault tree/event tree models. Simulation models represent the development of accident causes and consequences through time, and can take account of inter-dependencies and emergency response in a more sophisticated way. The risks are calculated for individual failure cases, with numerous possible influences represented by Monte Carlo sampling from their probability distributions, and the results are summed to obtain the total risks for each installation.

3.3 Factors Underlying the Choice of Model Type

3.3.1 Risk Ownership

DNV GL observes from the comparison of aviation, oil & gas and railway models in this survey that a key reason for the difference between industries is the ownership of the models, which reflects the nature of the industry and the underlying ownership of the risks.

For instance, the oil & gas industry has a regulatory regime that places most of the responsibility for managing major accident safety onto the operators of individual installations. Typically the operator is required to produce a Safety Case explaining how safety has been managed, and this may be based in part on a quantitative risk assessment (QRA), which incorporates a risk model of the installation. Oil & gas risk models therefore tend to address individual installations, not the whole network.

As another example, the nuclear industry also places most of the responsibility for managing major accident safety onto the operator. Nuclear risk models therefore tend to address individual installations, in a way that is very similar to the oil & gas industry.

By contrast, the aviation industry has a regulatory regime that places most of the responsibility for managing major accident safety onto the aircraft designers and air traffic network managers. Individual aircraft operators are responsible for implementing the safety measures that have been agreed internationally, but do not normally perform any risk modelling. Aircraft manufacturers and air traffic control organisations are required to perform QRA and therefore require risk models. These models are specified, and sometimes developed, by international organisations that manage the certification of aircraft or the control the air traffic networks. Aviation risk models therefore tend to address the whole network, not individual aircraft.

As another example, the maritime industry also places most of the responsibility for managing major accident safety onto international rule-making organisations. QRA is performed centrally for generic vessels, in a way that is very similar to aviation.

These distinctions are somewhat simplified, because the oil & gas industry sometimes combines the risks of individual installations to show the whole industry, while the aviation industry sometimes sub-divides the network risks to show individual aircraft or airports. Nevertheless, as a broad generalisation, decentralised industries such as oil & gas tend to build network risk models by accumulating risks from individual installations, whereas integrated networks like aviation tend to start with network models and sub-divide them.

Since the railway industry at the infrastructure manager level is also a network with QRA carried out centrally, these considerations suggest that the aviation and maritime industries may provide more relevant parallels at that level than the oil & gas or nuclear industries. However, at an EU level the Railway Safety Directive (2004/49/EC) clearly places the responsibility for safety on individual railway undertakings and infrastructure managers and hence when considered at an EU level the more relevant parallel is with the oil & gas and nuclear sectors. These differences are also reflected in considering data availability (see below).

3.3.2 Data Availability

DNV GL's experience in developing risk models in different industries is that the chosen approach is strongly influenced by the availability of data to build the model. Good practice in model building dictates that the model should make use of available data. Models that are developed qualitatively, with the intention of finding appropriate data later, rarely get completed. The timescale of implementing industry-wide data collection is usually greater than the practical model lifetime.

Industries with plentiful accident data, such as aviation and maritime, tend to build models that are closely based on this data. This keeps uncertainties low, as the results are closely connected to reality, but issues arise over trends and loss of data quality, especially as accident frequencies are reduced, and when considering individual aircraft or ships, rather than the whole fleet.

By contrast, individual oil & gas or nuclear installations may have little accident experience (indeed, newly designed installations may have no operating experience at all), so their risk models are typically built up from theoretical analysis of individual failure cases, weighted by failure frequencies from other sources. By necessity, they tend to be more creative in their analysis, but inevitably the results are more uncertain.

The availability of railway accident and incident data varies across the EU. At the level of an individual railway undertaking or infrastructure manager data availability is generally very good and at the level of an individual infrastructure manager's network the railway industry might be considered more similar to the aviation and maritime industries. However this data is not always consolidated or aggregated at a Member State level and rarely at an EU level other than that required for the Common Safety Indicators. At an EU level then the railway resembles the oil/gas sector.

3.3.3 Risk Controls

In principle, the structure of a risk model should be optimised to represent the types of risk controls that are in place, since the failure of these controls naturally form the main accident causes.

Some industries, such as aviation and nuclear, have multiple barriers against accidents. This type of defence in depth means that any accident is typically a combination of many different causes, or of a specific cause that is able to affect many different barriers simultaneously. Fault tree models were developed specifically to represent this type of risk structure.

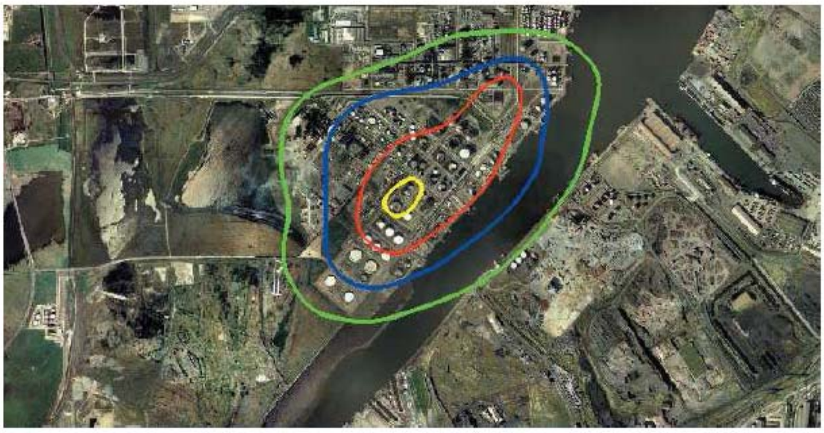
Other industries, such as oil & gas and maritime, are exposed to a greater variety of accidents, but each accident scenario has relatively few barriers to prevent it, and mitigation and evacuation may vary widely in response. This type of complexity means that an accident typically has relatively few causes, but long chains of consequences. Event tree and consequence models were developed specifically to represent this type of risk structure.

The railway industry has some features of both groups in this respect.

4 RISK MODELLING IN OTHER SECTORS

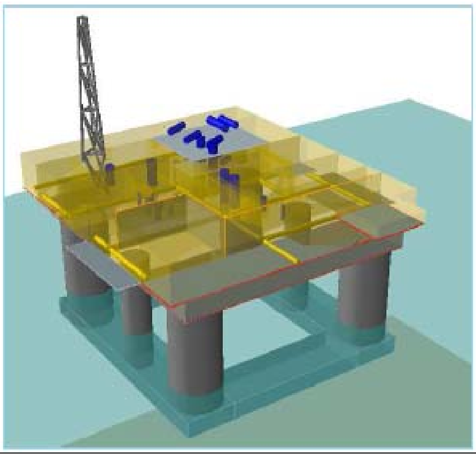
4.1 Oil & Gas Risk Models

4.1.1 Safeti

Model name /owner	Software for the Assessment of Flammable, Explosive and Toxic Impact (Safeti) – a commercial software package developed by DNV GL and licensed to over 300 organisations world-wide.
Scope /application	A software tool for carrying out quantitative risk assessment (QRA) of onshore process, chemical and petrochemical facilities. It is used to construct risk models of individual facilities, and provides flexibility to do this in different levels of detail.
Inputs	User-defined failure cases (i.e. accident scenarios) including material properties, initial pressures and temperatures, and hole sizes or release quantities; failure case frequencies; meteorological conditions, ignition source strengths and population distributions.
Modelling undertaken	Safeti analyses the consequences of each failure case, using models of discharge, atmospheric dispersion, liquid pool formation and vaporisation, fires, thermal radiation, explosions and toxic impact. It combines these with local population and meteorological conditions to obtain fatality impacts. It combines the fatality results with failure case frequencies and meteorological and ignition probabilities to quantify the risks.
Outputs	Individual risk contours, FN curves and rankings of risk contributors. Risk results are available graphically and may be overlaid on digitized maps (GIS), satellite photos and plant layouts.  Aerial photograph of plant with risk levels
Advantages	Safeti performs all the analytical, data processing and results presentation elements of a QRA within a structured framework. It is widely used and the Dutch government has adopted it as a standard approach for process plant QRA in the Netherlands.
Assumptions	Safeti assumes flat terrain, and models unimpeded gas and liquid dispersion.

Validation	The consequence models have been extensively validated against physical trials of material releases.

4.1.2 Safeti Offshore

Model name /owner	Safeti Offshore – a software package developed by DNV GL for consulting projects.
Scope /application	A software tool for carrying out quantitative risk assessment (QRA) of offshore installations. It is used to construct risk models of individual facilities, and provides flexibility to do this in different levels of detail.
Inputs	Rule-sets for developing failure cases (i.e. accident scenarios) including material properties, initial pressures and temperatures, and hole sizes or release rates; equipment populations; evacuation facilities; meteorological conditions, ignition source strengths and population distributions. The installation layout is defined using walls, decks, obstacles and ventilation in a graphical interface. 
Modelling undertaken	Safeti Offshore analyses the consequences of each failure case, using models of discharge (including isolation and blowdown) and escalation, as well as fire, smoke and explosion impacts (taking account of fire and blast protection). It combines these with platform population and evacuation, escape and rescue (EER) analysis to obtain fatality impacts. It combines the fatality results with leak frequencies derived from equipment populations and generic leak frequencies to quantify the risks.
Outputs	Individual risk values, FN curves and rankings of risk contributors. The 3D graphics show both the geometry and the consequence envelopes allowing event size to be visualized and aiding understanding of escalation predictions.
Advantages	Safeti Offshore performs the analytical, data processing and results presentation elements of a QRA within a structured framework. It is seen as the standard environment for offshore QRA in the future.
Assumptions	Safeti Offshore only models hydrocarbon releases, and does not address other risk elements such as transport accidents, collisions and structural failures.
Validation	The consequence models are based on those validated for onshore use in Safeti.

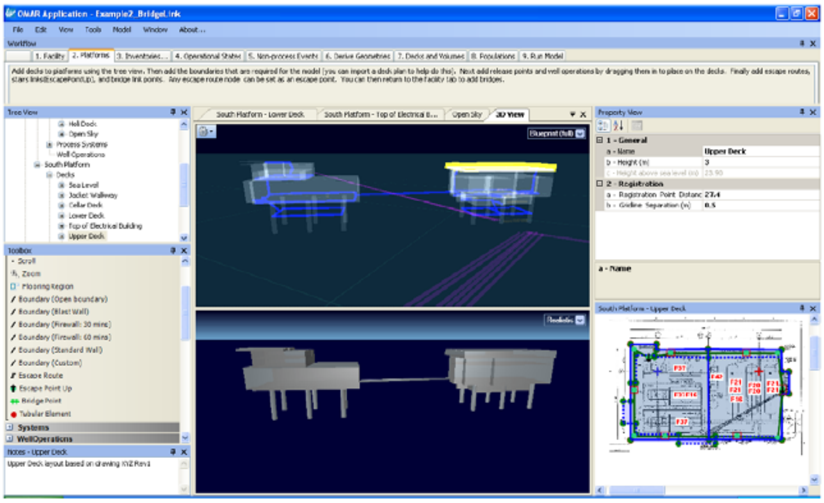
4.1.3 Soqrates

Model name /owner	Soqrates (Standardised offshore quantitative risk analysis total evaluation system) – an Excel-based package developed by DNV GL for consulting projects, but also licensed for use by offshore operators.
Scope /application	An Excel spreadsheet based software tool for carrying out quantitative risk assessment (QRA) of offshore installations. It is used to construct risk models of individual facilities, and provides flexibility to do this in different levels of detail.
Inputs	User-defined failure cases (i.e. accident scenarios) including material properties, initial pressures and temperatures, and hole sizes or release rates; equipment populations; evacuation facilities and personnel levels; and various details for non-hydrocarbon hazards. All input is spreadsheet-based.
Modelling undertaken	Soqrates analyses the consequences of each failure case, using models of discharge (including isolation and blowdown) and escalation, as well as fire and smoke impacts. It combines these with platform population and evacuation assumptions to obtain fatality impacts. It combines the fatality results with leak frequencies derived from equipment populations and generic leak frequencies to quantify the risks. Non-hydrocarbon risks are also modelled using event trees and historical data. These include non-process fires, collisions, helicopter impacts, transport accidents and occupational accidents
Outputs	Impairment frequencies, individual risk values, potential loss of life (PLL) and FN curves, broken down by hazard type and failure case. In contrast to Safeti Offshore, no visualisation of event consequence is available.

		PLL				IRPA			
Hazard	TRIF	Immediate	Escape	Evacuation	Total	Admin / Accommodation	Core Operations	Visiting Ops Support	Drilling
Process	1.316E-04	2.01E-03	0.00E+00	2.80E-05	2.04E-03	2.834E-05	3.525E-05	3.998E-05	3.654E-05
Risers	1.078E-05	2.60E-04	0.00E+00	1.76E-06	2.62E-04	4.659E-06	4.527E-06	4.562E-06	5.635E-06
Blowouts	2.259E-06	3.44E-05	0.00E+00	4.98E-07	3.49E-05	5.267E-07	5.946E-07	6.276E-07	8.183E-07
Ship Collisions	N/A	N/A	N/A	7.53E-04	7.53E-04	1.310E-05	1.310E-05	1.310E-05	1.637E-05
Helicopter Impacts	9.867E-07	8.54E-05	N/A	N/A	8.54E-05	7.114E-08	4.174E-06	4.686E-08	5.958E-08
Transport	N/A	1.70E-03	N/A	N/A	1.70E-03	2.954E-05	2.954E-05	2.954E-05	3.693E-05
Occupational	N/A	7.85E-03	N/A	N/A	7.85E-03	2.261E-05	1.273E-04	1.273E-04	3.782E-04
Non-Process Fires	9.975E-07	1.24E-05	0.00E+00	6.83E-07	1.31E-05	1.696E-08	2.818E-07	2.346E-07	3.394E-07
Other Fires	5.175E-08	1.17E-03	N/A	1.17E-04	1.28E-03	3.018E-05	2.111E-05	2.120E-05	2.615E-05
Cargo Oil Tank Fires	0.000E+00	0.00E+00	N/A	0.00E+00	0.00E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Structural Failure	N/A	0.00E+00	N/A	2.60E-05	2.60E-05	4.518E-07	4.518E-07	4.518E-07	5.648E-07
Mooring Failure	N/A	0.00E+00	N/A	0.00E+00	0.00E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Loss of Stability	N/A	0.00E+00	N/A	0.00E+00	0.00E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Total	1.47E-04	1.31E-02	0.00E+00	9.27E-04	1.40E-02	1.30E-04	2.36E-04	2.37E-04	5.02E-04
					POB	3	8	9	3
					Average IRPA	2.5729E-04			

Advantages	Soqrates performs the analytical, data processing and results presentation elements of an offshore QRA within a spreadsheet environment. It has been used to standardise the otherwise widely varying spreadsheet-based approaches to offshore QRA.
Assumptions	N/A
Validation	The consequence models are simplified versions of validated models. The leak frequencies and non-hydrocarbon risks make use of all available data.

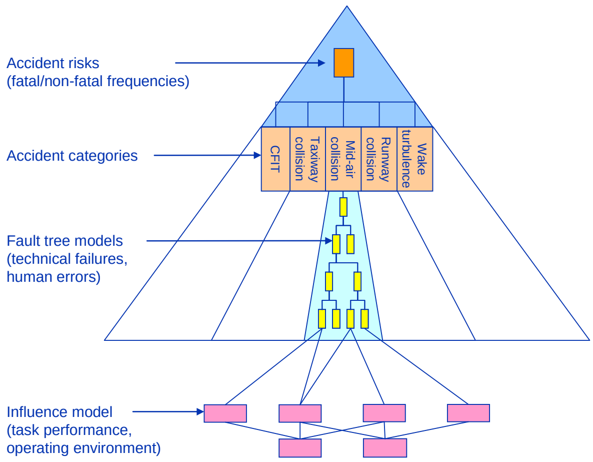
4.1.4 OMAR

Model name /owner	Offshore Major Accident Risk (OMAR) – a software package developed by Tessella for BP.
Scope /application	A software tool to apply BP's Major Accident Risk process to offshore facilities. It is used to construct risk models of individual facilities.
Inputs	User-defined platforms and subsea release sources. Each platform consists of a series of decks, with each deck containing a variety of boundaries, release sources and personnel escape routes. Users provide additional information for each volume such as ignition sources, degree of protection from smoke, etc. Variations in platform activity are modelled by dividing an operating year into one or more "Operational States" with each state consisting of a set of active process and non-process hazards, together with associated staffing levels. 
Modelling undertaken	OMAR analyses the consequences of each failure, using models of discharge (including isolation and blowdown) and escalation, as well as fire, smoke and explosion impacts. OMAR estimates the effects of explosions based on a historical database of CFD explosion simulation results. It combines these with platform population and models the movement of populations in response to fire, smoke and explosions to obtain fatality impacts. It combines the fatality results with leak frequencies derived from equipment populations and generic leak frequencies to quantify the risks. Non-process events including transportation hazards (helicopters and crew boats), environmental hazards (storms and seismic events) and ship collisions (passing and visiting vessels) are also modelled.
Outputs	Individual risk values, FN curves and rankings of risk contributors. The 3D graphics show both the geometry and the consequence envelopes allowing event size to be visualized and aiding understanding of escalation predictions.
Advantages	OMAR performs the analytical, data processing and results presentation elements of a QRA within a structured framework. The interface is user friendly, fostering study ownership at a local level in preference to reliance on centralized expert resources.

Assumptions	N/A
Validation	The consequence models are simplified versions of validated models. The leak frequencies and non-hydrocarbon risks make use of all available data.

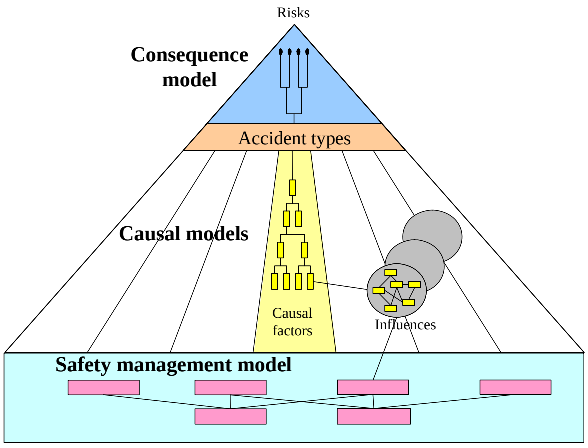
4.2 Aviation Risk Models

4.2.1 IRP

Model name /owner	Integrated Risk Picture (IRP) and Safety Target Achievement Roadmap (STAR) – a research model developed by DNV for EUROCONTROL.
Scope /application	An Excel-based fault tree and influence model representation of the contribution of Air Traffic Management (ATM) to aviation accident risks in Europe. It was used by EUROCONTROL to support safety assessments of individual air traffic control centres and of the overall Single European Sky ATM Research Programme (SESAR).
Inputs	User-defined ATM operational improvements, implementation profiles and their impacts on model elements; traffic levels, safety equipment provision and human & organisational performance standards (relative to current baseline).
Modelling undertaken	Quantification uses historical accident and incident experience combined with theoretical analyses and expert judgements. Fault tree models are used to represent specific causal factors for each accident category. An influence model represents more diffuse factors such as the nature of the operating environment and the quality of safety management, human performance and safety-critical systems.  The model adjusts the basic events and influences to represent an individual case, and propagates these through the influence model and fault tree to calculate the overall risk profile and causal breakdown. The STAR tool repeats the risk calculations for successive annual steps as traffic grows and operational improvements are implemented, in order to show whether the combined ATM system is on track to meet its risk reduction targets.
Outputs	Fatal accident frequencies, precursor incident frequencies, barrier failure and success probabilities, contributions of individual causal factors, and effects of operational improvements. Risk results are available in spreadsheet form.
Advantages	IRP provides a cumulative model of all risks in European ATM, which can be broken down to give a consistent estimate of risk in individual flights, airports or air traffic control regions.
Assumptions	IRP only addresses 5 major categories of accidents where ATM may make a significant contribution either in causing or preventing accidents. It uses quantitative fault tree and influence models which are very simplified representations of actual accidents.

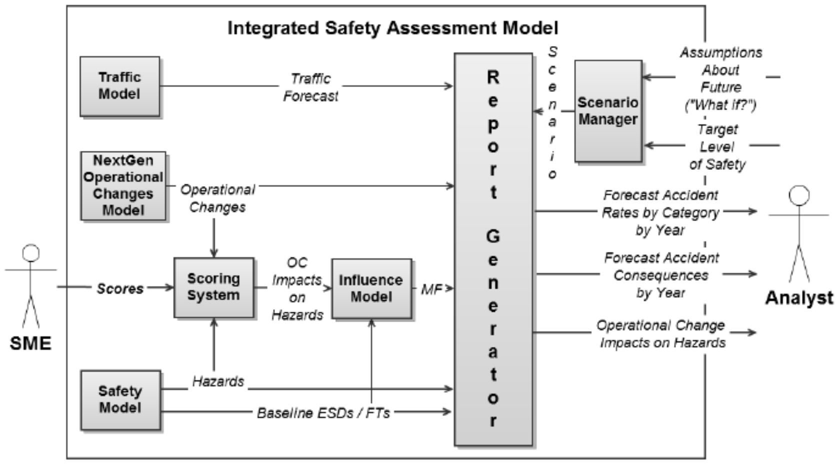
Validation	The models apportion available risk and causal data, so independent validation is limited, but the models were matched to historical risk trends.

4.2.2 CATS

Model name /owner	Causal Model of Air Transport Safety (CATS) – a research model developed by Delft University of Technology, NLR and DNV for the Netherlands Ministry of Transport.
Scope /application	A Bayesian Belief Network (BBN) representation of the causal factors underlying the risks of air transport accidents.
Inputs	User-defined flight characteristics, weather conditions and safety equipment provision.
Modelling undertaken	The CATS model uses a set of event sequence diagrams (ESDs) defining characteristic event sequences for each flight phase, each consisting of an initiating event and a sequence of pivotal events necessary for it to develop into an accident. The causes of each initiating event and pivotal event are quantified using fault tree models. To simplify development of these models, the ESDs have been grouped into broad accident types. The influences of flight crew, air traffic controller and maintenance performance are represented using BBNs, which also represent the common causes underlying the fault trees. A safety management model was also planned. The consequences of the events are modelled using historical data. In order to combine the different models, they are all implemented in a giant BBN. 
Outputs	Fatal accident frequencies, probability-fatality (FN) curves and contributions of individual causal factors.
Advantages	CATS provides a cumulative model of all risks in commercial aviation, which can be broken down to give a consistent estimate of risk in individual flights.
Assumptions	CATS uses a BBN which combines the ESDs, fault trees and influence models in a way that is theoretically sound but computationally awkward.
Validation	The models use available risk and causal data, so there is no independent validation.

4.2.3 ISAM

Model name /owner	Integrated Safety Assessment Model (ISAM) – a research model developed by Saab Sensis for the Federal Aviation Administration (FAA).
Scope /application	A web-based fault tree and event sequence diagrams (ESDs) representation of the causal factors underlying the risks of air transport accidents in the National Airspace System in the USA. It is used by FAA to coordinate safety assessments of operational changes under its NextGen programme.
Inputs	User-defined operational changes, implementation profiles and subject-matter expert (SME) scoring of their impacts on generic hazard categories.
Modelling undertaken	The model uses a set of event sequence diagrams (ESDs) defining characteristic event sequences for each flight phase, together with fault tree models of the causes of each initiating event and pivotal event. Quantification uses historical accident and incident experience for the fault trees and ESDs, combined with expert judgements by SMEs of the effect of operational changes on them. The model adjusts the basic events and influences to represent an individual case, and propagates these through the fault trees and ESDs to calculate the overall risk profile and causal breakdown.



Outputs	Fatality frequencies, fatal accident frequencies, precursor incident frequencies, contributions of individual causal factors, and effects of operational changes. Risk results are available in standard reports generated through a web-portal.
Advantages	ISAM provides a cumulative model of all risks in commercial aviation in the USA, which can be broken down to give a consistent estimate of risk in individual flights, airports or air traffic control regions.
Assumptions	CATS uses quantitative fault tree and ESD models which are very simplified representations of actual accidents.
Validation	The models apportion available risk and causal data, so independent validation is limited.

5 RISK MODELLING IN THE EU RAILWAY SECTOR

5.1 Survey of the National Safety Authorities

In order to identify existing risk models in the EU railway sector a short electronic survey was prepared. The content of this is detailed in Appendix 1. This survey was distributed by the Agency at the start of July 2015. The survey sought to identify if a quantitative or qualitative risk model was used in that Member State and if so sought some simple details and links for further information. All of the quantitative risk models were followed up and qualitative models where details were in the public arena.

This was reinforced by a review of the previous Agency research on Accident Precursors[1]. This report identified a number of existing risk models which were:

1. GB Precursor Indicator Model (PIM)
2. DNV Freight Train Derailment Precursors
3. Rail Optimisation Safety Analysis model (ROSA)
4. Risk landscape model - Federal Office of Transport for Swiss Railways
5. Irish Rail Safety Risk Model
6. Generic Error Modelling System (GEMS)
7. GB Safety Risk Model (SRM)
8. London Underground Quantified Risk Assessment (LUQRA)
9. Korean Risk Assessment Models

Of these the British railway risk models (Precursor Indicator Model and the Safety Risk Model) were followed up as was the Irish Rail Safety Risk Model. These are described in section 5.3. The risk landscape model was described in the Accident Precursors report as a concept that had not been developed. Direct contact, independent of the NSA survey, was made with existing DNV GL contacts within the Swiss Federal Office of Transport and Jernbaneverket seeking further details of the risk models they utilise and these are again described in section 5.3.

The DNV Freight Train Derailment Precursors, the London Underground Quantified Risk Assessment and the Korean Risk Assessment Model were not selected for further investigation as they were considered out of scope of this screening review as they are either not a risk model (the DNV Freight Train Derailment Precursors), relate to a metro system or are outside of the EU. However, it is noted that both the LUQRA and the Korean Risk Assessment Model are both based upon the use of fault trees as is the GB Safety Risk Model which is described.

The final two risk models identified in the Accident Precursors study are the GEMS and the ROSA models. GEMS is a risk model that focusses on human factors issues and is again out of scope of this study as it is not a risk model as assessed against the definition used in the introduction. The ROSA model is of greater relevance but it is not known if it is in general use. ROSA was a research project jointly funded by the French and German governments. The model itself is described in section 5.3 again, but with the caveat that the ownership of the model and its actual use have not yet been established.

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[1] Prospective Study into Harmonized Train Accident Precursors Analysis and Management http://www.era.europa.eu/Document-Register/Documents/PPR665%20Report.pdf

The models identified through the survey of National Safety Authorities and the Accident Precursors report are described in the subsequent sections.

5.2 Results of the NSA Survey

The survey was launched on 1st July 2015 and by 25th August 2015 a total of 17 responses had been received. This indicated that five Member States did not use a risk model, five Member States used a qualitative risk model and seven Member States used a quantitative risk model, to which Switzerland can also be added as it is known they use a quantitative risk model. These results are summarised below:

Table 1 – Overview of Member States Using Risk Models

No Risk Model	Qualitative Risk Model	Quantitative Risk Model
Austria	Channel Tunnel Safety Authority[2]	Czech Republic
Croatia	Denmark[3]	Ireland
Hungary	Finland[2]	Lithuania
Slovakia	Germany[3]	Norway
Portugal	Netherlands[2]	Sweden
		United Kingdom (2 models)
		Switzerland[4]
		Italy[5]

The survey also asked questions on the purpose or use of the risk model and whether it was publically available or was confidential. All of the quantitative models are confidential and while some details of them are available the precise details of both the model and the risk profile it produces are not publically available. This lack of transparency extends into the qualitative models for which only 2 of the 5 are available publically.

The purpose to which the risk model is put is shown in figure 1 and table 2 for both the quantitative and qualitative risk models. The most widely stated use is as a support for supervisory activity by the NSA. In effect using the model to identify areas of significant or increasing risk which the NSA can address as a part of its normal supervision or which an IM or RU could focus on as a part of its management of risk. Qualitative and quantitative risk models were also used to help in understanding the risk profile of a railway or individual IM and RU and as a part of continual improvement. Comparatively little use is made of the risk models to either justify investment in safety improvements (by predicting the improvement in safety that the investment will bring) or in supporting the use of the CSM on Risk Evaluation and Assessment (Commission Regulation (EU) No 402/2013). This is surprising as a quantitative risk model would naturally lend itself to uses such as this and suggests that for those Member States with a quantitative risk model, further benefit from it can be realised.

2 Qualitative model not publically available.
3 Qualitative model description publically available and included in section 5.3
4 Established via direct contact and not through survey response. Risk Model is for Dangerous Goods Transport only.
5 For railway tunnels only.

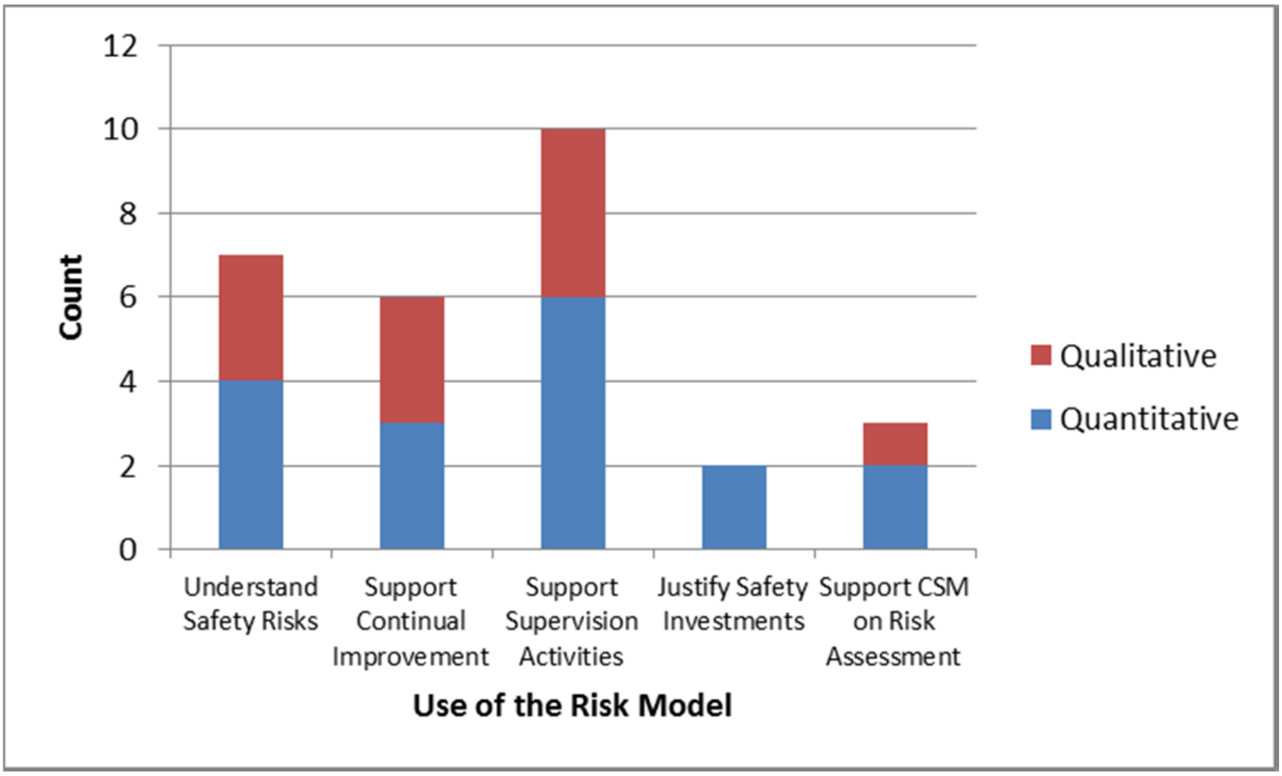


Figure 1 – The Uses of Qualitative and Quantitative Risk Models as Reported through the Survey of NSAs. The understanding safety risks column includes two quantitative models that are used for solely dangerous goods transport (Switzerland) and railway tunnels (Italy) and support decisions on the acceptability of the cumulative risk arising from these specific aspects of railway operations.

Table 2 – The Uses of the Risk Models as reported through the Survey. The name of the actor is listed in Appendix 2

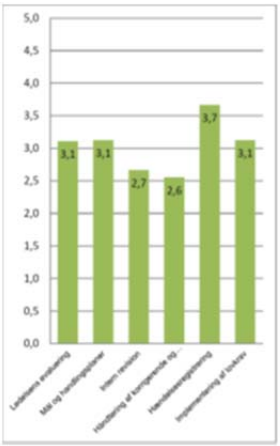
	Understanding Safety Risks	Support Continual Improvement	Support Supervision Activities	Justify Safety Investments	Support CSM on Risk Assessment
Qualitative	CTSA Finland Germany	CTSA Finland Germany	CTSA Denmark Finland Netherlands		Germany
Quantitative	Italy[6] Lithuania Switzerland[7] United Kingdom	Czech Republic Lithuania United Kingdom	Czech Republic Ireland Lithuania Norway Sweden United Kingdom	Ireland United Kingdom	Czech Republic United Kingdom

6 For tunnel risk only
7 For dangerous goods transport risk only

5.3 Description of the Models

The descriptions provided are based upon the results from the survey and subsequent follow up.The information has not been verified by DNV GL

Model name /owner	**Trafikstyrelsen** **Danish NSA**
Scope /application	Qualitative model
Inputs	The size of the organization, the result of the previous year's supervision activities, and an assessment of the maturity of the Safety Management System.
Modelling undertaken	The maturity evaluation is provided against the following aspects of the SMS: • Implementation of statutory requirements • Targets and action plans • Event registration • Management of corrective and preventative actions • Internal audit • Management review These are scored on a 1-5 scale where 1- Randomly, the company has not implemented safety management 2- Things are done without procedures, the company has implemented safety management, but it is not systematized and documented (sporadic and exclusively based on individual experience) 3- Procedures / system are implemented, the company has implemented a systematic and documented safety management that barely meets the requirements of the notices for safety certificates 4-Improving, analysis of data (past / present - reactive) / Learning The company has implemented a safety management system that ensures continuous improvement of safety on the basis of systematic analysis of recorded data. The safety management system is continuously developed based on the company's risk profile 5- Improving, future based / proactive across the entire organization The company has implemented a safety management system that proactively ensures improvement of safety through prevention. Safety "stems" from the management and safety management system is implemented in all relevant parts of the company

Outputs	A qualitative output that supports the NSAs supervision activities by focusing on the areas of greatest risk or weakness as shown in the model. In terms of the maturity evaluation this is a numerical assessment based on the 1-5 scoring matrix. 
Advantages	A clear simple tool that allows multiple railway organizations to be evaluated in a consistent manner.
Assumptions	That the SMS can be described against 6 components only.
Validation	None necessary. The model does not consider safety or risk output, but seeks to identify areas of potential weakness in the Safety Management System and its associated procedures. This can be fed back to the organization concerned for their improvement activities and used as a basis for NSA supervision.

Model name /owner	**Network Wide Risk Model** **Iarnród Éireann (Irish Rail)**
Scope /application	Quantitative Model that predicts the underlying risks on the Republic of Ireland's rail network which is run every three years. This is both network wide and location specific recognizing that it is often specific local features of the railway that drive the risks rather than generic or system wide issues.
Inputs	Precursor and incident data as recorded on the Iarnród Éireann network together with asset failure and location specific data. This data is captured in a comprehensive set of occurrence reporting and engineering databases.
Modelling undertaken	The model is primarily an asset based system. It uses fault and event trees to identify accident precursors and possible outcomes. Over 1,000 base events are described in the model. These are then modeled using fault and event trees using the incident and asset failure data described above. The output of this is a network wide prediction of risk. This network wide risk can then be apportioned across 227 separate locations and modified according to the specifics of the location and the condition of the assets there. This then creates a location specific model that uses exactly the same base events, fault and event trees as the overall network wide model but is based upon the specific locational data. There is a separate level crossing risk model which feeds into the overall risk model. It is the intention to have a separate risk model for all asset types which again will feed into the overall risk model. The model is updated on a two-yearly cycle.
Outputs	The risk model measures risk in equivalent fatalities (EF) per year and the risk is broken down by the degree of duty of care which IÉ has with regard to the particular accident type. **Prime duty of care** is assigned to accidents which are entirely within IÉ's control; **shared duty of care** is assigned to accidents which are influenced both by IÉ and the person who experiences the accident; **illegal act** is assigned to accidents where the person who suffers the accident is acting illegally. An assessment of the risk measured as equivalent fatalities is then made against the categories of trespass/vandalism, level crossings, third party (passenger accidents), staff accidents, structural failures, track defects, train defects and miscellaneous (irregular working). A prediction of the risk at specific locations as equivalent fatalities.
Advantages	The output of the Network Wide Risk Model is used to support the development of the three year safety plan and identify safety investments. The location specific prediction of risk can be used to identify specific areas of the network for which a safety investment is justified.

Assumptions	Experience and judgment is a necessary input for infrequent or rare events. The model will also be dependent on the quality of the data and the knowledge of the asset condition and other local factors at specific locations.
Validation	Comparison to the historical record. A correlation is assessed between the prediction of the model and the observed safety performance trend.

Model name /owner	**Safety Risk Model (SRM)** **Rail Safety and Standards Board (RSSB), UK**
Scope /application	Quantitative. The SRM seeks to produce an estimation of the underlying risks that exist on the British mainline railway (specifically that managed by Network Rail). It is used as a tool by railway stakeholders in Britain to understand their risks and manage or invest appropriately. A number of tools exist that allow a railway organization to map their specific risk profile from the SRM and to report the risk on a route or local basis.
Inputs	The model is populated with occurrence data from the Safety Management Information System (SMIS). SMIS is a record of all accidents and incidents (an event that could have resulted in an accident under different circumstances) on the British mainline network. For rare events in which few incidents are recorded technical experts are used to populate the model using a process of structured expert judgment.
Modelling undertaken	The model identifies over 131 hazardous events that can result in a safety accident or injury to a person; and more than 1700 accident precursors. These are then modelled by 121 separate models that provide an estimate of the risk to passengers, railway staff and contractors, and third parties (level crossing users, trespassers etc..). The hazardous events are further sub divided into almost 3,000 precursor events all of which are similarly modeled. The models of train accident risk most generally use fault and consequence trees to estimate the risk.
Outputs	The output of the model is a prediction of the underlying risk on the British mainline railway expressed as Fatalities and Weighted Injuries (FWI). Specific estimates of the frequency of accidents, number of fatalities, total FWI are made for each group exposed (passengers, staff, third parties) against each of the hazardous events and precursor events. This is expressed in tabular form and is typically updated every 18 to 24 months. The output, together with an analysis of trends and other aspects of the content, is published in the Risk Profile Bulletin by RSSB.
Advantages	This is a mature and well established model that is supported by a comprehensive occurrence reporting system.
Assumptions	The historical accident and incident record is indicative of the future record.
Validation	Trends in the historical accident and incident record that are used as an input to the model are all subject to a test of statistical significance and a thorough quality assurance process. Ultimate validation is through comparison to the accident and incident record over time.

Model name /owner	**Precursor Indicator Model (PIM)** **Rail Safety and Standards Board (RSSB), UK**
Scope /application	Quantitative. The PIM provides an assessment of the underlying risk on the British mainline network (Specifically that managed by Network Rail) of train accident risk which is considered to be around Potentially High Risk Train Accidents (PHRTAs): train derailments; train collisions; trains struck by large falling objects; and train explosions. As train accidents are so rare it considers precursors to make the assessment. It is used to provide a period by period assessment of the changes to train accident risk (although this is reported on a quarterly basis) and as such can be used to detect emerging trends in catastrophic risk from train accident as a part of the management of this risk by the railway industry.
Inputs	The model is populated with occurrence data from the British Common Occurrence Reporting system (Safety Management Information System (SMIS)) and information from the Network Rail (the main British Infrastructure Manager) specific to train accident risk being considered. SMIS is a record of all accidents and operational incidents (an irregularity affecting, or with the potential to affect, the safe operation of trains or the safety and health of persons.) on the British mainline network. Dependent on the type of incident the input information taken may be a simple count of the incident or a risk based assessment of the incident. In the later this assessment of significance is of the potential for the incident to have become an accident if the circumstances were slightly different and if so what the consequences might have been. The incidents considered are infrastructure failure, infrastructure operations, objects on the line, SPADs, level crossings, and train operations and failures. These 6 categories are then broken down into a total 21 sub-groups.
Modelling undertaken	The PIM models risk as frequency times consequence. The frequency being the number of incidents recorded per period and the consequence being the mean consequence for such an event as indicated in the Safety Risk Model (SRM). This consequence can be for all incidents of that type or for all incidents of a particular significance as determined in the inputs above.
Outputs	The PIM can provide an output in Fatalities and Weighted Injuries (FWI) or as a % of a baseline taken in 2006. In this way it shows movement in the risk of a train accident from 2006. This can be further broken down against the 6 categories, 23 sub categories or 40 lower level events for passenger, workforce or third parties.

Advantages	The PIM provides an output that is updated quarterly (monthly updates are possible) which shows how train accident risk is changing in a relatively recent time period.
Assumptions	It is reliant on the accuracy of the SRM and for those pre cursors that are risk ranked it is also reliant on the assessment of the significance of the incident which is a process based on expert judgment. For those pre cursors that are not risk ranked it is assumed that the risk varies in proportion to the frequency of the pre cursor.
Validation	The PIM is baselined against the Safety Risk Model (SRM). A qualitative appraisal is made comparing trends in the PIM with the observed trends in the count of train accidents.

Model name /owner	**Transportstyrelsen** **Swedish NSA**
Scope /application	Quantitative Used as an input to the planning of supervision activities by the NSA.
Inputs	The parameters of the infrastructure such as traffic intensity, speed limits, number of level crossings etc. The model also uses results from previous supervision.
Modelling undertaken	The model sums up all the parameters for each company and uses different intervals to estimate a recommended supervision interval. The parameters (see inputs above) are related to the key features of a railway's operation that might be expected to influence safety risk such as the intensity of traffic, speed, presence of infrastructure features that represent a higher risk such as level crossings.
Outputs	A recommended supervision interval that is used as only one of the inputs for the planning of supervision by the NSA.
Advantages	An easy way to get an estimation of the risk level at a company
Assumptions	The model only uses information that the NSA considers will affect how often it needs to undertake supervision at a certain company
Validation	The model is new and has not yet been validated

Model name /owner	**Agenzia Nazionale per la Sicurezza delle Ferrovie** **Italian NSA**
Scope /application	Quantitative Used to calculate the cumulative risk of railway traffic in tunnels of 1km or more in length.
Inputs	The parameters of the tunnel infrastructure such as traffic intensity, traffic type , speed limits, cross overs, stations, presence of dangerous goods. A database of tunnel accidents and incidents is used to provide input on the frequency of accidents.
Modelling undertaken	The model calculates the probability and consequence of various accident scenarios in a tunnel using fault and consequence trees.
Outputs	The cumulative societal and individual risks are then compared to acceptability criteria to determine of additional risk mitigations are necessary or desirable to reduce the calculated risk.
Advantages	This is primarily a methodology and associated database for calculating cumulative risk in railway tunnels.
Assumptions	The methodology is specified in Italian law: (http://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2006-04-08&atto.codiceRedazionale=06A03428). It is an officially recognised methodology for calculating risk and therefore is not considered by the analysts to have any assumptions.
Validation	The calculated risk can be compared to the actual history of accidents, incidents and near misses in the specific tunnel.

Model name /owner	**Quantitative Risk Model under the responsibility of the railway sector (IM and RU) in the Czech Republic**
Scope /application	Quantitative
Inputs	
Modelling undertaken	
Outputs	
Advantages	
Assumptions	
Validation	

No further input has been obtained from the Czech NSA in this projects timescale.

Model name /owner	**Sicherheits-Regelwerk Fahrzeuge (SIRF)** **Eisenbahn-Bundesamt, German NSA**
Scope /application	Qualitative This is applicable to railway vehicles only and supports the authorization to place new vehicles into service or the authorization of modifications to existing vehicles. It is used as a template to support the functional breakdown and hazard identification process required for the CSM on Risk Evaluation and Assessment (EC 402/2013).
Inputs	A description of the vehicle and the various functional technologies it contains.
Modelling undertaken	This is a structured process rather than a model. It - Systematically identifies all possible hazards and assigns them to the respective functions - Evaluates the features / hazards in terms of their safety requirement
Outputs	Systematic identification of hazard related to railway vehicles and the apportionment of a safety target for the railway vehicle against its various functions.
Advantages	It supports compliance with the CSM on Risk Evaluation and Assessment (EC 402/2013)
Assumptions	None
Validation	None

Model name /owner	**Valstybinę Geležinkelio Inspekciją (VGI)** **Lithuanian NSA**
Scope /application	Quantitative
Inputs	Currently only accident data is used
Modelling undertaken	The model is based upon machine learning algorithms. These are either regression analysis or decision tree algorithms depending on the aspect of railway risk being analyzed.
Outputs	Probability of an accident happening based on analysed incidents. Probability is calculated for one year.
Advantages	It helps to determine whether an incident poses substantial threat to the safety of the traffic and people. It also helps to analyze what could be the causes of the threat and what could be done in order to improve safety of the object.
Assumptions	The influence of the characteristics of an incident does not change over time.
Validation	Goodness of fit test; check whether the influence of a characteristic is in an expected direction.

Model name /owner	**Risk Matrix** **Statens Jernbanetilsyn,** Norwegian NSA
Scope /application	Quantitative The Norwegian NSA have established a Supervision Strategy outlining the long term priorities of the supervision activities. The strategy is supported by an annual Supervision Program, which includes some defined focus areas. The Supervision Program and the focus areas are established using a risk based model as support for the prioritisation.
Inputs	The basic risk categorisation parameter is train km, which is grouped into 4 risk categories. The model is used to plan the audits of the RUs and IMs which can range from annual auditing to a single audit in the period for which the SMS is certified. Then the priority of each RU is adjusted with respect to three categories: 1. Previous experiences with the RU 2. Reported incidents/accidents (The Norwegian NSA gets all reports on incidents and accidents from the RUs.) 3. RU complexity (has the RUs complexity changed during previous year, increased diversity in activities, more interfaces, etc.) A change in each category gives the RUs either -1, 0 or +1 as a "score". If the total score reaches -2 or +2 the RU increases or decreases in priority.
Modelling undertaken	The modelling is mostly performed by expert judgment in group meetings.
Outputs	Recommendations regarding priorities for the annual supervision activities and any focus areas.
Advantages	The model provides flexibility regarding the priorities for supervision.
Assumptions	In Norway there are 13 RUs and 1 IM and it is considered that the NSA experts have a good overview of what is happening in the RUs and IM.
Validation	The model has not been validated but has been used for several evaluations.

Model name /owner	**Jernbaneverket** **Norwegian Infrastructure Manager**
Scope /application	Qualitative To provide all the relevant safety and risk information for a specific location on the Norwegian railway network in a standard format using only one portal to access it rather than having to utilize many separate databases.
Inputs	Multiple separate sets of already existing data are used as an input. This includes location details, description of the railways assets present, time table planning, hazard identification, photographs and maps of the network, the database of accidents and incidents, and the database of risk assessments.
Modelling undertaken	The model provides risk information on any location on the Norwegian railway network. It does this by combining previously separate sets of risk information by their location. Hence, by selecting a particular location on the railway network the relevant risk information for that location can be displayed all together in a standard format without any need to visit multiple data sources.
Outputs	The risk tool provides a summary of the risk and hazards together with other relevant information at a given location on the Norwegian railway network. This includes descriptions of the infrastructure and train service, photographs of the location, identified hazards and risk control measures, and the accident history at the location. In the future it is intended to develop this further providing information on assumptions made or limitations in risk assessments as well as information on barriers/risk mitigations applied.
Advantages	The model is designed to provide a single point of access to multiple data sources and to present the output in a standard format. This obviates the need for the user to access multiple databases. It adds value to existing databases by increased use and thereby improved data quality. Incorporates the (informal) knowledge of drivers and track side workers and others.
Assumptions	None made. The model presents existing data from multiple sources in a single standard format.
Validation	None necessary. Annual "virtual walk-through" of the whole network together with major RUs.

Model name /owner	**Risk Screening** **Federal Office of Transportation, Switzerland** Name: Screening of the collective risk on individuals and the environment arising from the transport of dangerous goods by rail ("Risk Screening") ➔ These are actually two separate RE-models: they have major modules in common, but differ from each other in some methodological parts and parameters. For this overview, they are depicted in the same table. *Specific information for environmental risks is in italic.* Published by the Federal Office of Transportation, Switzerland Developed by the Swiss Federal Railways and the Federal Offices of Environment and Transportation and Ernst Basler + Partner, Switzerland.
Scope /application	Method to evaluate the collective risks on individuals and environment on the Swiss main railway network arising from the transport of dangerous goods by rail. Only tanks considered, no piece goods. Population categories considered: residents, working population, persons on railway platform and in passenger trains, if involved. Dangerous goods considered: flammable liquids, flammable and toxic gases (risk on individuals), *water soluble and non-soluble liquids floating / sinking to the bottom (risk on environment).* Damage indicators considered: lethality (risk on people), *damaged ground water used as tap water, and surface waters (risk on environment).*
Inputs	Input data: Dangerous goods: - Quantities of dangerous goods transported per segment and year, in total and per category (flammable liquids etc.) Rail specific parameters: - Max. speed of train - Localization of network-wide safety measures (e.g. hotbox detectors) - Rate of collision and derailment (real data from Swiss rail operators) Infrastructure: - Localisation and number of switches - Type of track (open line, station, tunnel, single/multiline) - Accessibility to track Population: - Population density (residents, working, on platform, in passenger train) *Parameters considered for environmental risk only:* - *Drainage system of track bed* - *Depth to water table* - *Direction of water flow (alongside track, to/away from track)* - *Type of soil* - *Supply rate of water intake*

Modelling undertaken	Elements of the risk estimation: - Determination of incident frequency, failure frequency and outflow factor of DG (fault trees) - Calculation of dispersion (dispersion models) - Scenarios considered: toxic cloud, VCE, BLEVE, fire, fire and explosion in sewage system (event trees) - Calculation of effects (lethality, *pollution of water*) - Calculation of consequences: consideration of population density, *local environmental parameters* and local measures of safety and intervention
Outputs	Overview on the risk situation on the Swiss main railway network, presented as coloured indicators every 100m on the network map. FN-diagrams for each segment of the railway network.
Advantages	- Overview on the actual risk situation on the whole rail network - Identification of risk hotspots to define further measures to reduce risk - Rough estimation and forecast for future critical situations due to spatial planning (increase of population density) or increased transport quantities
Assumptions	The developers have made many assumptions, mainly when defining local failure rates: - The number of incidents with dangerous goods is proportional to the sum of all collisions and derailments on the network (this assumption is made due to lack of statistical data for DG events). - Definition of 3 switch categories (number of switches: 0, 1-4, > 4): The local rate of derailment on a track segment with more than four switches within 300m is 3 times higher compared to track segments with 1-4 switches within 300m. - A correction factor is included for the influence of safety systems (e.g. hot box detectors or stalling detectors). - A correction factor is included for the velocity dependency of the release rate. - The rate of release per tank car and km is reduced by a factor of 10 in fortified tank cars (for chlorine and propane). These assumptions have to be verified and adapted by comparison of data on international level.
Validation	- Sensitivity analysis of two Screening versions each time an update has been made (2001, 2006, 2011, 2015) - Comparison of a precursor tool (used by the Swiss Federal Railways) with the TNO-method (Gruner AG, 2014) - Ongoing: Detailed comparison of methodology and parameters with the current risk estimation methodologies in Netherlands (HART 2014) and Flanders (risk analysis system 2014).

Model name /owner	**Rail Optimisation Safety Analysis (ROSA)** **Funded jointly by French and German government research programmes.** Ultimate ownership uncertain but DB and SNCF are reported as using it.
Scope /application	Quantitative ROSA models the railway at a network or national level. It can be used to take an EU level safety target and apportion it between different Member States and then different networks or lines in that Member State. It can also support analysis of the introduction of new or improved safety barriers by providing a before and after risk profile for the railway.
Inputs	The ROSA model is a generic or idealized version of a railway network. It is quantified by providing estimates of the number of different asset types (e.g. level crossings) and estimates of the incident rates of train-vehicle collision at an unprotected crossing. The event tree then calculates the consequences of a collision. Finally estimates are made of the number of assets with safety barriers applied (e.g. crossings with greater protection). The barrier model then applies these mitigations to the combined fault and event tree.
Modelling undertaken	The model describes 57 starting point hazards which are then modelled in turn using fault and consequence trees to quantify the risk for the 57 starting point hazards. It additionally has a barrier quantification model that quantifies the effectiveness of safety barriers employed and which can be used to support a cost benefit analysis for further investment in existing or additional safety barriers.
Outputs	The apportionment of an EU or national level safety target to the various lines or assets types on a railway network. An assessment of the effectiveness of new or additional safety mitigations.
Advantages	The model operates at a generic level and as such is not fed by direct accident and incident data, so that its data requirements reduced.
Assumptions	The model is reliant on the initial estimates of assets, hazardous incidents and the effectiveness of barriers.
Validation	Validation was undertaken using previous examples of investments in safety mitigations for which the accident rate before and after the mitigation were known. The model is then run for this example and the model compared to the known historical outcome from introducing the safety measure.

6 CONCLUSIONS

On behalf of the European Railway Agency DNVGL has undertaken a brief screening review of railway risk models and risk models in the oil/gas and aviation domain. The focus of this has been quantitative models.

In total 9 quantitative and 5 qualitative models have been identified in the railway sector. The most wide spread use of these is in supporting the NSA in its supervisory activity although many other uses are reported including creating a better understanding of the risk profile of the railway at a national or local level. Comparatively little use is made of quantitative risk models to support the justification for a safety investment or risk analysis in accordance with the CSM for Risk Evaluation and Assessment.

In the main the quantitative risk models utilise fault and consequence tree modelling as the basis for their calculations. This is most prevalent for rolling stock or train accident risk. Other risks are more commonly modelled using regression analysis.

7 APPENDIX 1 – THE SURVEY OF NSAS

Dear Sir/Madam,

The European Railway Agency (the Agency) has commissioned Det Norske Veritas Germanischer Lloyd (DNV GL) to undertake a short screening exercise to review relevant risk models used in the railway domain or in other industries. The Agency defines Risk Model and Risk Profile as:

- Risk Model: Tool designed to draft the risk profile of an entity which could be a railway organisation or a Member State
- Risk Profile: List of risks or unwanted events to which the entity is exposed as a given point in time and which may lead to an accident.

The purpose of this is to learn what sort of risk models are employed in the EU railway sector as a support tool to assessing railway safety performance or risk profile.

DNV GL is performing a survey to first identify those Member States which currently employ a risk model. These can be quantitative risk models that provide a numerical assessment of safety risk, qualitative models that provide a pictorial representation of risk, a geographical representation of risk across a railway network or other. The purpose of the study is simply to understand the variety and diversity of risk models currently used.

This survey is very short and is intended to take under 5 minutes to complete. If you require any assistance with the survey or help please do not hesitate to contact DNV GL at

jonathan.ellis@dnvgl.com or +44 7768 114510.

The survey is written in English but please feel free to respond in your native language if you would prefer.

I would like to kindly ask you for your cooperation and notably for providing relevant information.

If you are able to send specific information on any railway risk model such as specification, algorithms or underlying assumptions used you may send them in confidence to jonathan.ellis@dnvgl.com where they will be very gratefully received.

Thank you for participating in our survey. Your feedback is important.

1. Please could you indicate which Organisation you are responding for and provide a contact for follow up.

Name

Company

Email Address

Phone Number

2. Within your Member State do you have a Risk Model of the Railway?

Yes

No

If you have answered no and do not have a railway risk model then the survey is complete. Please press "done" at the bottom of the page.

Thank you for your help.

3. Please could you indicate who in your Member State owns or is responsible for the risk model (please tick as many as apply).

NSA

NIB

Ministry

IM

RU

Other (please specify)

4. Please describe the type of risk model?

Other (please specify)

Quantitative - it provides a numerical indication of risk

Qualitative - it provides a map or picture of risk

5. Please describe what the risk model is used for (tick as many as apply).

To better understand the underlying safety risks on the railway network.

To support continual improvement in safety on our railway.

To support supervision activities by focussing it on the areas of greatest risk as shown in the model.

To justify safety investments by being able to quantify the improvement in safety (reduction in risk).

To support quantified risk assessment such as that in the CSM on risk evaluation and assessment.

Other (please specify)

6. Is the model available to the public?

Yes - publically available

No - it is only available to approved persons with a log in

No - it is confidential

7. If possible please provide a link to the risk model or send any details you are able to

jonathan.ellis@dnvgl.com

8. Please could you provide a contact who we can speak to regarding the risk model.

Thank you very much for your help.

All responses will only be used for the purposes of this study.

8 APPENDIX 2 – THE IDENTITY OF THE ORGANISATION USING THE RISK MODEL

Member State	Risk Model Owner, type of actor
CTSA	High Speed 1, IM
Czech Republic	Railway sector (IM and RU) in the Czech Republic
Denmark	Trafikstyrelsen, NSA
Finland	Finnish Transport Safety Agency Trafi, NSA
Germany	Eisenbahn-Bundesamt, NSA
Ireland	Iarnród Éireann (Irish Rail), IM
Italy	Agenzia Nazionale per la Sicurezza delle Ferrovie, NSA
Lithuania	Valstybinę Geležinkelio Inspekciją (VGI), NSA
Netherlands	Inspectie Leefomgeving en Transport (ILT), NSA
Norway	Statens Jernbanetilsyn, NSA
Sweden	Transportstyrelsen, NSA
Switzerland	Federal Office of Transportation, NSA
United Kingdom	Rail Safety and Standards Board, industry body owned by IMs and RUs.

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