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European Railway Agency

STUDY ON MIGRATION OF RAILWAY RADIO COMMUNICATION SYSTEM FROM GSM-R TO OTHER SOLUTIONS

SYSTRA

ERA 2015 04 1 RS

STUDY ON MIGRATION OF RAILWAY RADIO COMMUNICATION SYSTEM FROM GSM-R TO OTHER SOLUTIONS

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Glossary – List of Acronyms

3GPP	Third Generation Partnership Project
BTS	Base Transceiver Station
BSS	Base station Sub System
CAPEX	Capital Expenditure
CCM	Change Control Management
CCTV	Closed Circuit Television
COTS	Commercial off the Shelf
FRS	Functional Requirements Specification
EDOR	ETCS Data Only Radio
EIRENE	European Integrated Railway Radio Enhanced Network
ERA	European Railway Agency
ERIG	European Radio Implementers Group
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
ETSI	European Telecommunications Standard Institute
EU	European Union
FRMCS	Future Railway Mobile Communications System
GID	Group Identification
GPRS	General Packet Radio Service
GPH	General Purpose Handheld
GSM	Global System for Mobile Communications
GSM-R	Global System for Mobile Communications Railway
IM	Infrastructure Manager
ISO	International Organisation for Standardisation
LTE	Long Term Evolution
LTE-A	LTE Advanced
MI	Mandatory for Interoperability
MNO	Commercial Mobile Network Operator
MS	Member State
MORANE	MObile radio for RAilway Networks in Europe

MOTS	Modified off the Shelf
NSS	Network Sub System
OPEX	Operational Expenditure
OPS	Operational Shunting Handheld
OPH	Operational Handheld
PPP	Public-Private Partnership
PPDR	Public Protection and Disaster Relief
RAN	Radio Access Network
RISC	Rail Interoperability and Safety Committee
RU	Railway Undertaking
SIM	Subscriber Identity Module
SRS	System Requirements Specification
TETRA	Terrestrial Trunked Radio
TSI	Technical Specifications for Interoperability
UIC	International Union of Railways (Union Internationale des Chemins de Fer)
UMTS	Universal Mobile Telecommunications System
URS	User Requirements Specification

1. EXECUTIVE SUMMARY

The European Rail Agency (ERA) commissioned Systra to conduct a "Study on migration of railway radio communication system from GSM-R to other solutions", project ERA 2015 04 1 RS. This is the Executive Summary of that study.

The purpose of the study, which has been conducted between September 2015 and May 2016, was to reach conclusions on possible migration scenarios for the introduction of new radio communication systems as a replacement of GSM-R, and to provide recommendations for managing the migration, based upon economic modelling using information about the business cases of *Rail Undertakings (RUs), Infrastructure Managers (IMs),* and the *Member States (MS)*.

1.1 Background and context

GSM-R is an interoperable track-to-radio technology used by many infrastructure managers (IM) and railways undertakings (RU) for operational voice communications. GSM-R also acts as the data bearer for the *European Train Control System (ETCS).* The use of GSM-R is legally mandated in the *Technical Specifications for Interoperability (TSI)* that are applied in European Union (EU) and in some adjacent countries.

GSM-R is a *Modified Off-the-shelf Technology (MOTS)* system. GSM-R is based on the second generation *Global System for Mobile Communications (GSM)* communications standard. GSM-R meets most needs well, but it is widely expected that GSM-R will become prohibitively expensive to operate circa 2030 due to obsolescence of the underlying GSM technology. Given the long planning and deployment cycles in the rail sector, it is necessary to begin now to identify a successor and to start to plan for migration.

The *Future Railway Mobile Communication System (FRMCS)* group within *International Union of Railways (UIC)* is tasked with preparing specifications for the successor to GSM-R. The UIC recently published version 2.0 of a "User Requirements Specification".

The current study is part of a sequence of planning activities initiated by the European Rail Agency (ERA) and the European Commission. Previous studies relating to this topic include "Survey on operational communications (study for the evolution of the railway communications system)", Analysis Mason (2014); "Study on use of commercial mobile networks and equipment for 'mission-critical' high-speed broadband communications in specific sectors", SCF (2015); and "Evolution of GSM-R", IDATE (2015).

The time frame for the migration is crucial. Guidance to this study from the ERA, based on previous discussions with stakeholders, has been to assume:

- Draft requirements / specifications by 2018 – 2019;
- A possible start of deployment in 2022; and
- Support for GSM-R will continue to be available until at least 2030.

1.2 Drawing on the experience of the migration from analogue systems to GSM-R

In considering implications of the future evolution of operational rail communications, it is natural to turn to past experience, primarily the still ongoing migration to GSM-R itself.

This experience suggests that migration is complex, and needs careful planning and preparation. Coordination among a range of different stakeholders is essential.

GSM-R deployment and migration was a long process. For medium size Member States (with a few thousand route km each), the time line starting from planning to end of migration was minimum of seven years. For larger Member States, the individual migration time line sometimes required up to 19 years.

1.3 Views and considerations for Infrastructure Managers (IMs), Rail Undertakings (RUs), and the Member States (MS)

There are parallels in the views of Infrastructure Managers (IMs), Rail Undertakings (RUs), and the Member States (MS), but also important differences in perspective.

Among IMs, the single most important factor driving the need for migration is the expected obsolescence of GSM-R technology. Once the underlying GSM technology is no longer supported by suppliers, the cost of maintaining these networks (OPEX) can be expected to increase; moreover, it may become impractical to deploy new GSM-R equipment on new lines. This risk of obsolescence determines the migration end date, which in turn influences the migration start date.

Among RUs, by contrast, there is no rush to migrate to next generation technology. Regulation at European level is viewed (and by a wide margin) as the main driver for migration.

Both RUs and IMs expect the migration to begin in 2025.

Both IMs and RUs expressed a clear preference for the replacement of all cab and handheld devices with dual mode radios (i.e. capable of supporting both current GSM-R and the successor Next Generation (NG) technology) as a key mechanism for achieving migration.

Most IMs assume that the IM will own the future infrastructure. Some IMs are however open to alternative operational or ownership models, where for instance infrastructure is shared with *Public Protection and Disaster Relief (PPDR)*, or is owned and operated (subject to suitable Service Level Agreements (SLAs) by commercial *Mobile Network Operators (MNOs).*

1.4 Migration scenarios

A range of different migration scenarios are possible. We have considered:

- A scenario where no migration takes place. This is improbable (and expensive), but it provides a baseline against which other scenarios can be compared.
- Scenarios where the overlap between current GSM-R and future NG technology is short (just one year), medium (not more than five years), or long (more than ten years).
- Scenarios where some Member States migrate earlier than their neighbours.

1.5 Modelling the migration

We have developed a parameterized Excel model in order to estimate CAPEX and OPEX cash flows for trackside and on-board equipment over time (using current euro and integrated with a Net Present Value (NPV) methodology) under the various scenarios. The model reflects Systra's extensive experience with economic models and GSM-R deployment projects.

It was necessary to make assumptions about a wide range of factors, including the radio interface (and especially the spectrum band in which it would operate); the end applications that would be used; and the core network to be deployed. We also made assumptions about the life cycle of equipment (15 years for trackside BSS equipment, 12 years for cab radios). Since the model is parameterized, it could be used to explore a wide range of alternative assumptions if desired.

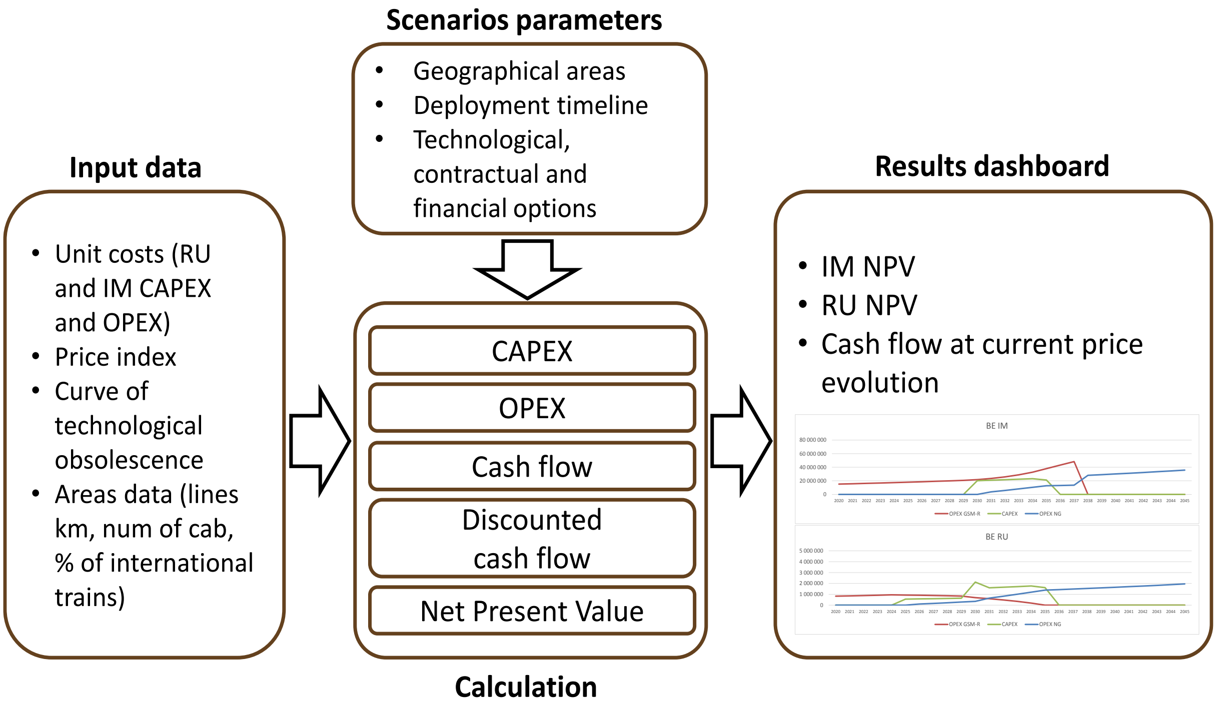
Our modelling reflects the size of GSM-R networks in different countries (small, medium, large) named unanimously A, B, C, D, F and all Europe. We also modelled cross-border effects between countries of different size (A-B, D-F and C-D. The questionnaire provided very little data on cost differences among the Member States; consequently, we assumed that costs were similar among the Member States.

The model also reflects a range of scenario data and other input parameters:

- Geographical areas selected for the scenarios (including the km of line, number of cab radios, percentage of international trains);
- Deployment timeline, in percent of achieved deployment;
- Unit costs (e.g. per km of track, and per cab radio);
- Economic impact of technological obsolescence; and

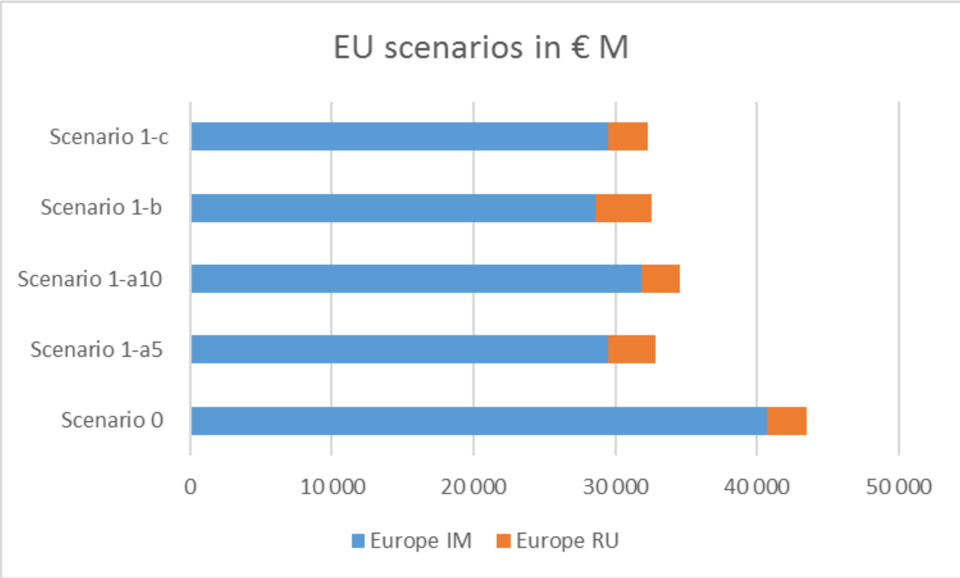
- Technological factors (which new generation technology is chosen), contractual factors (operated by the IM, by a PPP, or by a third party), renewal of equipment (GSM-R and NG), and financial options (financial discount rate).

Conceptually, the model can be understood as shown in the figure that follows.



1.6 Findings

The results of the modelling analysis are fairly clear (see the following figure), even with the preliminary state of what is known today about the eventual migration. First, we see that Scenario 0 (where no migration takes place) is considerably more expensive than scenarios where migration takes place with an overlap of GSM-R and Next Generation technologies of one year (Scenarios 1-b and 1-c); of five years (Scenario 1-a5); or of ten years (Scenarios 1-a10).



Second, the cost carried by the IMs exceeds that carried by the RUs by quite a wide margin.

Third, the scenario with the longest migration (1-a10) is the most expensive for the IMs. Parallel operation of both technologies implies higher OPEX for the IMs. The overall percentage difference is not great, but it is great in comparison to the costs to RUs.

Fourth, costs for the RUs are nearly the opposite of those for IMs, in the sense that scenarios with a long migration period are better for the RUs than shorter migration periods. The reason is that a longer migration period enables the RUs to replace existing cab and handheld equipment with dual-mode equipment at such time as it would have been due for replacement anyway.

This apparent result that the optimal time frame for migration for the RUs is not the same as that for the IMs has important policy implications. It needs to be understood in conjunction with other key findings of this study:

- IMs and RUs agree that the preferred migration scenario involves upgrading of all cab and hand-held equipment to dual-mode. This needs to happen *before* the IM discontinues GSM R operation.
- As previously noted, the RUs see little immediate benefit in migration. They have little interest in migrating before they are required to migrate.
- The TSI will presumably be enhanced at some point in time to reflect a requirement for Next Generation technology; however, the current legal framework does not explicitly

require RUs to upgrade equipment that conformed to the TSI that was in effect when the equipment was most recently put in service, upgraded or renewed[1].

The ***misalignment of incentives*** means that RUs are likely, in the absence of some public policy intervention, to delay the migration beyond the date is globally optimal. The cost to IMs of this delay would be substantially greater than the savings to the RUs; moreover, it would complicate the migration, especially in regard to cross-border rail traffic (since some IMs might migrate, while others might be unable to migrate).

1.7 Recommendations

As a first recommendation, we suggest that the ERA ***continue to use the model*** developed for this project to refine the estimates of likely costs of migration as decisions are made (for instance, about the technology to be used and the spectrum band(s) in which it will operate). In many cases, it will be possible to alter parameters without any need to change the logic of the model.

As a second recommendation, attention to ***coordination between IMs and the RUs that use their infrastructure*** is needed. To a large degree, this could be handled as a Member State matter.

One aspect of this coordination, however, merits special attention. ***Good, accurate databases of the upgrade status of rolling stock*** and the areas in which they are authorised to run could potentially help enormously in the coordination and the decision making for both RUs and IMs[2]. The use of the European vehicle and infrastructure register databases (such as European Centralised Virtual Vehicle Register (ECVVR)) is deemed to be an important step to ensure that migration planning is as optimal. It is therefore essential that this data is accurate and up-to-date. Today, data provided by the Member States is often incomplete or incorrect. A mechanism that might be considered would be to condition any State Aid to the RUs for the upgrade to GSM-R on the RU providing good, timely and accurate information on the status of rolling stock upgrades to ERA for inclusion in the rolling stock register.

Finally, we think that ***the level and nature of Member State and/or IM financial compensation to the RUs*** in support of the migration needs careful consideration going forward. The misalignment of

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[1] See Article 5(2) of the Railways Interoperability Directive: “Subsystems shall comply with the TSIs in force at the time of their placing in service, upgrading or renewal, in accordance with this Directive; this compliance shall be permanently maintained while each subsystem is in use.”

[2] This is in principle an issue for hand-held equipment as well, but we assume that upgrades to hand-helds are easier to deploy.

incentives previously noted could easily lead to deployment delays, thus substantially increasing costs for the IMs and also increasing the complexity of the migration as a whole[3]. Financial compensation to the RUs would seem to be the most natural way to address this concern.

[3] If incentives were aligned, the migration would represent a Pareto improvement, where at least one person is made better off and nobody is made worse off. In practice, the migration appears instead to potentially represent a Kaldor–Hicks improvement, where those that are made better off (Member States and IMs) could hypothetically compensate those that are made worse off (RUs) and thus lead to a Pareto-improving outcome.

2. INTRODUCTION

Highlights

- The need to migrate European operational rail communications to a successor technology to the current GSM-R has long been recognised by firms in the sector and by the European Rail Agency (ERA).
- This study seeked to respond to six specific questions posed by the ERA in regard to the eventual migration to a successor technology to GSM-R.
- This study consisted primarily of (1) data gathering, (2) analysis, and (3) construction of an economic model of the eventual migration. The data gathering in turn was based mainly on desktop research, discussions with UIC and ERA, and questionnaires sent to IMs and RUs.

2.1 Document purpose

This document is the **Final Report** of the ERA study 2015 04 1 RS: “Study on migration of Railway radio communication system from GSM-R to other solutions” conducted by Systra.

The purpose of this Study, conducted between September 2015 and May 2016, was to reach conclusions on possible migration scenarios and to provide recommendations for managing the migration, based upon economic modelling using information about the business cases of RU/IM/MS for the introduction of new radio communication systems as a replacement of GSM-R.

This Final Report contains detailed analysis, main conclusions, recommendations and underlying justifications.

2.2 Study scope and objectives

GSM-R is an interoperable track-to-radio technology used by many infrastructure managers (IM) and railways undertakings (RU) for operational voice communications and acts as the data bearer for ETCS (European Train Control System). GSM-R is legally mandated in the Technical Specifications for Interoperability that are applied in European Union.

GSM-R is a MOTS (modified off the shelf technology) system. GSM-R is based on the GSM second generation mobile communications standard. GSM-R meets most needs well, but it is widely expected that GSM-R will become prohibitively expensive to operate circa 2030 due to obsolescence of the underlying GSM technology: Given the long planning and deployment cycles in the rail sector, it is already necessary to identify a successor and to begin to plan for migration.

The UIC Future Railway Mobile Communication System (FRMCS) group is tasked with preparing specifications for the successor to GSM-R. The document “User Requirements Specification” currently in version 2.0 was recently published by UIC Identifies the needs to be considered for the future system.

The study is part of a sequence of planning activities initiated by the European Rail Agency (ERA). Earlier studies are described in Section 3.1.

The aim of this study was to work on migration scenarios, providing guidance to ERA on the optimal timeline of a migration from GSM-R to its successor, and the conditions to make it successful across Europe. Economic aspects are the key part of this migration study.

In particular, this study provides answers to the following questions:

1. What may be criteria and business drivers for decisions on starting the migration for RU's and IM's in the different MS (include CCS TSI functionality and all other usages)?

2. How does this interfere with MS decisions on network models (i.e. relationship with MS decisions on network models)?

3. What are the potential migration scenarios and planning?

4. What can be significant cost drivers or cost savers for the different RU's, IM's and MS?

5. How to ensure interoperability during the migration?

6. Which tools can be used to create migration scenarios that are well balanced and acceptable for RU and IM, on MS as well as on EU scale?

Another objective of this study is to provide an economic model and to assess its sensitivity to the relevant parameters in the appropriate scenarios. The model has been used to simulate the impact of national or EU decisions regarding start of deployment, speed, phasing out of GSM-R. Interesting cases that have been considered are first and last implementers, as well as how migration scheduling affects costs for IM's and RU's. It will be important to identify possible tools and impact - to influence individual plans.

The final results of the study are designed to help ERA to provide detailed information to the Commission and stakeholders, in particular on:

- the optimal timeline for the migration (incl. justification, options)
- the conditions to make it successful

2.3 Summary of the methodology

2.3.1 Methodology

The methodology was defined, aiming at answering the 6 migration questions that ERA specifically asked to be addressed in this study. To achieve these objectives, a methodology inspired by the European Commission Guidelines for Better Regulation, and specifically, the "Better Regulation Toolbox" chapter 8 (methods to identify, assess and quantify costs and benefits) was used.

The structure of this methodology is summarized in the figure below:

	Step 0 : Inception	Step 1: Data collection	Step 2 : Data analysis and options definition	Step 3: Options assessment	Step 4 : Recommendations
Objectives	• Set the bases to ensure the project direction and management.	• Build the evidence base concerning stakeholders status related with GSM-R (contracts, business case, business model, Opex&Capex, operational constraints...).	• Make a clear statement of the problem to be solved • Set the migration scenario option list • Interoperability and roaming	• Assess the economic balance of the identified options for each stakeholder	• Synthesis main findings and provide recommendations • Answer the 6 questions defined in the tender specification

Expected outcomes	KICK OFF PRESENTATION
	KICK OFF REPORT
	PROJECT PLAN
		INTERIM REPORT
		• RU/IM/MS questionnaire
		• RU/IM/MS business cases, including :
		  • GSM-R projects status
		  • Contracts strategy, conditions and lifecycle
		  • Stakeholder's categorization (freight/passenger, IM/RU, ..large/small
		  • Economic model parameters
			INTERIM REPORT
			• Mapping of the rollout of network and onboard equipment for different stakeholders (IM/RU)
			• List of migration scenario options
			• Choice of an adapted scenario evaluation tool
				FINAL REPORT
				• Economic model
				• Migration scenario options multicriteria evaluation
				• Sensitivity analysis to simulate impact of national or EU decisions regarding start of deployment, speed, phasing out GSM-R (early adopter / last implementation, tools to influence individual plan)
					FINAL REPORT
					• Recommendations on migration scenario, identifying optimal transition period and start conditions needed

Tools	• Meeting with ERA	• Desk research • Interviews RU/IM/MS, possible PPDR, urbain Rail, public operator	• Study performed by analysis • Desk research • Possible complementary interviews	• Economic model • Desk research • Possible complementary interviews	• Desk research • Possible complementary interviews

Step 0: Inception:

The objective was to lay the foundation to ensure project direction and management. It included a kick-off meeting with ERA, a Kick-off Report and Project Plan preparation and delivery.

Step 1: Data Collection

The objective was to build the evidence base concerning the status of relevant stakeholders related with GSM-R.

The outcomes were RU/IM/MS migration drivers information and business cases elements that included:

- GSM-R projects history, time plan and current status;
- Contracts strategy, conditions and lifecycle;
- Expectations concerning the future system and deployment
- Economic model parameters.

For the development of a model (definition), Systra identified the most relevant data that was needed to be collected and used in the model (in coordination with ERA).

To achieve these objectives, Systra planned to carry out the following tasks:

- Desktop research, reviewing and assessing previous studies.
- Preparing a questionnaire and establish Interviews with key stakeholders:
    - European Infrastructure managers
    - European Railway undertakings
    - Member states representative
    - Commercial Mobile Network Operators (MNO);
    - Industrials (not limited to GSM-R Industry Group).

In the end the questionnaire was limited to IMs and RUs and it was decided not to carry out interviews.

Step 2: Data Analysis and Options Definition

The objective was to develop an overview of the current situation and to create a clear statement of the problem to be solved and questions to be answered. Based on the overview and problem statement, Systra defined the migration scenario option list, including interoperability and roaming aspects.

The objectives were:

- Migration drivers.
- A mapping of the historical rollout of GSM-R network and on board equipment for different stakeholders.
- A mapping of contracting strategies and system life-cycle management for different stakeholders.
- A list of migration scenario options.

- The choice of a scenario evaluation tool.
- Model parameters and cost data.

To achieve these objectives, Systra carried out the following tasks:

- Data collection and analysis
- Additional desktop research

Step 3: Option Assessment

The objective was to assess the economic balance of the identified options for each stakeholder.

The objectives were:

- Migrations drivers analysis
- An evaluation of migration scenario options
- An economic model
- Sensitivity analysis

To achieve these objectives, the main task was to shape, structure, feed and test the robustness of a model that can be used as a tool to create migration scenarios that are well balanced and acceptable for RUs and IMs.

The methodology was based not only on the Better Regulation guidelines philosophy, but also on other experience with economic models and with GSM-R deployment projects.

Step 4: Recommendations and Report Finalisation

In a final step, the main findings, conclusions and recommendations were summarised to provide answers to the six primary migration questions posed in ERA's Terms of Reference.

2.3.2 Sources of information

There were two principal sources of information used for this study and for the economic model.

The first source was UIC and ERA general information on the time plan for deployment of GSM-R in Europe, on network size, and on GSM-R terminals including cab radios and EDOR.

The second source of information was the Questionnaire that we built and sent to all RU and IM representatives. The main objectives were (1) to obtain general information about GSM-R migration including drivers and constraints and (2) to gather cost information elements on CAPEX and OPEX on infrastructure (IM) and cab radios (RU) for the economic model. The questionnaire included questions on the next generation time plan.

The collated data was used in the following way to address the initial objectives of this study:

1. What may be criteria and business drivers (IM/RU/MS) for decisions on starting the migration for RU's and IM's in the different MS (include CCS TSI functionality and all other usages)?	*Questionnaire, Scenario analysis*
2. How does this interact with MS decisions on network models (i.e. *relationship with MS decisions on network models)*?	*Cost analysis, questionnaire*
3. What are the potential migration scenarios and planning?	*Questionnaire, ERA information*
4. What can be significant cost drivers or cost savers for the different RU's, IM's and MS?	*Questionnaire, analysis*
5. How to ensure interoperability during the migration?	*Analysis, scenario definition*
6. Which tools can be used to create migration scenarios that are well balanced and acceptable for RU and IM, on MS as well as on EU scale?	*Economic model, analysis*

2.3.2.1 The Questionnaire

The questions were divided into 4 sections. The first related to generic information of the organisation including GSM-R network size and/or fleet. The aim was to evaluate what should be migrated and how large is GSM-R for each stakeholder. The second section was designed to collect information on the previous migration to GSM-R (time plan, drivers, complexity, lessons learnt) to evaluate the difficulties of a possible future migration. This section was entitled "The past situation". The third section, "The current situation" was focused on contracting aspects and life-time cost range for OPEX and CAPEX. The aim was to evaluate migration drivers and also to build the model. The final section, "The future," aimed to collect information on the GSM-R successor and the possible migration process including time scales.

The questionnaire provided elements for the cost analysis in a way that helps to determine the likely cost range and the likely duration of the migration (see the Economic Models chapter).

The questionnaire also contributed to the analysis of migration scenarios and drivers.

2.3.2.2 Questionnaire results

The questionnaire was sent mid-January 2016 to representatives of various organisations who were requested to distributed the questionnaire within their respective entities. At the completion of the exercise at the end of March 2016, 13 responses were received which fall in 3 groups:

- Organisations that are both IMs and RUs: 3 answers
- Organisations that are IMs only: 8 answers (11 including IM/RU answers)
- Organisations that are RUs only: 2 answers (5 RU answers including IM/RU answers).

40% of European IMs were contacted. In terms of network size, these IMs represents almost 70 % of the total railway network (in route km) and 65% of the GSM-R network planned in Europe. The responses received can be viewed as providing a reasonably representative sample of all IMs in Europe, despite the fact that more responses were received from western and northern countries than from eastern countries. It should be noted that detail of the responses received varied considerably, where some responses provided only a relatively small amount of information (either because the respondent did not have the necessary knowledge, or because the information requested was viewed as confidential), whereas other responses were quite comprehensive.

There were only few responses compared to the substantial number of RUs in Europe. The RUs that responded represent only a low proportion of RUs in Europe. As a first approximation, we estimate that they represent up to maximum of 25 % of the number of cab radios in Europe. As a consequence, it is difficult to draw meaningful conclusions for railway undertakings. Furthermore, as with IMs, some RU answers were not complete to due lack of information or confidentiality aspects.

We thank all of the survey participants for their help and their time. We also thank CER and EIM representatives for their help and support, as well as the UIC ERIG chairman and the RTC group who also supported this work.

In most respects, the responses are detailed enough to provide useful information for this study; however, the cost information that was provided was often declared confidential. These limitations in the permissible use of cost data resulted in a simplified cost simulation in the economic model. One option could be to present the model to stakeholders in order to solicit a reaction potentially resulting in additional information being provided.

We would like to thank all participants of the questionnaire which helped define and evaluate future migration scenarios.

Summary

- The questionnaire answers gave information for the economic model as well as migration drivers
- Due to the high proportion of Infrastructure Managers taking part in the survey a good level of information was achieved even if some elements, in particular costs, remain confidential.
- Conversely as so few Railways Undertaking took part and since there was a wide variation in their responses the conclusions that can be drawn from this part of the survey are limited.

3. CURRENT STATUS OF NEXT GENERATION TECHNOLOGY FOR OPERATIONAL RAIL COMMUNICATIONS

Highlights

- This study is part of stream of studies and activities driven by the European Rail Agency.
- We have identified a number of operational and interoperability requirements that are reflected throughout our analysis.
- We assume the following overall time constraints throughout: (1) Draft requirements and specification by 2018 – 2019; (2) Possible start of deployment toward the end of 2022; and (3) Support for GSM-R until 2030 and beyond.
- We assume that the successor technology will be a modified off-the-shelf system IP-based technology (with Rail and possibly PPDR-specific enhancements), and that there will be a clear split between the application layer and the bearer layer. Different network ownership models are possible.

3.1 Previous studies

This study is part of a series of enquiries led by ERA and the European Union aimed at ensuring the future of the European interoperable railway radio communication system for train operations. GSM-R technology is based on second generation (2G) digital mobile technology and there is a need to identify a successor. This successor is required starting from 2020 to 2030. Prior to this study, other studies have been carried out that collectively set the framework we must consider.

A study entitled "Survey on operational communications (study for the evolution of the railway communications system)", produced by Analysis Mason on behalf of ERA 2014, presents and evaluates 6 options of system evolution from the current situation:

(1) retain GSM-R,
(2) new technology with same band,
(3) new technology with new band,
(4) new technology with third party,
(5) multiple prescribed technologies,
(6) multiple technologies without prescription.

Figure 1. GSM-R deployment in France

This study considers that radio spectrum positioning and availability as it is key factor for evolution and it gives an overview of current systems and services. There are also terminal/cab radio considerations in term of evolution interoperability and as a tool of transition. The terminal should support different technologies including the legacy GSM-R radio in order to facilitate the transition and to avoid an excessively long or abruptly short transition period.

Another study, initiated by the European Commission and written by SCF, was published in 2014, considering the use of commercial mobile networks and equipment for "mission-critical" high-speed broadband communications in specific sectors, such as rail, energy and *Public Protection and Disaster Relief (PPDR)*. This study identified possible opportunities for commercial Mobile Network Operators (MNOs) to meet mission critical communication needs. This study identified the following policy options:

(1) dedicated networks and dedicated specialized equipment,
(2) commercial MNO networks and commercial equipment,
(3) dedicated networks with commercial networking equipment,
(4) hybrid networks; and
(5) a common multi-purpose network.

The options defined by the ERA study have been assessed by an IDATE / WIK-Consult team in a report published in 2015. The goal was to evaluate the feasibility of each option, and to select the most suitable ones. The study focused on possible operator concepts for railways, frequency availability, evolution of the terminals and network infrastructure and economic aspects. It drew a distinction between decisions to be taken at European level, and those to be taken at Member State level. The IDATE/WIK study identified 21 various Findings and also 11 different Recommendations.

3.2 Migration Plan

Different standardization groups such as UIC Future Radio Mobile Communications System (FRMCS) Project or ESTI Rail Transportation Working Group Next Generation Radio for Rail (NG2R) discuss and develop working assumptions in a number of areas including migration planning.

The primary basis for this Systra study is the existing European framework in terms of rules and interoperability requirements for rail which includes:

- The GSM-R successor and migration plan must maintain interoperability and roaming throughout Europe. It is assumed that migration should be seamless from a traffic and service point of view.
- Regarding interoperability, the basic objective, as defined in the Interoperability Directive, is the free movement of trains. In the context of this study, it can be described as the principle that before, during and after the migration, every CCS TSI compliant train has to be allowed to run on the railway infrastructure which is in the scope of this TSI.

Following on from this, the proposed migration plan will be based on the following assessments proposed by Systra for this study:

- It shall be noted that currently some national technical rules (NTRs) are applicable which add requirements for the access of trains in a certain MS. Also some optional features of GSM-R are in use. In order not to complicate the migration study, the starting point of the study is that all trains and infrastructures are fully compliant with the CCS TSI. In the case that we identify NTRs or options that might create obstacles or additional burdens to a smooth migration, Systra will note the concern, but they will be kept out of the economic modelling.
- Additionally, considerable work is necessary on the radio systems specifications ensuring that

    - Rail operation functionality is de-coupled from its underlying transport and is future-proof
    - National and functional specificities must be reduced
    - Transport specifications must generally converge with generic standards, such as 4G-LTE or future 5G common specifications.

- Assumptions on terminals are required to elaborate scenario and migration plan. As indicated in previous study, multimode and adaptable terminals are required to support the transition between different technologies inside each country (including the ability of cab radios to continue to operate on lines that still use GSM-R and have not yet been upgraded during the migration), and also to assure interoperability through European Countries.
- Depending of scenario deployment and level of interoperability required by stakeholders, interworking development solutions could be required and may increase complexity. For example, there is a need for a functional requirement for in-call inter–technology handover
- For the migration plan, different criteria can be identified that include ease of migration, cost of migration, and the time plan on which to migrate.

3.3 Migration timeframe

The migration mechanisms and the migration time frame are central subjects to raise early on in the process of GSM-R replacement. We have attempted to consider all possible migration scenarios and their associated economic impact, even though the technology and spectrum to be used are still in the discussion phase.

The guidance from EC concerning the indicative time line for a new technology introduction, is:

- Draft requirements / specification by 2018 – 2019
- Possible start of deployment in 2022 (need to confirmed by industries)
- In the meantime, the industry has confirmed that support will continue until 2030

This time frame is the working basis for this study, leading to the conclusion that the introduction of new technologies and transition from the current GSM-R technology to the new one will take place roughly between 2023 and 2030. This implies a long period of coexistence with GSM-R all around Europe, inside MS, and/or at the borders between MS.

Our terms of reference call on us to identify the factors that are likely to trigger the migration in different Member States, and the appropriate timing to mitigate the risks of obsolescence of GSM-R.

Depending of the migration scenario, this optimal time frame can be different.

As the GSM 2G market starts to decline rapidly during this decade and even faster in the 20's, a negative impact on cost and availability is expected due to decreasing industry chain support. The impact on terminals is likely to be greater and occur more rapidly as observed in other similar professional sectors.

3.4 Technology consideration for migration

The analysis of future technologies will be part of separate study (possibly including satellite communications).

It is expected that the successor technology will be a modified off-the-shelf system IP-based technology (with rail and possibly PPDR-specific enhancements as we note below), and that there will be a clear split between the application layer and the bearer layer. The definition of the interoperability attributes of the air interface includes two possible variants: (1) using Over-the-Top (OTT) applications, or (2) using specific features (e.g. LTE capabilities that are based upon PPDR requirements). This is under investigation.

Different network ownership models are possible but high Quality of Service and high RAM (Reliability, Availability, Maintainability) requirements for both voice communication and data transmission support for ETCS imply significant constraints.

Radio spectrum bandwidth are still under discussion for rail applications. A migration deployed in the existing UIC bandwidth (873-880 MHz and 918-925 MHz) or close to it will be optimal in terms of radio site reuse and deployment timescales. A potential frequency change to a higher band would lead to considerable cost increases and longer deployment timescales to obtain the equivalent grade of service (installation of additional radio sites).

Note: This technology consideration does not impact the approach of the study itself but when relevant it is included in the assumptions (no change in the model but in the assumptions). The approach based on what is known today. The approach can accommodate a wide range of ownership models and technologies.

Summary

- As the GSM 2G market starts to decline rapidly during this decade and even faster in the 20's, a negative impact on cost and availability is expected due to decreasing industry support. The impact on terminals is likely to be greater and occur more rapidly as it has already been observed in other similar professional sectors. Different network ownership models are possible but high Quality of Service and high RAM (Reliability, Availability, Maintainability) requirements for both voice communication and data transmission support for ETCS imply significant constraints.
- Radio spectrum bandwidth is still under discussion for rail applications. A migration deployed within the existing UIC bandwidth (873-880 MHz and 918-925 MHz) or close to it will be optimal in terms of radio site reuse and deployment timescales. A potential frequency change to a higher band would lead to considerable cost increases and longer deployment timescales to obtain the equivalent grade of service (installation of additional radio sites).

4. LESSONS THAT CAN BE LEARNED FROM THE ON-GOING MIGRATION TO GSM-R

Highlights

- In understanding future migration characteristics, it is helpful to study the still ongoing migration to GSM-R itself.
- This experience suggests that migration is complex, and need preparation and to be carefully planned and coordinated although the different stakeholders.
- GSM-R deployment and migration was a long process. For medium size Member States (with a few thousand route km each), the time line starting from planning to end of migration was minimum of 7 years. For larger Member States, that individual migration time line sometimes required up to 19 years.
- The maintenance and re-contracting activity is still ongoing for GSM-R

4.1 GSM-R implementation

4.1.1 Infrastructure deployment

GSM-R has had considerable success across Europe. The UIC ERIG group regularly collects information from IM participants on GSM-R network deployment and used in this chapter. The survey responses confirm this information. Soon, GSM-R networks will have covered almost 75% of the European railway network (27 countries in Europe including Norway and Switzerland) which represent approximately 163 000 route km. Deployment is either completed or reaching completion in countries with large rail networks such as Germany, France, Italy and Belgium. Elsewhere, particularly in eastern European countries, GSM-R network is still in development.

European Network size	In km of line	Percentage of (%)	
		Total network	GSM-R network
Total Railway Network	218 726		
GSM-R planned	162 978	74,5%	
GSM-R constructed	114 782	52,5%	70,4%
ETCS L2 (km) planned	38 470	17,6%	23,6%

ETCS L2 (km) in operation	6 451	2,9%	5,6%

Table 1. European Network size (source: UIC ERIG)

For GSM-R infrastructure, it is important to note than 6 countries make up 60 % of the total coverage and that three of these countries represent 37 % (Germany, France, UK). Up to now, ETCS Level 2 represents a small proportion of GSM-R lines (only 5.6 %), but ETCS Level 2 will grow to reach more than 20% coverage over the coming years. The following information gives a clear view of GSM-R network in Europe now and in the foreseeable future (*source: UIC ERIG*).

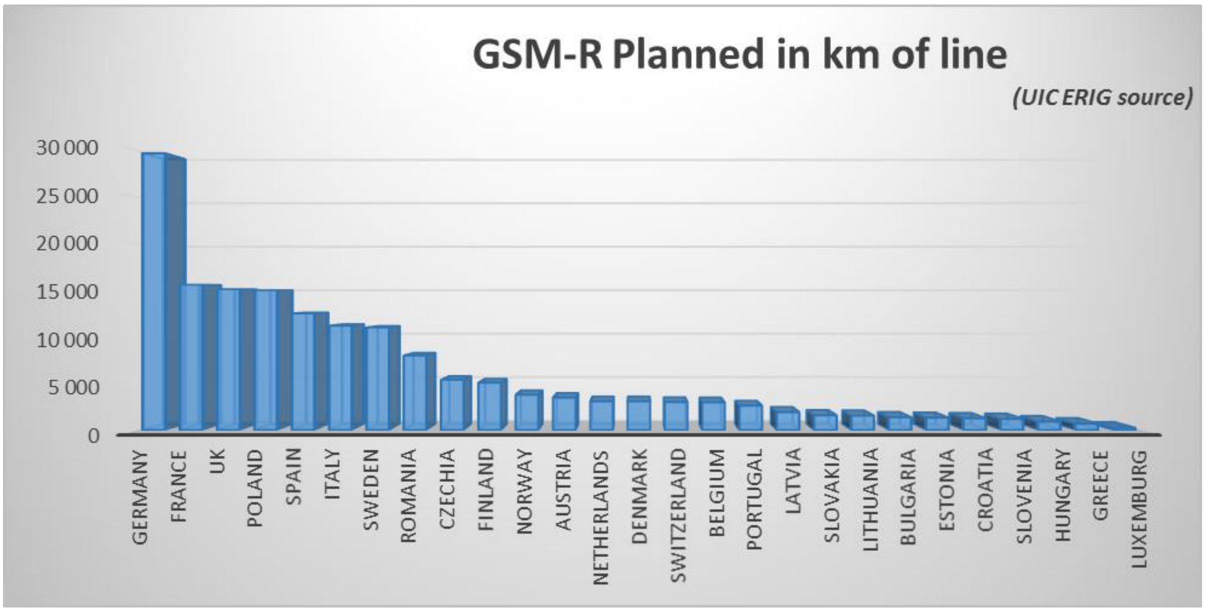

Figure 2. GSM-R infrastructure planned in Europe (source UIC ERIG)

A GSM-R network is composed of a number of sub-systems as highlighted in the figure below. Radio sites provide coverage along track, in stations and other locations. One or more GSM-R Base Transceiver Station (BTS) are located in each radio site. The core network deals with the communication service. There are several central equipment's in the core network that comprise the Network Sub System (NSS). Note that between BTS and NSS, there are BSC (Base Station Controllers). Another component of the GSM/GSM-R network is the Operation and Maintenance Centre (OMC) used to supervise the network. Finally, the Fixed Terminal Sub-system provides the telephony services and equipment to railway controllers (this includes the dispatcher terminals).

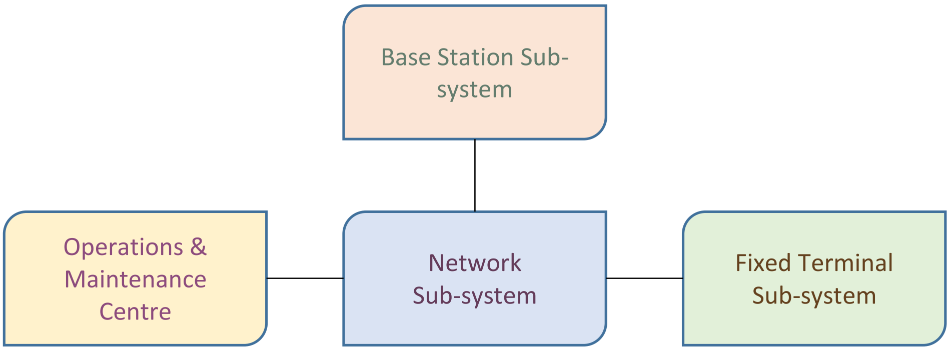

Figure 3. Functional GSM-R Network Architecture

In terms of radio site infrastructure, approximately 18 000 radio sites have been built to date in Europe for GSM-R. The coverage per site in railway km is highly variable due to the environment and level of service. This coverage varies from a minimum of 3 km to a maximum of almost 12 km with an average and median between 6 and 7 km.

Typically, each Infrastructure Manager has deployed a minimum of 2 core network sites which contain NSS, FTS and OMC equipment. Due to the critical nature of these sites they are usually geographically separate to ensure full redundancy in case of major damage or disaster. The cost importance in terms of % of the core network depends on the size of the network and the number of radio site.

4.1.1.1 Deployment and migration Time line

Deployment and migration are 2 different phases to prepare launch of service for railway. Deployment phase include engineering study, civil work, installation, integration and commissioning, it is a long process but this phase has usually little interaction with railways activities (in some case, co-activities has to considered and field work slot is required). Migration phase interacts directly with railway operational activities. This phase should be prepared and planned with all different operational stakeholders in order to avoid all functional disruption that can have impact on security or traffic management.

The earliest GSM-R deployment started in 1998, with the majority starting around 2001. Deployment is expected to be finished in 2020 at the latest. That means that the deployment at a European level will have taken more than 20 years in total.

- Within each Member State, migration typically started two years after the start of deployment, and in some cases much later. This period allows time to complete the network rollout and to organise migration.

- Within each Member State, the end of the migration period is usually one year or more after the end of implementation. It seems that the latest date of migration that has been announced is 2025.

Even if migration time is substantial throughout Europe, there are Member States that have migrated far more quickly. We note that many countries started migration between 2001 to 2005. Some medium size Member States finished their migration in a minimum of 2 or 3 years. For large Member States, it typically took more than 10 years (12 to 15 years) to implement and migrate their service.

Year of	Early adopter	Average	Median	Latest
Start of implementation	1998	2006	mid 2005	2013
Start of Migration	2000	2008	2007	2017
End of GSM-R implementation	2004	2014	mid 2014	2020
End of GSM-R Migration	2006	2015	2014	2025

Table 2. GSM-R implementation and migration plan (Source ; UIC ERIG)

In sum, GSM-R deployment and migration was a long process. For medium size Member States (with a few thousand route km each), the time line starting from planning to end of migration was minimum of 7 years. For larger Member States, that individual migration time line sometimes required more than 15 years, and in some instances up to 19 years. There are several potential explanations for the long duration of deployment. In most Member States, GSM-R deployment required the creation of a large number of new radio sites along the railway line. Former analogue radio system sites could not be re-used in most of the cases (not same band, technology very different and rather old). Compared to public mobile operator, radio site deployment along the track is much more complex to plan and to carry out. We note that for migration to a new technology, the re-use of radio sites is likely to be key in terms of schedule and cost. In case of frequency modification attribution (i.e. less bandwidth or different frequency range), IM will potentially require additional radio site that will significantly impact cost and timescales. In that way, the reuse of existing radio sites in the future is extremely important in cost and delay.

4.1.1.2 Investment evaluation

The SCF report Study on the use of commercial mobile networks and equipment for mission critical operations indicated in 2012 a total cost trackside equipment evaluation of approximately € 8.8 billion for 154 284 km of line which equates to € 58 792/km.

Using the cost elements detailed in Section 7.2.2.3 Timeline and financial assumptions and information from the questionnaire sent during this study a figure was derived for investment (CAPEX) on the infrastructure side of € 9.8 billion based on 163 000 km of line equating to € 60 000 per km (which is in close agreement with the previous estimate by SCF). Civil works and site construction including towers represents the largest part of the investment. Another important investment is generally the transmission network (adaptation of existing infrastructure or deployment of new cables and equipment). This investment is more complicated to evaluate because it depends on the existing fixed infrastructure and previous investment.

OPEX cost is evaluated to be € 3 300 per km without technology renewal cost.

By comparison the CAPEX evaluation on RU side for cab radio for EU represent a limited amount of this investment. In Section 7.2.2.3, we evaluate this investment from 12 % to 22% according the number of equipped rolling-stock. It is evaluated to 1.4 billion for the whole of Europe including equipment and installation. It is assumed that installation forms up to 50% of the total figure. This assumption leads us to evaluate the cab radio market at approximately €700 million. Note that this evaluation does not include hand portable and other equipment including radio transmission.

4.1.2 Terminal equipment

In a GSM-R network, there are different types of radio equipment. This section deal with all kinds of terminal equipment including cab radios, EDOR, and other GSM-R equipment.

Each of these GSM-R devices has at least one SIM card as required by standards. From a technical point of view, each type of equipment has a different SIM card configuration (i.e. profile). SIM cards are owned by the IM even if they are installed in RU equipment, inasmuch as they are considered to be an integral part of the network and not of the terminal. This situation is still true when a train and cab radio roams on the infrastructure of another IM in a neighboring country then the SIM still viewed as being part of the infrastructure of the originated country. Roaming agreement and roaming interworking allow interoperability and hence communication service to foreign trains.

Note: Fixed Terminals are national-specific and hence outside the scope of this report.

The number of cab radios in Europe used in this study are presented in section 7.2.2.2 Railway Undertaking assumptions. A figure of 64 000 cab radios was identified which is derived from two sources: (i) the total number of planned EDOR and voice cab radios (71 329) and (ii) 48 662 for installed cab radios (Installed 5% EDOR and planned 11%). In the simulation it was agreed with ERA an intermediate number of 64 000 and 20% of EDOR for most countries. In the following, we present an rough evaluation of planned cab radio and EDORS equipment's in each European country. Note that the data source is UIC ERIG and not directly from RUs source. It can be considered as approximate figures.

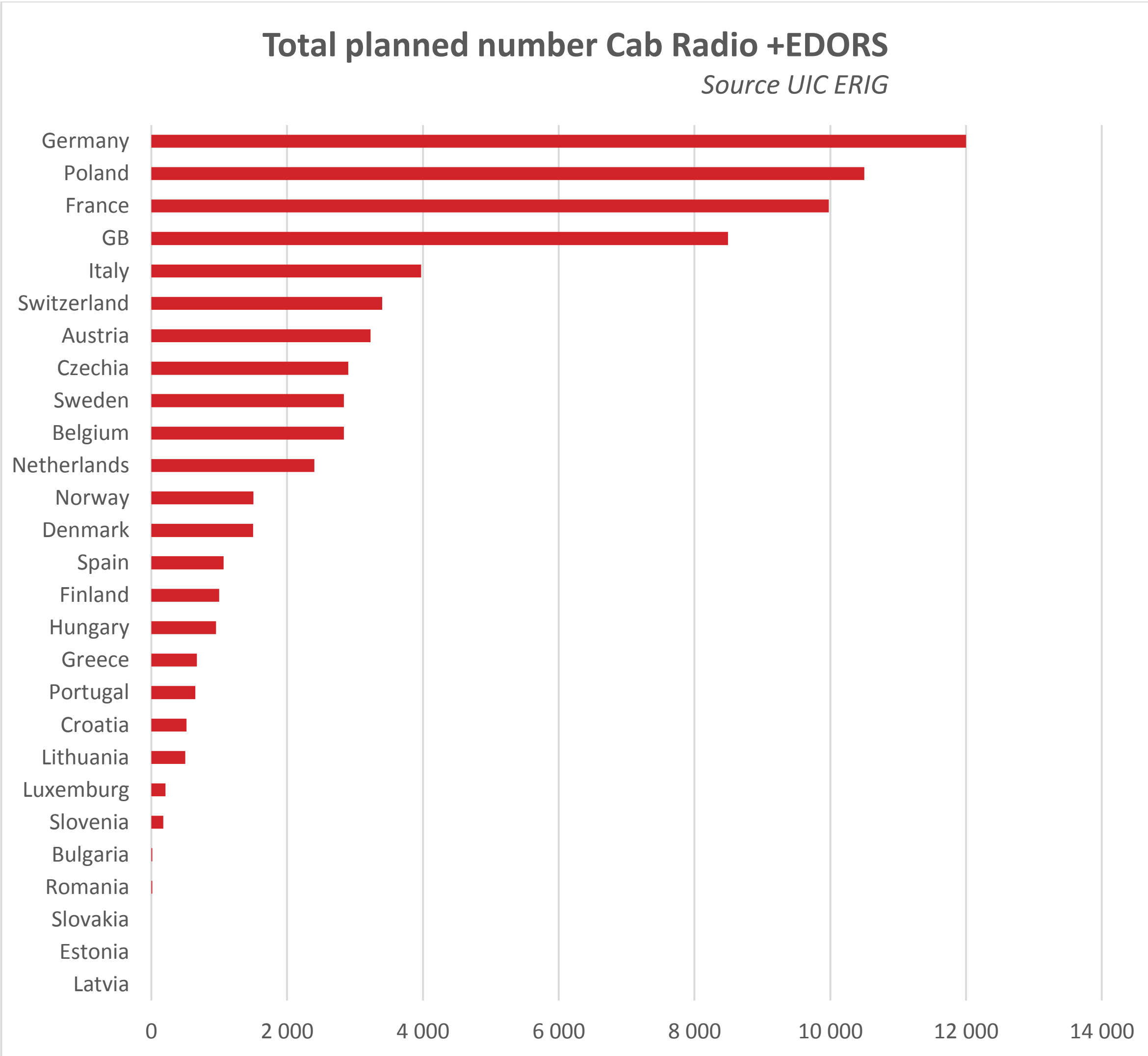

Figure 4. GSM-R cab radio and EDORS planned in Europe (source UIC ERIG)

4.1.2.1 Cab radio for voice service

Due to relatively low number of responses to the questionnaire from RUs, and due also to the large number of RUs in Europe, the questionnaire does not provide definitive information on cab radio quantity and future evolution. The responses nonetheless suggest that RUs plan a relatively low increase in GSM-R cab radio deployment. A growth of less than 10% in the number of GSM-R cab radios is indicated for the foreseeable future in Member States where GSM-R is fully migrated. This low growth can be explained by the fact that most Member State have already deployed totally or a part of their GSM-R infrastructure. Even if infrastructure deployment is not finished, cab radio replacement is largely commenced in order to facilitate train and traffic management.

It can be noted that the part of the dual-mode cab radios (analogue/ GSM) varied from country to country.

4.1.2.1.1 Share of international traffic

The questionnaire provides interesting data on the share of international trains and the share of traction units potentially used for international traffic. The share of train units that cross borders is under 10% in most Member States, but is much higher in some Member States (from 20% to a maximum of 50%). We can conclude that the share of international trains is a national attribute that differs widely among European Member States. These characteristics concerning cross-border train traffic are an important parameter for our modeling of scenarios.

4.1.2.1.2 Time plan for procurement and deployment

The time necessary to prepare the technical specifications, to carry out the procurement activity, and to obtain necessary approvals can be considerable. For an RU with a large train fleet, this could take up to five years. Once the deployment of on-board equipment has been synchronized with the network infrastructure upgrade, a minimum of three years is necessary to migrate a fleet of between 5.000 and 10.000 cabs.

In any case, IMs and corresponding RUs are required to coordinate their deployment to avoid unnecessary delay. Note that the use of dual-mode cab radio allows greater freedoms to RUs to migrate their rolling stock independently of the infrastructure deployment programme. The choice of dual-mode or mono-mode solution depends on various factors one of which is railway operations (how emergency calls are treated for example). For GSM-R introduction different scenarios were used.

Some RUs have demonstrated shorter time scales to organize cab radio migration (just one or two years).

4.1.2.2 ETCS Data Only Radio (EDOR) equipment

ETCS Data Only Radio (EDOR) devices are installed in trains with ETCS Level 2 Signaling in addition to cab radios for voice services. In some cases, the cab radio incorporates transceivers for data. In most Member States, trains with EDOR represent a small share of trains with cab radios (under 10%). This share is expected to increase in the next few years, however, and is expected to reach 30% to 50% in some Member States. Note that EDOR equipment can have at least two but sometimes three radio modules per device, depending on the RU’s choice and desired level of reliability.

4.1.2.3 Handhelds and other equipment

IMs and RUs can employ GSM-R handheld equipment for various purposes. It will presumably be necessary to replace and upgrade all of this equipment as part of the migration.

IMs may use different handheld terminals for operational staff such as General purpose, Operational, and Shunting radios. IMs may also have a few cab radios in maintenance vehicles.

RUs mainly depend on cab radios and EDOR. They may also have GSM-R handhelds for their own purposes.

Trackside GSM-R equipment will also need to be upgraded. This includes trackside phone or modem radio equipment, as well as trackside equipment used by the controller (i.e. secondary controller).

Finally, RUs and IMs also have other radio handhelds based on technologies other than GSM-R (for public or professional use). Migration of these non GSM-R devices may also be candidates for upgrading as part of the migration if an equivalent service is available under the successor to GSM-R.

4.1.3 Roaming status

4.1.3.1 International roaming agreements

IMs have already put in place international roaming agreements. GSM-R network are interconnected to ENIR networks, and connections are operational. Centrally located Member States already have several bilateral agreements and will continue to extend them according to requirements in the coming years. The remaining Member States either already have agreements in place, or plan put them in place once their networks are in service. As in public mobile networks, international roaming occurs with GSM-R. It is now operational and organized. The ability to use existing approaches to international mobile roaming is a key interoperability advantage for mobile technologies compared to other technologies. It is important to maintain the ability to exercise international roaming in any future technology evolution.

4.1.3.2 Roaming with public Network

There is a large diversity of approaches concerning national roaming agreements. National roaming onto commercial mobile networks is possible because the GSM-R frequency band falls within the 900 MHz GSM band that is also used by public mobile operators.

Across Europe, some IMs currently have national roaming agreements on a part of their rail network or even nationwide. Generally, this service is used for areas not covered by GSM-R along the track or as a fallback to GSM-R. Some IM used public networks as a temporary solution during deployment as an ease to facilitate somehow migration phase. It was the case in Switzerland for example.

These agreements can continue as long as GSM is still existence in the 900 MHz band, but some public operators have already announced the end of GSM (e.g. Switzerland in 2020) and public GSM-frequency band re-farming is organized in most countries.

These GSM national roaming considerations might also influence future decisions as to migration time scales for GSM-R. Commercial mobile operator may propose in the next few years to cease GSM services and instead to propose to 3 G or 4 G service for voice and data for all their customers (professional or public). In that situation, some IMs and RUs will have to consider technology evolution for at least a part of their service.

Note: According EU rules, when public roaming is used in principle it should be available for used by cross-border trains in order to be interoperable.

4.2 GSM-R migration

The replacement of analogue radio systems by GSM-R system across Europe provides many lessons learnt and will help identify the most appropriate way to introduce a new generation technology of radio also called Next Generation (NG). Until now, many Railways Undertakings, Infrastructure Managers and Member States have such experience and can provide valuable feedback.

The experience of migration from analogue system to GSM-R highlights that one of the most critical aspects of a successful introduction a new radio system project for a railway is a clearly defined migration strategy defined at the beginning and that is followed throughout the life of the project. Whilst the technical solution implemented may be very good in terms of innovation, efficiency etc. it is how the users of the existing systems are migrated to the new system that matters to the success of the overall project.

For each specific stakeholder, there is no one solution that is ideal; it all depends on the precise nature of the railway concerned. In general, the principle aspects that need to be considered for the implementation of a complete GSM-R system comprising fixed infrastructure and on-board equipment are:

- Vertical integration – is the rail infrastructure managed by the same entity as train operations.
- Size of the national infrastructure.
- Size of the train fleet of the different RU’s.
- Number of classes of vehicles.
- Geographical reach of the various vehicles – what part of the fleets operate cross border and on what rail networks.
- Overall project programme constraints.
- Deployment of the fixed infrastructure including transmission and fixed telephony.
- Availability of vehicles for fitment and testing.

- Availability of drivers for testing and training.
- Impact of possible train delays (as a result of the implementation of GSM-R) on safety, operations and revenue.
- Safety and regulatory regime.
- Interoperability with neighbouring rail networks.
- Project funding.
- Interoperability and interworking between different areas according deployment and bringing into service or even, in some cases, between different IM in a same country.

The migration timeframe varied from country to country. The minimum seems for a medium size country seems to be of 4 years and a maximum in large countries is around or event more than 10 years. All IM that provided responses to the questionnaire indicate they prepared a migration strategy and plan that need to be elaborated with all the relevant internal stakeholders. The total time to prepare this migration is quite long and represents a minimum of 6 months to a maximum a few (2, 3 or 4) years.

Concerning the migration timescale there are differences between IM and RU. It seems than in some countries due to a long period of deployment on the IM side, RUs adapt their deployment and extend their schedule especially for regional trains if GSM-R is not operational yet in a particular area. In that way, we can consider a coordination on the deployment planning of cab radio.

We notice than some “early adopter” countries will start replacing GSM-R site equipment as they have reached the end of their life. This change is much quicker than the first deployment because there is far less work to do (i.e. no civil works). As an initial estimate, the cost is probably between 30 to 50 % of the cost of the initial deployment. This information is particularly interesting to evaluate future migration on the IM side.

It is interesting to note that due cab radio lifetime equipment some RUs have already initiated an equipment renewal programme. For RU, it is comparable project to the analogue to GSM-R migration management.

4.2.1 Migration organization

An interesting question about migration is to know how IMs and RUs organize migration to integrate it in their operational plan to minimize the impact on traffic and safety. For that, parallel operation (here analogue and GSM-R) on a national or local (line, or area) scale can be avoided. Operating and maintaining two technologies in parallel is economically less efficient.

For many countries, the national migration project had been split into multiple sub-projects of lower complexity such as line by line and service by service or area by area, whilst covered by a single programme management organisation. It seems there is almost no operational overlapping of GSM-R and analogue system on the track-side for a given line or given area (hard switchover). In some cases, a time limited backup with previous system was accepted. In such a context, dual-mode equipment is requested.

Another case indicated a longer parallel operation with a migration of the infrastructure first and then a migration of cab radio. This migration process did not require the installation of dual-mode cab radios.

An interesting case, is a country having a previous roaming agreement with GSM/GSM-R equipment. Here, the migration process was a mainly SIM card replacement project.

Some IMs indicate that they had a pilot Line to initiate the migration process.

4.2.2 GSM-R Migration Drivers

4.2.2.1 Possible migration drivers

In this section, the main drivers that can influence the migration strategy from one technology to another for the different stakeholders are identified. These drivers are evaluated in the past migration (analogue network to GSM-R) and also for the future one (i.e. GSM-R to Next Generation).

A list of drivers is presented below for IM and RU.

Drivers for IM and RU to migrate to a New Technology	Observations
Equipment (IM or RU) reliability decrease	Over the lifetime of the infrastructure the equipment is likely to degrade resulting in a lower system availability if there is no regular equipment renewal.
Increase of maintenance cost	Spare parts become increasingly difficult to source and maintenance contracts become more and more expensive as newer technologies are promoted by suppliers. Qualified technicians also become harder to find. This is likely to be one of the most important drivers for migration.
Product end of life, end of support for equipment assets	Once a technology is no longer supported by the manufacturers the cost of keeping these networks increases and the possibility of deploying new equipment on new lines becomes almost impossible. This driver will most impact the migration end date.
Cost reduction	Cheaper and more efficient operation of the infrastructure is a necessity for IMs. A new network could be cheaper to install and run than continuing to operate an ageing and soon life-expired technology. This is particularly true if the majority of the civil engineering infrastructure is retained.
Introduction of new services, new applications	A new technology is likely to offer additional services to users and the network operator. For the IM this could mean increasing the efficiency of the network (support more traffic, e.g. ETCS with GSM-R, broadband for with NG).
EU regulation	One of the biggest external drivers for migration could come from new European directives resulting in a requirement to migrate to a new system (or even a new frequency band).
Relationship with other plans, e.g. Introducing ETCS, new lines, etc.	GSM-R network was a main requirement to develop ETCS 2. Then in some country, ETCS 2 was the driver to install GSM-R. In the case of the future NG, IMs rolling out ETCS level 2 and above will need to investigate the impact

	on their GSM-R networks. If the design and a particular network is not compatible with a major ETCS deployment (unable to support the additional traffic) one option could be to migrate to a more efficient technology providing it meets the requirements of ETCS. In parallel, RUs renewing their rolling stock will want to ensure that the on-board radio equipment will not need to be replaced in the near future (additional cost). New rolling stock fitted with near life-expired GSM-R will have to have their business case reviewed.
New technology standard and equipment availability	More modern and advanced technologies are constantly being developed resulting in new equipment being available in the general telecoms market.
Other reasons (such as national requirement or network infrastructure sharing …)	A particular MS may have specific reasons to migrate away to a new technology e.g. a national government decides to impose/favour. infrastructure sharing between transport and PPDR. A RU could be forced to migrate the new system if an IM migrates to the new system and switches off the former technology.

4.2.2.2 Survey results

The questionnaire gives information on migration drivers on GSM-R and evaluation on the complexity level.

For Infrastructure Managers, the technological obsolescence of the analogue radio was the principal driver to perform a migration. European Regulation including TSI was a secondary driver. New service capability including ETCS or safety critical services (such as REC or DSD) was also important. These views are shared between IM. It is important to note that GSM-R as digital radio system introduced a large amount of new services, especially end-user voice services, as well as in network management and supervision aspects. It was a major technological step-change compared to the analogue system. It still interesting to note that in some cases (e.g. shunting) GSM-R does not provide enough capacity and IMs still use analogue or other digital radio systems (such as TETRA).

Others drivers such as an increase of maintenance cost (OPEX++), equipment performance or spectrum availability were not considered as having the same level of importance.

Some IM had others reasons to initiate a migration, for example to unify radio systems so to have only one rather than several systems (one radio system per service such as shunting, maintenance). Other reasons indicated by IMs were:

- end of service contracts
- spare part shortage
- obligation to vacate existing spectrum

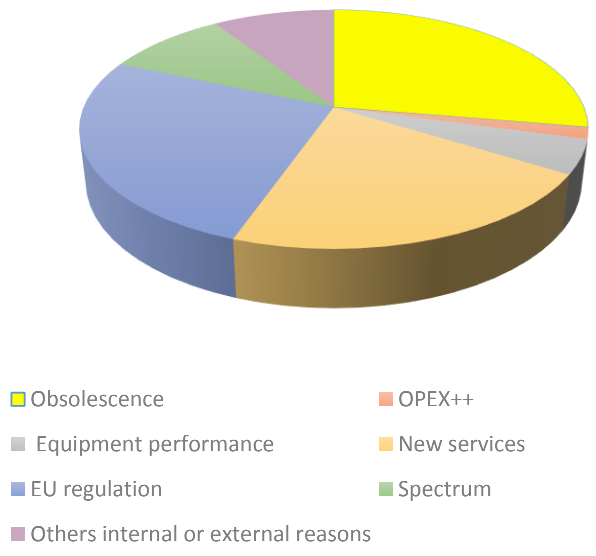

Figure 5. GSM-R Migration drivers evaluation for IM

Railway Undertakings and Infrastructure Manager had the same reasons to migrate to GSM-R.

For RUs, the technology obsolescence of the analogue radio was also the main driver to perform a migration. European regulation and new service capability were also important.

Others drivers such as an increase of maintenance cost (OPEX++), Equipment performance or spectrum availability were not considered as important as for IM. There are additional reasons indicated by RUs.

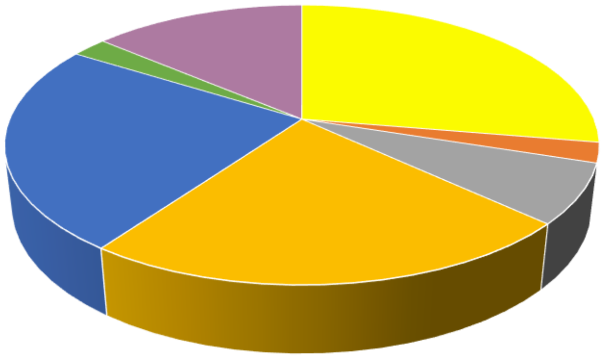

Figure 6. GSM-R Migration drivers evaluation for RU

4.2.3 Migration complexity

Infrastructure Managers tend to evaluate migration complexity as high (Normal to Very Complexed). It is a common view. Note that one RU indicates that a midlife renewal can be considered as low complexity from a technical point of view but still medium complexity from organizational point of view. We can imagine than it requires less effort for equipment renewal compared to a full migration.

The RUs who responded to the survey evaluated migration complexity as well as IM rather complex but not very complex. It is a common view between RUs.

4.3 Equipment lifecycle and contract renewals

In this section, we attempt to map contracting strategies and system lifecycle management for different stakeholders.

We can make assumptions on migration starting date and also on GSM-R end of life: the earliest migration date can be expected in 2023 and the GSM-R end of life will not occur before 2030.

Information in the public domain suggests that Infrastructure Managers are concerned about network maintenance and end of support starting in 2022:

- Netherlands: 2022
- Germany: 2025

- France: 2025

Possible negotiation may extend these deadlines but with no warranty and with additional risk (financial and technical).

Some Infrastructure Managers have already started the initial internal discussion on migration. One of them indicated that the migration could be based upon parallel operating of GSM-R and NG between 2025 and 2035, offering a 10 years transition for RU's.

4.3.1 Infrastructure Manager situation

4.3.1.1 Life time cycle and renewal strategy

In the questionnaire most IMs indicate an expected operational lifetime not before 2025 but not much after 2030 due to possible limited duration of support from industry. All IMs have recently implemented NSS upgrades (2015) or plan one before 2019 (release R4). Some countries already plan a BSS renewal to enhance availability for example. Such replacement is planned from 2017 to 2022/2025.

4.3.1.2 Contracting aspects

All countries have different supply and management contract with industry or other players (e.g. public-private partnership). It is useful to know how this contracting aspect may influence a future migration in terms of cost (i.e. obsolescence cost and OPEX) or in terms of decision and planning.

IMs indicated that the end date of contracted support for GSM-R network range from 2021 to 2030 with the majority being between 2022 to 2025. For most of them, it seems there is no direct relation to economic technical lifetime of the network but in another way some IMs notice a risk for extension of contract or re contracting, in case of a supplier abandoning the market. Additionally, it appears that the cost of 2G RF element could increase due to 2G public networks being shut down. On the other hand, we can also imagine possible interaction on the renewal of GSM-R if a successor of GSM-R emerges. Some suppliers can adapt their strategic position depending on their market position. It can be noted that in the past, after first transition between analogue to GSM-R some IM used decommissioned equipment to be used as spare parts. This situation may occur again with GSM-R as it nears the end of its life. In that case, it important to note that for some equipment especially concerning radio sites, compatible public GSM equipment (no specific GSM-R chipset BTS) may also be used thus offering IMs access to potential second hand market.

4.3.2 Railway Undertakings situation

4.3.2.1 Life time cycle and renewal strategy

The expected lifetime for cab radios are differently evaluated but a reasonable assumption is from 10 to 15 years. However, some RU expect more than 20 years and, if possible, more aligned to vehicle lifetime (25/30 years). A lifetime of more than 20 years might be considered to be too optimistic compared to the first approach.

Cab radio and EDOR have independent lifetimes with the exception of integrated cab radio voice + data (e.g. Thalys) that are clearly dependent on each other.

4.3.2.2 Contracting aspects

From a migration point of view, it is interesting to note that some RUs have already managed cab radio contract extensions or contracts for a first renewal.

Most RUs indicated that they have contracts up to 2025. There will still be an uncertain situation on the terminal side when the infrastructure suppliers will confirm end of product life.

From a technology point of view, cab radios are less complex than infrastructure to maintain and it can may be easier to continue product support for a while. We can also expect to have dual mode GSM-R/NG. But, the risk identified is the end of support by suppliers or technological obsolescence. The main concern is that a cab radio supplier discontinues its work in the market. This is a risk due to the low number of suppliers. One IM indicated that situation already happened in the past, the result being increased delays and cost. An additional high risk that could rapidly occur concerns a possible shortage of specific GSM-R components (chipsets) for cab radio or handset equipment. This situation is well known in other industries. In that case, suppliers may create a specific stock corresponding to their committed market in order to ensure production and maintenance, but in that case they may refuse new sales. In some cases, this shortage situation leads to the creation of a second hand market for industrial products. Some IMs and RUs have already experienced this situation for analogue network equipment.

There are important differences in this regard between RUs and IMs. IMs are procuring standard GSM/GSM-R equipment (e.g. BTS) which are a *Commercial Off-The-Shelf (COTS)* product in common with other markets. Cab radios are however specific to the railway market and hence a niche market with limited growth.

RUs using GSM-R hand-held portables for maintenance or shunting requirements may also encounter this situation as this is also a limited market. For example, one manufacturer recently announced the end of a product line.

4.4 Lessons learnt and requirements for next generation migration

All of these parameters and criteria are relevant for the migration of GSM-R to its successor. The principal options for the migration from a system such as GSM-R to another one are based on a dual infrastructure or/and dual fitment of the train, which may differ between Member States. The migration can be progressive or occurring in one go (“big bang”), according to the country or area. Migration scenarios are elaborated with all of the various cases in subsequent sections of this report. Each scenario implies conditions and consequences.

The consequences of each scenario are different depending on whether it concerns the RU or the IM. These criteria are mainly:

- timescales (short or long migration period),
- potential additional cost for RU or IM,
- possible functional impact for end-users or applications.

It is important to note that the total cost of a migration on EU scale depends also on characteristics specific to each Member State (among them the age of investment in GSM-R, type of contract and duration for operation and maintenance).

Regarding lessons learnt from GSM-R with through the questionnaire, the stakeholders focus on different interesting items, particularly items concerning business transformation and early engagement of all train operation and others players. Stakeholders suggest the need for a strong commitment from the company board, and the need to build a dedicated and committed team with high technical and management skills. On project organization, it seems important to not underestimate the complexity of migration, including the time need for preparation, and the cost of the migration. End-user staff representatives should be engaged in the process of migration because they will need to obtain some assurance of good working and training before migration.

One stakeholder focused on the cab radio evolution and recommended that cab equipment be mechanically and electrically compatible to former systems in order to accelerate the system migration. Early involvement of RUs is needed to change on board equipment and to adopt changed processes. Subsidization of new equipment could contribute to a quick launch.

4.4.1 Technological limitation of GSM-R

The answers to many questions in the survey highlighted GSM-R limitations including:

- Capacity limitation (spectrum) for shunting.
- Functional limitations to easily design a small group of user (handhelds).

It will be interesting to check and possibly offer service corresponding to that requirement with future technology.

Summary

- Radio Site deployment along the track along the track is much more complex to plan and to carry out. We note that for migration to a new technology, the re-use of radio sites is likely to be key in terms of schedule and cost. In case the available frequencies were to change substantially from those used for GSM-R (i.e. less bandwidth or a different frequency range), IMs might potentially be obliged to create a lot of additional radio sites, thus increasing cost and delay substantially.
- GSM national roaming considerations might also influence future decisions as to migration time scales for GSM-R. Commercial mobile operators may propose in few years to stop GSM service, and to propose instead 3G and/or 4G service for voice and data for all of their customers (both professional and public). In that situation, some IMs and RUs will have to consider rapid technology evolution for at least a part of their service.
- IMs and corresponding RUs are required to coordinate their deployment to avoid unnecessary delay. The use of dual-mode cab radios potentially allows greater freedom to RUs to migrate their rolling stock independently of the infrastructure deployment programme, and also offers greater freedom to IMs since it de-couples deployment timeframes somewhat. The choice of dual-mode or mono-mode solutions depends on various factors, one of which is railway operations (how emergency calls are treated for example). For GSM-R introduction different scenarios were used.
- An additional high risk that could rapidly occur concerns possible shortages of specific GSM-R components (chipsets) for cab radio or handset equipment. This situation is well known in the industry. In this case, suppliers might create a specific stock corresponding to their committed market in order to ensure production and maintenance. A possible consequence is that a supplier might refuse new sales.

5. MIGRATION TO THE NEXT GENERATION

Highlights

- Triggers are identified to start migration for IMs, e.g. core network migration, and RUs, e.g. implementation of ETCS on-board or replacement of cab-radios. Another trigger for migration could be that a public operator no longer supports GSM technology and roaming.
- It can be observed from the replies received that no IMs have concrete plans to implement a successor but many envisage that deployment will commence from 2022-2025 with the first lines in service by 2025.
- None of the RUs have concrete plans to migrate to a Next Generation radio system. Some think that it may happen from 2025.
- As GSM-R is a mandatory technology for rail, a migration implies legal aspects to deal with technology evolution. Hence EU and MS should also prepare migration by proposing modifications to the legal framework.

This chapter presents the results of the survey sent to Infrastructure Managers (IMs) and Railway Undertakings (RUs) in relation to their views on the next generation system and also other observations. This chapter also present others observations on migration especially at Member State level.

The main area of the survey related to drivers for migration from GSM-R to the Next Generation system. Triggers are identified to start migration for IMs, e.g. core network migration, and RUs, e.g. implementation of ETCS on-board or replacement of cab-radios. Another trigger for migration could be that a public operator no longer supports GSM technology. Note that with some GSM-R networks, there is roaming on to public cellular networks (in rural areas or used as a fall back if there is an interruption to GSM-R service).

As indicated in the previous chapter, an IM can also be triggered by the option of sharing of infrastructure with public protection and disaster recovery organisations (PPDR). This is dealt with in section 5.3 Member State situation.

These drivers and other factors were assessed in the questionnaire and the results are summarised in this chapter. The original questionnaire replies from each of the railway organisations can be found in the annexes.

It is observed that in some cases the results vary considerably between IMs and RUs, while in other cases there appears to be a consensus. In the case of migration drivers where respondents were required to rate migration drivers on a scale from lowest to highest, the results are presented in a summary chart followed by a second chart indicating the standard deviation. This is to highlight the scale of the differences in the ratings.

5.1 Infrastructure Manager

A summary of the results of the answers to the question provided by IMs is presented below. A total of 11 IMs replied to the questionnaire:

ORGANISATION	COUNTRY
Banedanmark	Denmark
Infrabel	Belgium
Trafikverket IT	Sweden
SNCF Réseau	France
CFR	Romania
RFI	Italy
LR Lithuanian Railways	Lithuania
Network Rail	UK
SBB	Switzerland
Prorail	The Netherlands
DB Netz AG	Germany

Table 3. Questionnaire participation IMs list

5.1.1 Plans to implement a successor to GSM-R

It can be observed from the replies received that no IMs have concrete plans to implement a successor but many envisage that deployment will commence from 2022-2025 with the first lines in service by 2025. The IM indicating the earliest migration date is ProRail: 2024.

5.1.2 Migration drivers

The questionnaire asked IMs to rate on a scale of 1 (least important) to 5 (most important) a pre-defined list of migration drivers. A summary of the findings relating to the favoured migration options is presented below. The values in the chart are the mean average ratings for all IMs.

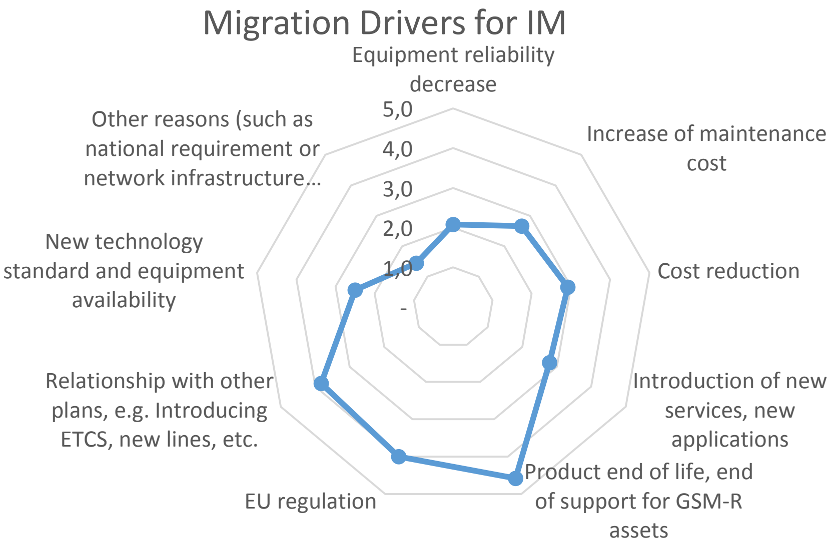

Figure 7. Principal migration drivers for IM

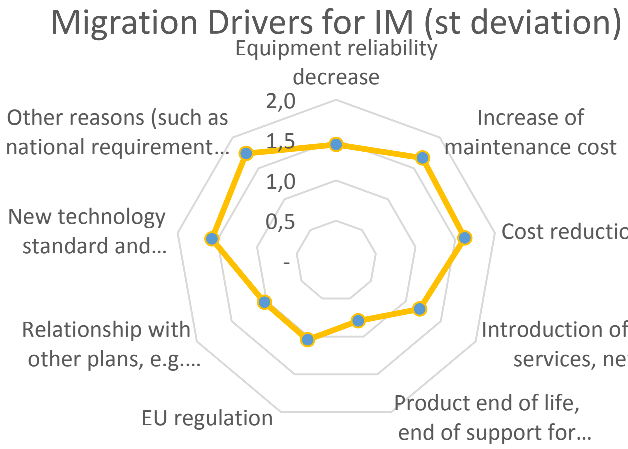

Figure 8. Variety of answers for Migration drivers for IM

The results appear to indicate that IMs consider that the most important drivers for migration are:

- Product end of life, end of support for GSM-R assets: once GSM-R is no longer supported by the manufacturers the cost of keeping these networks increases and the possibility of deploying new GSM-R equipment on new lines becomes almost impossible. This driver will most impact the migration end date. The low standard deviation on the results for this driver indicate that almost all IMs are in agreement that this is the most important driver.

- EU regulation: new European directives resulting in a requirement to migrate to a new system (or even a new frequency band).
- Relationship with other plans, e.g. Introducing ETCS, new lines, etc.: IMs rolling out ETCS level 2 and above will need to investigate the impact on their GSM-R networks. If the design and a particular network is not compatible with a major ETCS deployment (unable to support the additional traffic) one option could be to upgrade to next generation technology.

On the contrary drivers that are not considered as important are:

- Equipment Reliability: Over the lifetime of the infrastructure the equipment is likely to degrade resulting in a lower system availability in case of no regular renewal.
- New technology standard and equipment availability: more modern and advanced technologies are constantly being developed resulting in new equipment being available in the general telecoms market.

One IM indicates new applications including capacity or new rail applications as another driver.

When given the opportunity to provide their own reasons for migration to a Next Generation technology network a broad range of answers were received which are presented below:

Capacity: SBB (for ERTMS), Banedanmark

Shunting: SBB

M2M communications: SBB

Services for trackside workers: SBB

New track-to-train services: SBB

Obsolescence of GSM-R: SBB, RFI, ÖBB Trafikverket,

Cost reduction: LR, Banedanmark

EU regulations: RFI, ÖBB

Enhanced reliability: Banedanmark

Passenger services: Banedanmark

Enhanced business services: Banedanmark

Obsolescence relates to when GSM-R is no longer supported by the manufacturers the cost of keeping these networks increases and the possibility of deploying new GSM-R equipment on new lines becomes almost impossible. This driver will most impact the migration end date.

Cost reduction is a requirement since spare parts for GSM-R will become increasingly difficult to source and maintenance contracts become more and more expensive as newer technologies are promoted by suppliers. Qualified technicians also become harder to find.

Introduction of new services and capacity: a new technology is likely to offer additional services to users and the network operator. For the IM this could mean increasing the efficiency of the network (support more traffic, e.g. ETCS).

EU regulation: new European directives resulting in a requirement to migrate to a new system (or even a new frequency band).

5.1.3 Ownership and Control

From the questionnaire and different answers, we can notice the following elements:

Almost all of the respondents envisage owning the Next Generation network even if all will consider that option but with limitation due to rail application and high level of service requirement. In its response, ProRail states that owning the network is not a requirement. Banedanmark states that they do not envisage owning the network, and DB says it is under discussion.

- In addition, the questionnaires tried to obtain reactions to the following proposition: Sharing the Next Generation network with other parties (e.g. emergency services): There is a mix of answers. Some categorically say no: SBB, CFR, ÖBB, LR. Some say yes: Trafikverket, Network Rail. The remainder are keeping their options open.
- Radio service provided by a third party private or public operator: A majority of IMs would consider the possibility using a third-party operator instead of building their own networks, particularly for non-critical communications (i.e. video off-load) on low-traffic lines. This solution can also be used to achieve faster coverage, as has already been done with GSM-R in some countries. Two IMs are against the idea: CFR and LR, whilst one is awaiting the outcome of the FRMCS work: Network Rail.
- Drivers for sharing or outsourcing to third party: By far the most important factor raised by the IMs is cost reduction, which was mentioned by almost all of the respondents. Frequency management and faster availability of new technologies are next on the list, followed by broadband and passenger services. For one IM, the only driver is regulatory: CFR.

However, the results could be strongly influenced by MS decisions. Please refer to Section 5.3, Member State situation.

5.1.4 Applications unsupported by GSM-R

In answer to the question "Do you plan or already use applications which cannot be supported by GSM-R and require broadband radio networks and which are these?", there were a broad range of answers:

Applications unsupported by GSM-R that require broadband:

- ETCS over IP: Banedanmark
- ATO: Banedanmark
- OKMS: Banedanmark
- Remote maintenance services: Banedanmark
- Remote control of freight braking and camera surveillance: ProRail
- Passenger internet Access: RFI, ÖBB, LR
- Train staff internet access: RFI, ÖBB, LR, DB
- Photo and video for trackside staff: Network Rail
- Video remote train monitoring: Network Rail
- Shunting radio: France (not all lines are covered by GSM-R)

CFR and SBB do not have plans for such applications.

5.1.5 Introduction of new public technologies for some applications

When asked "Do you plan to introduce new (public standard) technologies like 4G for specific non-interoperability related applications for these applications? If yes and you indicate it." there were two main groups:

- No: LR, DB, RFI, CFR, Trafikverket
- Yes: SBB, France (legal requirement to provide in-train coverage by public operators in LTE 700 MHz), ÖBB already has an agreement with public operators, Banedanmark, Prorail.

5.1.6 Maintenance costs of Next Generation system

It is clear that almost none of the IMs have an idea of the costs to maintain a Next Generation technology system. Two IMs (RFI and ÖBB) state that this because the Next Generation has yet to be identified. Only one respondent came back with an estimation: SBB (€15M/year).

Despite most IMs not knowing the precise maintenance costs, all (with the exception of Network Rail) expect a cost reduction in comparison with GSM-R technology.

5.1.7 Co-ordination on national plan for introduction of Next Generation system

A number of IMs (SNCF, DB, ÖBB, Prorail) are coordinating with state bodies (e.g. the ministry of telecommunications) for the introduction of Next Generation networks. SNCF and DB are going a step further and evaluating the need for additional spectrum.

5.1.8 Preferred migration method

For those that have an idea of their migration strategy from GSM-R to Next Generation networks, the breakdown is as follows:

Install dual-mode (or multi-mode) radios in all trains to allow them to travel over GSM-R and new-technology covered infrastructure: Prorail, SBB, ÖBB, SNCF, DB.

Deploy new network infrastructure in parallel to GSM-R allowing single mode trains fitted with GSM-R or with a new technology to travel over the same line.: RFI (over a long period), LR.

A mixture of both scenarios, e.g. line or area dependent: SBB (rural lines), DB (special scenarios).

Network Rail has yet to decide on its preferred migration method as it is awaiting the outcome of the on-going work on FRMCS.

5.1.9 Conclusions for IMs

The most significant conclusions from the survey relate to the drivers and reasons for migration from GSM-R to a Next Generation system. When asked to rate in order of importance migration drivers, the single most important factor mentioned was obsolescence of GSM-R technology. Obsolescence relates to when GSM-R is no longer supported by the manufacturers the cost of keeping these networks increases and the possibility of deploying new GSM-R equipment on new lines becomes almost impossible. This driver will most impact the migration end date.

Other major drivers included EU regulation (new European Directives resulting in a requirement to migrate to a new system or even a new frequency band) and relationship with other plans such as introducing ETCS or new lines.

When given the opportunity to provide their own reasons for migration, obsolescence again topped the list followed by EU regulations, traffic capacity and the desire to introduce new services to staff and passengers.

There is a consensus that IMs will envisage starting to migrate to the Next Generation system in 2025 and that the network infrastructure will be owned by the IM.

The preferred migration method from GSM-R to Next Generation is based on the installation of dual-mode cab radios.

However, the results can be influenced greatly by MS decisions. Please refer to Section 5.3, “Member State situation”.

5.2 Railway Undertakings

A summary of the results of the answers to the question provided by RUs is presented below. It should be noted that responses from only 5 RUs were received:

RU	COUNTRY
Banedanmark	Denmark
NS Netherlands Railways	The Netherlands
LR Lithuanian Railways	Lithuania
ATOC	Great Britain
SBB	Switzerland

Table 4. Questionnaire participation RUs list

5.2.1 Plans to implement a successor to GSM-R

None of the RUs have plans to migrate to a Next Generation radio system. NS thinks that it may happen from 2025.

ATOC states that it is dependent on the outcome of FRMCS and national government decisions expected in 2017. It estimates a timeframe from 2024-2028.

SNCF states that migration is not a priority but may start before 2026.

5.2.2 Migration drivers

The questionnaire asked RUs to prioritise a pre-defined list of migration drivers and the results were:

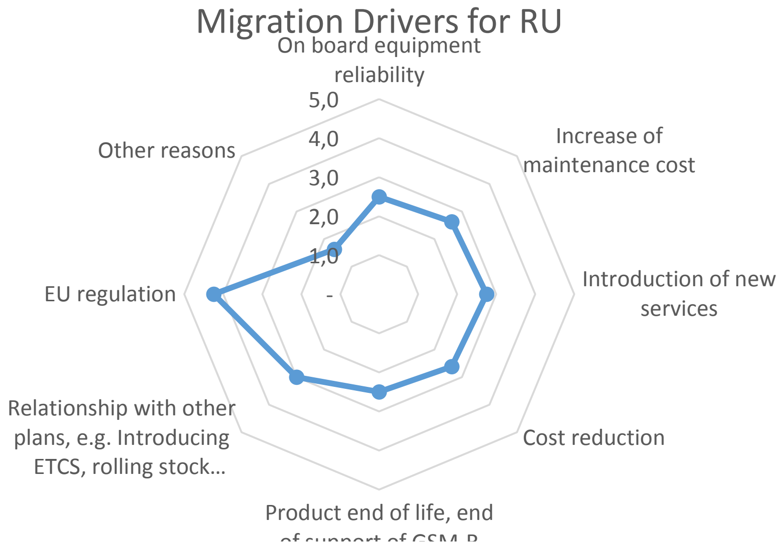

Figure 9. Principal Migration drivers for RU

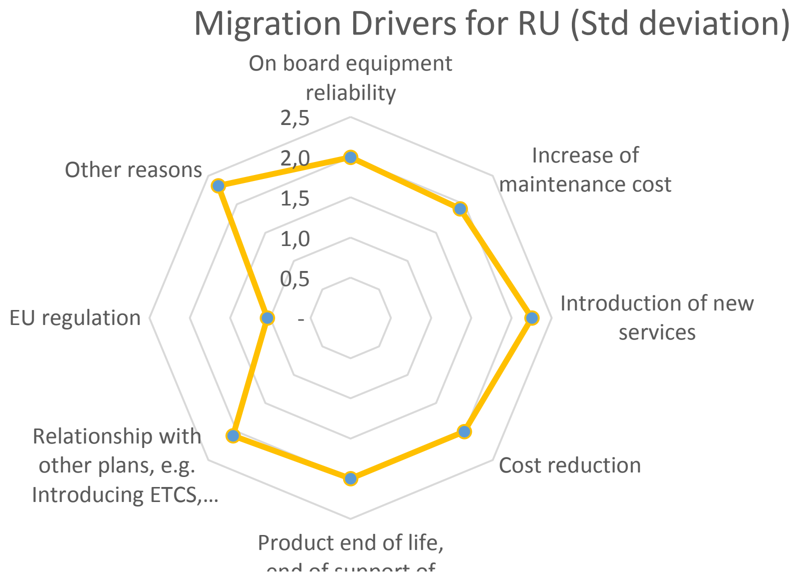

Figure 10. Variety in answers in migration drivers for RU

Here different results were observed compared to the IM:

- EU regulation: new European directives resulting in a requirement to migrate to a new system (or even a new frequency band). This was by far the most important driver for the RUs.

There does not appear to be a consensus on the remaining drivers which include:

- Relationship with other plans, e.g. Introducing ETCS, rolling stock renewal or upgrade: RUs renewing their rolling stock want to ensure that the on-board radio equipment will not need to be replaced in the near future (additional cost). New rolling stock fitted with near life-expired GSM-R will have to have their business case reviewed.
- Introduction of new services: RU are more likely than IMs to demand new user services particularly to satisfy passenger demands.
- On board equipment reliability: Over the lifetime of the system, the on-board equipment is likely to degrade resulting in a lower system availability.

The only migration driver common to both IM and RU appears to be EU regulation. RUs appear to be less concerned about product end of life than are IMs.

- RUs mention other potential driver such as increase of interference, or end of public GSM roaming, or the new technology being cheaper.

When given the opportunity to provide their own reasons for migration to a Next Generation technology network the only additional information provided came from NS and SNCF:

NS:

- First reason to keep the operation ongoing, as the future system is expected to replace GSM-R for mission-critical functions.
- Second reason is, when the system supports that, to migrate to one technology for cost reasons.
- Third reason is the network capacity for broadband applications.

SNCF refers to EU regulation. New European directives could result in a requirement to migrate to a new system (or even a new frequency band).

5.2.3 Ownership and Control

Whilst not a specific RU question, ATOC considers cost savings to be a possible driver for sharing of infrastructure or the use of services provided by a third party private or public operator.

5.2.4 Applications unsupported by GSM-R

When asked “Do you plan or already use applications which cannot be supported by GSM-R and require broadband radio networks and which are these?” the results were:

- Passenger information systems: NS
- Diagnostics: NS
- Real-time monitoring: NS

- CCTV: NS
- Push-to-talk (train and support staff): NS
- Passenger internet access: NS, RFI, ÖBB, LR
- Train staff internet access: NS, RFI, ÖBB, LR, DB
- Security staff: SNCF
- Maintenance/supervision applications: SNCF

Trafikverket does not have any applications that are either in use or planned that cannot be supported by GSM-R.

5.2.5 Introduction of new public technologies for some applications

In answer to the question "Do you plan to introduce new (public standard) technologies like 4G for specific non-interoperability related applications for these applications? If yes and you indicate it." Trafikverket said yes and so did SBB which referred to shift planning and shunting.

5.2.6 Costs of Next Generation system

The only response received to the two questions related to cost of a Next Generation system came from SNCF: "Migration costs are very important for the on-board equipment. Maintenance cost reduction, if any, won't be sufficient to justify migration costs. There is a need for CAPEX cost reduction for RUs compared to the GSM-R on-board equipment (cab radio and EDOR which are far too expensive)."

5.2.7 Preferred migration method

NS states that "Not yet considered and has a strong dependency on the infrastructure migration plan."

ATOC states that "This will depend on the strategy adopted following FRMCS output".

SNCF states "deploying new network infrastructure in parallel of the existing one allowing to have only one technology on-board at a time is the best thing as dual-mode radio on-board is much more expensive."

5.2.8 Conclusions for RU

The most significant conclusions from the survey relate to the drivers and reasons for migration from GSM-R to a Next Generation system. When asked to rate in order of importance migration drivers the RUs were unanimous in citing EU regulation indicating that RU are not pushing for a Next Generation technology and think that this will occur only if there is a legal requirement to do so.

As far as the migration method is concerned, it appears that RUs have yet to make up their minds on the matter and are awaiting confirmation on how infrastructure will be deployed.

Broadband applications for staff and passengers were mentioned by almost all of the RUs.

When given the opportunity to provide their own reasons for migration, obsolescence again topped the list followed by EU regulations, traffic capacity and the desire to introduce new services to staff and passengers.

There is a consensus amongst RUs that IMs will envisage starting to migrate to the Next Generation system in 2025 and that the network infrastructure will be owned by the IM.

Both IM and RU respondents indicated that the preferred migration method from GSM-R to Next Generation is based on the installation of dual-mode cab radios.

As was the case for IMs, the position of RUs will be influenced by MS decisions. Please refer to Section 5.3 “Member State situation”.

5.3 Member State situation

As a first approach, the main drivers for migration strategy on Member State level are the following:

Drivers for EU and Member State	Observations
New services	As part of a wider digital or economic strategy, the EU may impose requirements for the provision of new services.
Spectrum	Pressure from other radio users such as public mobile phone operators may persuade the EU to migrate railways from the coveted 900 MHz band.
EU regulation	Member States must transpose and apply EU regulations.
Interoperability	Interoperability should remain a foundation, and no regression is possible.

Table 5. Drivers for MS

The business drivers on network models for IMs and RUs are cost and functionality; however, these drivers may be strongly influenced by decisions at Member State level on items such as sharing of network resources (with PPDR for example), and decisions on spectrum.

As GSM-R is a mandatory technology for rail, a migration implies legal aspects to deal with technology evolution. Hence EU and MS should also prepare migration by proposing modifications to the legal framework. The two main documents concerned are Railways Interoperability Directive and Control-Command and Signalling Technical Specification for Interoperability (CCS TSI):

- Railways Interoperability Directive: http://www.era.europa.eu/Document-Register/Pages/Directive-interoperability.aspx

  This sets the general legal framework in the railway domain. The scope can be found in Article 1, and the applicability of the obligations can be found in Article 5 of the Directive 2008/57/EC. In particular, Art 5.2:
  "Subsystems shall comply with the TSIs in force at the time of their placing in service, upgrading or renewal, in accordance with this Directive; this compliance shall be permanently maintained while each subsystem is in use."

  This means that the provisions in a TSI apply when a subsystem (trackside or vehicle) is placed in service (it requests to a National Safety Authority the Authorisation for Placing in Service = APIS), which means, it is a new subsystem; or when the subsystem is upgraded or renewed. Definitions of the terms used can be found in Article 2 of the same Directive.
  As a principle, when a new TSI is in force, there is no retroactive obligation to already existing subsystems. The TSI itself should take care of the compatibility of the subsystems.

- Control-Command and Signalling Technical Specification for Interoperability (CCS TSI):

  http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012D0088-20150701
  The deployment plan for ERTMS is indicated in chapter 7. In particular, the dates in section 7.3.4 and 7.3.5 correspond to the plans communicated by the Ministries of Transport of each Member State.
  A new version of the TSI was been approved in February 2016, and it is currently in the translation services of the Commission. It is expected that it will be published around June-July 2016 and will be in force 20 days after publication.
  Additionally, on the ERTMS deployment plan, a document entitled "European Deployment Plan" will be updated each year according information given by Member States.
  It is interesting to note that this new version includes a path to the introduction of an ERTMS evolution.

In a similar manner, for GSM-R migration, a path to migrate needs to be established to maintain interoperability and save investment. This process, at EU level, needs to be initiated well in advance to inform RUs and IMs.

Additionally, Member States have other items to focus on for migration. These items are:

- Spectrum availability: As expressed by IM and RU, frequency band and spectrum allocation for evolution is a key element. To date, there are no spectrum decision concerning rail and radio evolution.

- Network model ownership (dedicated or shared network): Different possibilities on network ownership can be promote technically and legally by EU and MS. This situation can help IMs to migrate more quickly to a new technology.

The need for having a dedicated network was challenged, although there was no specific justification provided on the pros and cons; decisions at Member State level on this subject may also have a strong influence. Previous studies such as “Evolution of GSM-R” from IDATE in 2015 and “Study on use of commercial mobile networks and equipment for "mission-critical" high-speed broadband communications in specific sectors” from SCF in 2013 presented preliminary views, but we do not discuss this topic further since there is very little new information available since the publication of these reports.

Concerning the network model itself, it will be interesting to have a deeper analysis in order to better understand why IMs want to own their own networks or still use a dedicated network. The questionnaire responses provide only limited insights in terms of quality of service and availability.

Summary

- The single most important factor of migration Drivers for IM mentioned was obsolescence of GSM-R technology. This driver will most impact the migration end date. Other major drivers included EU regulation (new European directives resulting in a requirement to migrate to a new system or even a new frequency band) and relationship with other plans such as introducing ETCS or new lines.
- RUs were unanimous in citing EU regulation as the primary driver for migration, thus indicating that RUs are not pushing for a Next Generation technology and think that this will occur only if there is a legal requirement to do so.
- Broadband applications for staff and passengers were mentioned by almost all of the RUs.
- There is a consensus among respondents that IMs will envisage starting migration to the Next Generation system in 2025 and that the network infrastructure will be owned by the IM.
- The preferred migration method from GSM-R to Next Generation is based on the installation of dual-mode cab radios.

6. MIGRATION SCENARIOS

Highlights

The scenarios considered are at Member State Level:

- **Scenario 0: No migration from GSM-R to Next Generation**. GSM-R technology is maintained until the end of the time period for the whole of Europe.
- **Scenario 1a: Dual network GSM-R and NG during a long overlap**
- Option 5y: dual Network approach - Long overlap period but limited to 5 years
- Option 10y: single network approach - Long overlap period i.e. at least 10 years
- **Scenario 1b & Scenario 1c: Single network NG**: Rapid transition from GSM-R to Next Generation with limited overlap period (1 year). In scenario 1b, RUs and IM deploy very quickly (2 years in same time window). In Scenario 1c: RUs start to deploy in advance /IM and they both finish in same time.
- RU will install new on board equipment in advance to prepare a quick transition.
- **Scenario 2: Dual network GSM-R and NG** during a long overlap (5 or 10 years) but NOT in the same time window (2 to 5 years) for two neighbors (4 different cases).
- **Scenario 3**: **Single network NG** during a short overlap (1 year) but NOT in the same time window (2 to 5 years difference) for two neighbors (2 different cases).

6.1 Migration scenario options

Migration concerns the following aspects:

- radio interface (between train and track, so affecting both on-board and trackside equipment),
- end-to-end applications (on-board and trackside)
- core network (IM).

Compared to the previous migration (from analogue radio to GSM-R), several compatible assets exist and may be re-used, for example the core network, radio sites, transmission, on-board installations. Where relevant, this has been taken into account in the analysis.

6.1.1 Migration assumed pre-requisites

The core network evolution before the migration path of the GSM-R air interface can be one of these.

Some main scenarios are described and after it is possible to create additional scenario derived from the main ones.

For the analysis, we propose that:

- Step one: identification of main and sub scenarios
- Step two: select the ones to be analysed (with justification)
- Step three: perform the analysis, using the model and relevant parameters.

We considered 7 different scenarios. Scenario 0, 1a5, 1a10, 1b and 1c are scenarios on a MS level or with a national approach. Scenario 0 is the reference scenarios. Scenarios 2 and 3 are scenarios with a cross border approach. The 2 scenarios imply at least 2 countries with potentially 2 different approach and time line for migration.

6.1.1.1 Scenarios at MS level:

Scenario 0: No migration from GSM-R to Next Generation. GSM-R technology is maintained until the end of time for the whole of Europe:

This scenario (”do nothing”) is a reference scenario created as a base for comparison on cost. This scenario is not realistic because it does not take into account the fact that there will inevitably be a GSM-R end of life.

This scenario depends on the possibility for telecommunications equipment suppliers to continue to support hardware and associated software. Additionally, independent of technology obsolescence, equipment itself has a life cycle. This period is dependent on each piece or type of equipment. In reference to the Questionnaire Answers, we have assumed that for cab radios, a reasonable estimated lifetime can be 12 years and for BSS equipment it can be 15 years. At the other end of the spectrum, core network (NSS) equipment can have intrinsically extended lifetimes however these are usually derived from equipment destined for public network operators and support large amount of software. However, because of this obsolescence reaches particularly these Equipment. Network supervision equipment have relatively short lifespans. It should also be noted that there are only three GSM-R suppliers in the world, 2 European and 1 Chinese. This situation could evolve (reduction in the number of suppliers) putting additional pressure on IMs.

Scenario 1a: Dual network GSM-R and NG operation during a long overlap

- Option 5y: Dual Network approach - Long overlap period but limited to 5 years.
- Option 10y: Dual network approach - Long overlap period i.e. at least 10 years.

In this scenarios, we have considered that during a long overlap (5 or 10 years), IM is obliged to maintain and operate in the same time two networks that are the GSM-R network and also the Next Generation one. We called this situation Dual Network approach. This situation can be caused but the IM itself (long deployment and migration phase) or/and by the RU with a long process deployment or others situations (single mode /dual mode cab).
This scenario is nationally oriented. The situation is that an IM on a national railways network already has full GSM-R coverage on all or part of its infrastructure for voice applications and also for in some cases ETCS application. The IM decides for various reasons (as described in the previous chapter) to

deploy a next generation solution and progressively bring this new network into service on all or part its infrastructure.

However, in order to be used, train drivers and others users need to be equipped with terminals able to communicate using the new technology. Additionally, controllers should also be able to communicate to users easily and without any degradation of services with these new network.

Depending on functional aspects and service integration, an IM can accept to have a dual network in service on the same line (i.e. GSM-R and next generation radio technologies both transmitting).

Alternatively, if there is a lack of service integration, an IM can decide to use only one network per geographic area (i.e. either GSM-R or next generation). So next generation technology is deployed line by line. In any case, this situation forces IM to manage a long migration period in its railway network. And also, this situation conducts to operate in a same time the 2 technologies i.e. GSM-R and the new one.
In this scenario, we can consider that there is a relatively low level of co-ordination between IM and RU in the cab radio equipment upgrade. We propose to analyse 2 duration options: one relatively short (in 5 years) and the other a longer period (10 years).

Scenario 1b: Single network NG: Rapid transition from GSM-R to Next Generation with a limited overlap period (1 year). All the RUs and IM will deploy rapidly (2 years in same time window) their equipment's and they will organize a quick transition.

This scenario is nationally oriented. The situation is that an IM on a national railways network already has full GSM-R coverage on all or part of its infrastructure for voice applications and also for in some cases ETCS application. The IM decides for various reasons (as described in the previous chapter) to deploy a next generation solution. Before to bring this new network into service on all or part its infrastructure, a coordination is established in order that all RU's migrate on board equipment's in the same time window. After deployment and test, both IM and RUs migrate and switch off rapidly the previous technology (i.e. GSM-R).

In contrast to the previous scenarios 1a5 or 1a10, a coordination is established between IM and RUs for the migration in advance of network deployment. This situation lets the IM to reduce to a limited and short migration period in his network. In this case, the IM operates the 2 technologies i.e. GSM-R and the new one in parallel only during a very short period of migration. The co-ordination between the IM and all the RU using the network results in a deployment plan that fully takes into account on which lines trains travel which allows RUs to plan any required works on rolling stock (install a next generation cab radio next to the GSM-R one or to replace it with a dual-mode cab radio or eventually to replace directly with single cab radio). According of the strength of the agreement on coordination deployment and technologies maturity on on-board equipment, RUs can optimize the on board equipment deployment. But in case of a short timescale it will force RUs to take rolling stock out of service specifically to install cab radios as periodic maintenance cycles are typically longer than 1 year

Scenario 1c: Single network NG: Rapid transition from GSM-R to Next Generation with limited overlap period (1 year). RUs will install new on board equipment in advance compare to IM deployment to prepare a quick Transition. They will both finish in same time. This scenario is similar in some way to

Scenario 1 b but there is an optimization on RUs side. Due to coordination, RUs is able to start Next Generation technology deployment few years before IM in order to reduce the migration period. This Scenario implies that the technology is ready and tested in advance compare to IM equipment especially for early adopters. This Scenario gives more to RUs to deploy and then lets them to benefit from periodic maintenance cycle to organize migration and also to benefit from natural cab radio renewal cycle.

6.1.1.2 Border crossing scenarios:

Scenario 2: Dual network GSM-R and NG during a long overlap (5 or 10 years) but NOT in the same time window (2 to 5 years) for two neighbors (4 different cases).

This scenario is an international or cross border scenario. It is the same scenario as 1a but includes neighbouring IMs.

This will allow the simulation between countries in Europe that have already interoperability with GSM-R. In this situation, there are at least 2 different IMs and several RUs including historical and new national or international operators. Interoperability should be considered for ETCS and voice service.
Migration drivers will be different for each stakeholder and particularly for each IM. Each IM constructed its own GSM-R network and each IM will have different roadmaps to replace GSM-R even though GSM-R equipment end of life will occur to all of them. But the time window is Europe-wide. We propose to analyse a time window from 2 years as a minimum to 5 years or possibly more.

These different cases oblige IM to operate both technologies in the same time.

Firstly, as in scenario 1a, we can consider that there is a relatively low level of co-ordination between IM and RU in the cab radio equipment upgrade. We propose to analyse 2 duration options: one relatively short (in 5 years) and the other a longer period (10 years).

Additionally, we will consider the international situation with a time window between next generation availability on track side. This time window can be short (2 to 5 years). There are 4 case studies in this scenario.

Scenario 3: **Single network NG** during a short overlap (1 year) but NOT in the same time window (2 to 5 years difference) for two neighbors (2 different cases).

This scenario is an also international or cross border scenario. It is the same scenario as 1.b including the neighbouring IM situation as in scenario 2.

It will allow the simulation between European countries that already have interoperability with GSM-R. In this situation, there are at least 2 different IMs and several RUs including historical and new national or international operators. Interoperability should be considered for ETCS and voice service.
Migration drivers will be different for each stakeholder and particularly for each IM. Each IM constructed its own GSM-R network and each IM will have different roadmaps to replace GSM-R even

though GSM-R equipment end of life will occur to all of them. But time window is Europe wide. We propose to analyse a time window from 2 years as a minimum to 5 years or possibly more.

These different cases oblige IM to operate both technologies in the same time.

Firstly, as in scenario 1b in scenario 3, we can consider a high level of co-ordination between IM and RU for the cab radio equipment upgrade on a national base with a short overlap (1 year). Additionally, we will consider the international situation with a time window between Next Generation availability on track side. This time window can be short (2 to 5 years). There are 2 case studies in this scenario.

Note

The economic modelling of the scenarios should take into account the economic impact (such as obsolescence or cost reduction achieved through a shared network) rather than the scenarios themselves. Shared networks (with PPDR for example) or the use of public networks is not considered as a stand-alone scenario but rather a national cost issue. In the model, it is possible to introduce network sharing for a whole railway network or part of one (e.g. rural lines).

6.2 Scenario descriptions for simulations

The scenarios are defined to consider the following distinct situations:

- Transition / no transition from GSM-R to NG;
- Dual/Single network;
- Limited / long and very long overlap;
- Optimum/not optimum coordination between IM of neighbor countries.

All the scenarios time lines are presented in the following draw:

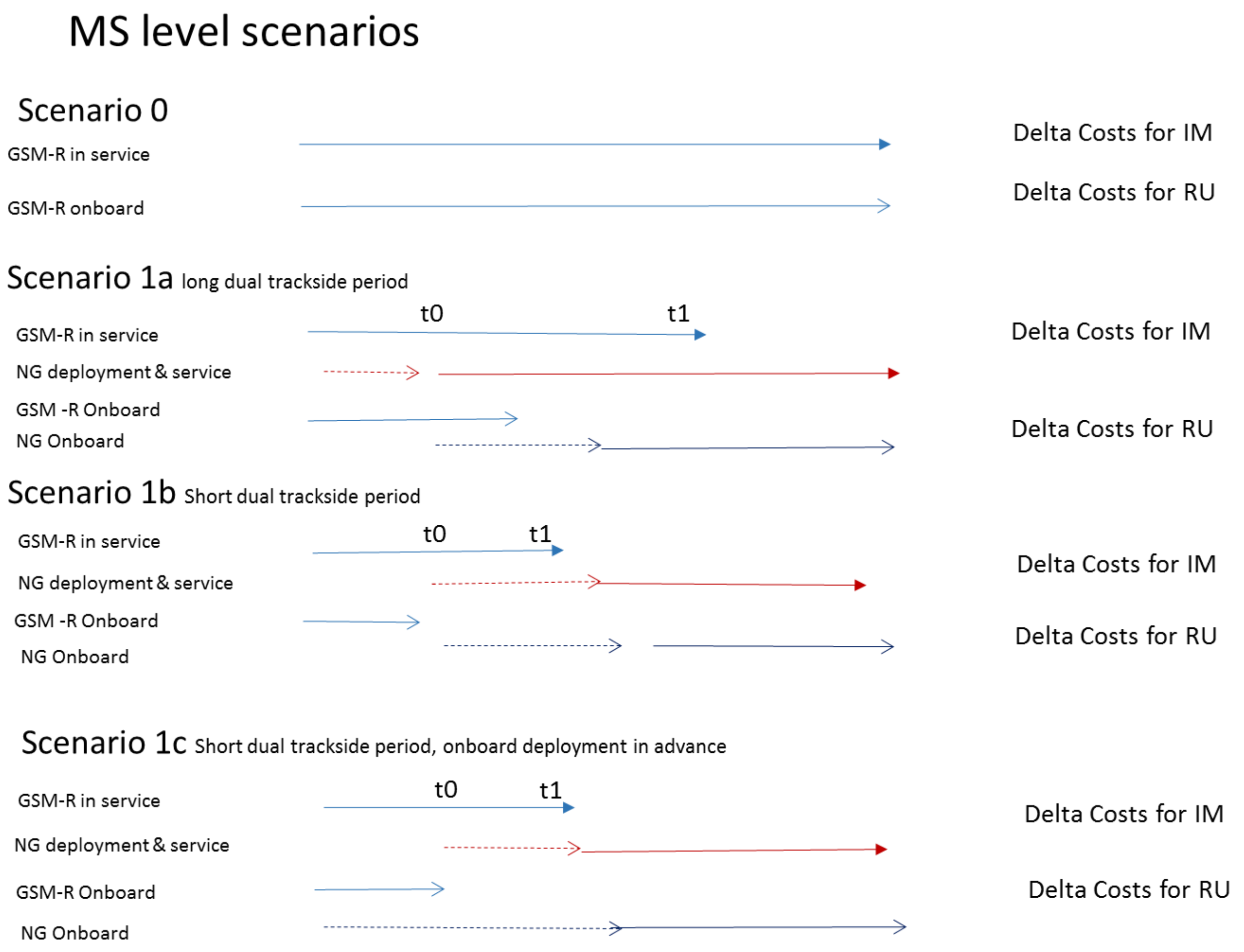

Figure 11. Scenario options

All the selected scenarios defined to cover those situations are described in chapter 9.1 Section 9.1.1.

As example we propose to simulate different countries different in term of network size and fleet size. We tested the model and the different scenarios at MS Level with the following countries. The countries are named as following: Country A (A), Country B (B), Country C (C), Country D (D), Country F (F).

Countries named A and B are limited in term of network size (around 3 000 km of lines covered by GSM-R) limited in term of cab radio (less than 2 500). Countries named C and D are large countries (more than 15 000 km and around 10 000 cab radio). Country F is medium in term of network size (more than 5 000 km) and small concerning number of cab radio (2 500). We also made evaluation for whole of Europe in the same time window.

For cross border scenarios, we made evaluation for different countries with different size. A case with 2 comparable countries of limited network size with The Country A (A) and Country B (B). A case with 2 comparable countries of large network size with Country D (D) and Country C (C). A case with 2 different countries in term of network size (one large and one limited) with and Country D (D)- Country F (F), and Country A.

7. ECONOMIC MODEL

Highlights

- The economic model is one of the tools recommended to be used in order to evaluate the impact of a regulatory evolution project. In the case of this study, the goal was to evaluate the main costs and benefits of railway radio communication system migration from GSM-R to other solutions, for key stakeholders: IMs and RUs.
- The principal output of the model is an evaluation of the CAPEX and OPEX for the different scenario options for the identified stakeholders.
- The function of the model is to simulate the economic aspects of migration scenarios. The scenarios are defined as a deployment timeline, for a specific area, with technological, contractual and financial parameters. The result obtained is an estimate of the project annual cash flow, and the net present value of the project.
- The model that has been produced is relatively flexible. It could possibly be used in the future with updated parameters for more detailed modelling, once further details of migration have been established.

7.1 Objectives and methodology

The objective was to assess the economic balance of the identified options for each stakeholder.

The achieved outcomes are:

- Migration scenario
- Economic model
- Sensitivity analysis

To achieve these objectives, the main task was to shape, structure, feed and test robustness of a model that can be used as a tool to create migration scenarios that are well balanced and acceptable for RU and IM.

The methodology was based on the Better Regulation guidelines philosophy and on SYSTRA's own experience with economic models and GSM-R deployment projects.

Concerning Better Regulation guidelines philosophy, we understand that actions in the field of European Union policies must aim at building a simple, stable and predictable regulatory framework, meeting policy goals at minimum cost and delivering maximum benefits, and ensuring EU competitiveness in the global economy, while maintaining social and environmental sustainability. The achievement of these objectives implies that the evolution of the regulatory framework includes a process of evaluation of policies already in place, the assessment of problems and alternative solutions and the active engagement with stakeholders.

The economic model is one of the tools recommended to be used in order to evaluate the impact of a regulatory evolution project. In this study, the aim was to evaluate the main costs and benefits of railway radio communication system migration from GSM-R to other solutions, for key stakeholders: IMs and RUs.

The first step was to define the scope of the model and identify the actors that have to be included and the main economic flows to be considered.

The second step was to identify the flows specifically affected by the migration project, and the ones sensitive to variations in different scenarios and options.

This included CAPEX and OPEX estimates.

The experience with GSM-R shows that the majority of the costs are directly borne by the Infrastructure Manager. The cost of trackside infrastructure modification is especially high, and can change from one IM to another. The difference is partly driven by the kind of network and the kind of internal organization of the IM, and the existence of other structural projects if implemented simultaneously in the same infrastructure. Those elements determine the flexibility and reactivity of the IM, and its ability to deal with complex operations in a limited time, with potentially a high impact on deployment cost due to interface management and delays. The evaluation includes certification costs, test and commissioning, which can represent a relevant portion of total costs.

The cost is also influenced by the chosen technology. If the deployment requires important civil works on trackside equipment and locations, the cost will be much higher than a solution allowing reuse of existing infrastructure and locations.

The model considers the IM situation and the situation of the RU. It is important to take into account the impact of the migration plans of IMs on RUs.

The principal output of the model was an evaluation of the CAPEX and OPEX for the different scenario options for the identified stakeholders.

A sensitivity analysis was carried out on the results in order to evaluate the robustness of the model and specifically included a test of the impact of uncertainty on the unit costs.

It should be noted that the current legal framework (CCS TSI) does not provide the mechanism of mandatory retrofitting, so it is not possible to force railway undertakings (RU) to make modifications to cabs. In this study the possibilities and effects of funding mechanisms to accelerate the migration are addressed.

7.2 Model and scenario parameters

The function of the model was to simulate the economic aspects of migration scenarios following the scenario descriptions that appeared in Chapter 6. The scenarios were defined as a deployment time line, for a specific area, with technological, contractual and financial parameters. the results obtained are an estimate of the project annual cash flow and the net present value of the project.

A full list of parameters including cost aspects was established. Due to the fact that the difference between the scenarios is relevant, it can be considered to exclude cost factors that do not have direct links with migration. This way the overall costs are made visible.

This chapter presents the general structure of the model, the main assumptions considered, the data used to run the model, and the results of the simulation of selected scenarios.

7.2.1 Model structure

The structure of the model was divided in 4 parts:

Input data such as:

- **Unit costs:** CAPEX and OPEX unit cost, per line km for the IM and per cab radio for the RU;
- **Price index:** forecast of cost inflation;
- **Technological obsolescence curve:** forecast of the impact of technological obsolescence in OPEX costs (for GSM-R in our case, not for Next Generation);
- **Areas data:** basic data concerning the areas concerned by the simulation scenario: km of line, number of cab radios, percentage of international trains.

Scenario parameters such as:

- Geographical areas selected for the scenarios,
- Deployment timeline, in percent of achieved deployment,
- Technological (which Next Generation technology), contractual (operated by the IM, by a PPP, or by a 3rd party), renewal of equipment (GSM-R and NG) and financial options (financial discount rate considered).

Calculation module of:

- IM and RU CAPEX and OPEX
- Project cash flow at current price,
- Discounted cash flow,
- Net present value of the project.

Result dashboard:

- Net present value of the project for the Infrastructure Managers,
- Net present value of the project for the Railway Undertakings,

- Graphical representation of the evolution of the Cash Flow at current price.

The following illustration presents a schematic view of the model structure:

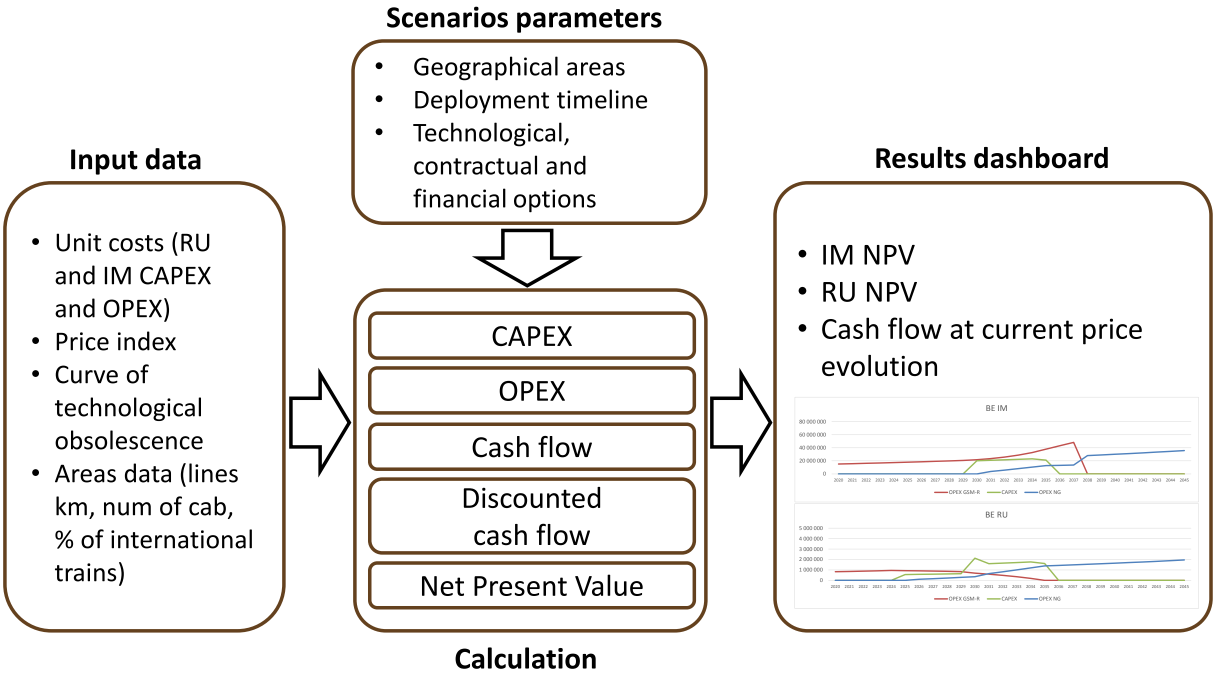

Figure 12. Summary representation of the economic model structure

The model data processing was divided into the following parts:

- Estimation of the number of line kilometres of infrastructure and of on board cab radio impacted by the migration;
- Selection of adapted unit cost;
- OPEX and CAPEX distribution in time (in %);
- Project Cash Flow in current €, without inflation nor technological obsolescence effect;
- Cash Flow in current €;
- Discounted Cash Flow and Net Present Value of the projects.

The illustration bellow describes the processing flow:

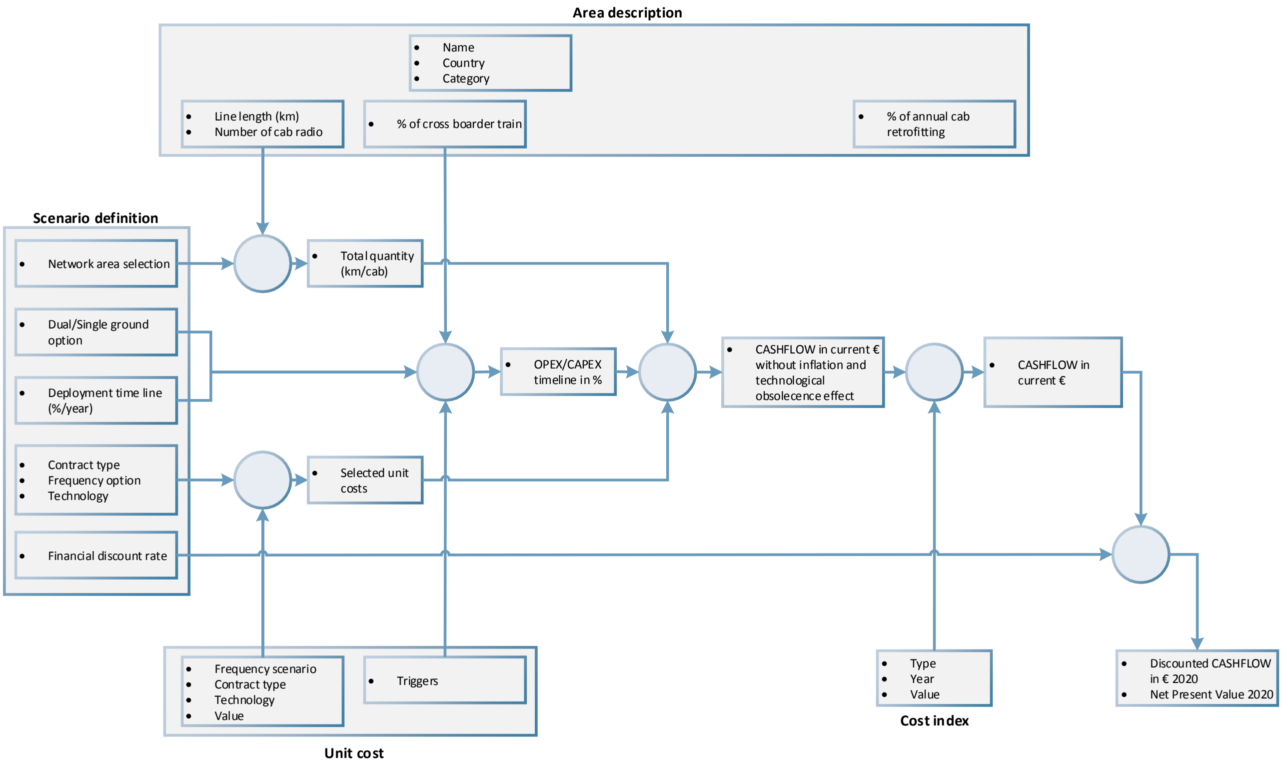

Figure 13. Summary representation of the economic model data processing

The input data for each processing steps were:

- For total quantity (km and cab radio) estimation:
  - Scenario selected area;
  - Table of area description including line km and number of cab radio.

- Selection of adapted unit cost estimation:
  - Scenario selected contract type, frequency option and technology;
  - Table of unit costs.

- OPEX and CAPEX distribution in time (in %) estimation:
  - Scenario selected Dual or Single ground technology option;
  - Scenario deployment timeline;
  - Area description of the % of cross-border train;
  - Unit cost triggers, defining the percentage of deployment when costs are activated and inactivated (Ex: GSM-R OPEX for IM is counted if deployment is >= 0%, and is no more considered when deployment is >95%);

- Project Cash Flow in current €, without inflation nor technological obsolescence effect estimation:
  - Total quantity (km and cab radio);
  - Selected unit costs;
  - OPEX and CAPEX distribution in time (in %).

- Cash Flow in current € estimation:
  - Project Cash Flow in current €, without inflation nor technological obsolescence effect;
  - Costs index.

- Discounted Cash Flow and Net Present Value of the projects estimation:
  - Cash Flow in current €;
  - Financial discount rates.

7.2.2 Model assumptions

There are two categories of assumptions:

1. Assumptions based on the results of the questionnaire (e.g. with ranges)
2. Assumptions proposed by Systra based on previous experience and knowledge of the rail industry.

In the model, there is a need to separate assumptions for IMs and for RUs. For each of them, there are cost assumptions such as CAPEX and OPEX as well as quantity assumptions.

The level of information obtained (with very limited information about differences among the Member States) leads us to use the same level of cost assumptions for all countries in Europe, even though the model is capable of introducing differences in the future.

For each country depending on the scenario, the quantity assumptions differ.

Finally, we have also timeline assumptions directly connected to each scenario and also financial assumptions. These assumptions are also common for all scenarios and countries.

7.2.2.1 Infrastructure manager assumptions

On the IM side, the quantity in the model is indicated in terms of km of line covered by radio. We consider as a comparative approach the same size of network for GSM-R and future new technology (NG). In the model, assumption is required on CAPEX (Capital Expenditure) for new technology and also OPEX (Operational Expenditure) for GSM-R and also NG.

In the questionnaire GSM-R cost evaluation for CAPEX and OPEX was included. Note that on the whole the responses were detailed except those relating to cost aspects that are sometimes declared as being confidential. This constrains us to have a simplified cost simulation in the economic model. Furthermore, it is difficult to compare figures due to differences in the way respondents provided information, e.g. was the cost of the transmission network included or not in the figure supplied, consolidation of figures (long time, change in contract organization).

For CAPEX, the following range was proposed:

Range €/km	Min	Max
1		< €20 000
2	€20 000	€30 000
3	€30 000	€45 000
4	€45 000	€60 000
5	€60 000	€75 000
6	>€75 000	

Table 6. CAPEX cost range for IMs

On average, and with the inclusion of radio sites (equipment, installation and test), core network, transmission, we are able to evaluate a cost of €60 000 per km for GSM-R.

For NG, under the same frequency band, we consider that IM will be able to reuse the existing GSM-R radio sites and masts and will therefore only need to change the radio site equipment (without any new additional sites for lines that are already covered). This is because radio propagation distance is dependent on the frequency and not on the type of technology used. Based on previous experience, and as a first approach, we consider that this situation means that 50% of GSM-R network can be reused for the NG network. Consequently, we have assumed a cost of €30 000 per km for NG. This assumption will be common for all following simulations because we do not have sufficient details on a per country basis even if the model is able to manage that.

The model provides the possibility to include renewal equipment cost during the usage of a technology. We also have assumed a cost of €30 000 per km for GSM-R cost renewal. In a first approach, we consider a life time of 15 years for infrastructure equipment and we apply that for GSM-R renewal in Scenario 0. In other scenarios, we apply that cost renewal to future generation (NG) up to the start of the NG deployment. These elements can be changed.

It is important to note that the share of the core network investment varies according network size: its importance decreases the larger the network (high number of radio sites).

The model itself is able to take into consideration a frequency change. As indicated above, the propagation distance is inversely related to the frequency of operation: the higher the frequency, the shorter the propagation distance. For example, by migrating from the 900 MHz band for GSM-R to say 2 GHz (2000 MHz) for NG, the propagation distance is halved and as a consequence roughly twice as many radio sites will be required. There is no simulation with this specific case because it is not related to migration itself, but rather to frequency regulation.

On OPEX, there were significant variations in responses to the questionnaire from 500 €/km per year to almost 7 000 €/km per year for GSM-R, and also as a percentage of investment from 2.5 % to 10%. As a result of this large deviation, we have assumed 3 300 €/ km and per year, that is an equivalent of 5.5% of investment (GSM-R).

In the model, we will also assume that GSM-R OPEX is equivalent to NG OPEX. In case of dual network operation, we consider that that the OPEX for NG is only 50% as great as that of GSM-R if GSM-R is still maintained (in other words, the combined OPEX is 1.5 times as great as that of a GSM-R-only network, rather than twice as great). This assumption is based on the fact that radio sites are the same and that civil works and site installation cost operation will be supported by GSM-R.

Concerning size of the network, the following network sizes are taken (data from questionnaire and UIC ERIG):

Country	**GSM-R and NG covered lines**
Country A	3 100 km
Country B	3 200 km
Country C	16 000 km
Country D	27 995 km
Country F	5 400 km
All Europe	163 000 km

Table 7. Network size

7.2.2.2 Railway Undertaking assumptions

On the RU side, we have made an estimation of CAPEX and OPEX for GSM-R and NG.

The questionnaire responses provide the following CAPEX range per traction unit:

Cost range	**Min**	**Max**

1		<€10 000
2	€13 000	€20 000
3	€20 000	€27 000
4	€27 000	€34 000
5	>€34 00	

Table 8. CAPEX cost range for RUs

In average and with inclusion of equipment, installation and test, we are able to evaluate €18 000 per cab radio for GSM-R. In the case of a train fitted with EDOR equipment we consider twice that cost (€36 000). The questionnaire responses give us a large range of cost between €16 500 to a maximum of €30 500. The average was about € 18 000.

For OPEX cost for GSM-R and per year, the replies to the questionnaire provide a figure between €500 to more than €10 000. We have assumed €1 000 per year and traction unit. In case of EDOR equipment, we also consider 2 times that cost (€2 000).

By extension and due to lack of detailed information, we consider that NG cab radio cost and end of life will be aligned with that of GSM-R cab radio. Additionally, we consider in all scenarios that we can either have single or dual mode cab radios. Note that due to the relatively low cost of technology compared to the cost of installation, the impact of this assumption is not considered significant. The possibility to have single mode or dual mode cab radios is linked to national railway organization and operation.

In terms of cab radio quantities, the responses to the questionnaire provide very little concrete and accurate figures. This situation is due to the separation of activities between IM and RU and also a low RU participation in the questionnaire. We complemented these figures with information taken from the UIC ERIG table and in some cases derived from the number of SIM cards. Note: SIM cards belong to IM and are given to RU for their usage, but the number of SIM cards usually includes a proportion of additional cards for maintenance.

Country	Cab Radio Number	Share of EDOR

Country A	2 400	20%
Country B	2 300	20%
Country C	9 500	5%
Country D	12 000	20%
Country F	2 500	20%
All Europe	64 000	20%

Table 9. Cab and EDOR number

Concerning EDOR equipment, we take the figures given by the questionnaire where relevant (e.g. Country C) or we consider a common figure for other countries. Note that the migration scenarios begin after 2020 and that figure should include ETCS 2 expansion.

As common assumptions, scenarios consider the flowing data:

- Share of cross-border trains: 20%
- Share of cabs retrofit per year based on a life cycle of 12 years: 8.3%
- Share of trains retrofit per year based on a life cycle of 30 years: 3.3%

We observe that the questionnaire gives us indications on life-cycle of cab radios and the share of cross-border trains but we do not have sufficient data to arrive at definitive conclusions. We notice significant variations of life-cycle time between 20 years to 10 years depending on RU but there is not enough data to arrive at any firm conclusions.

We also include an assumption of train retrofit with a lifecycle of 30 years for all trains and all countries.

7.2.2.3 Timeline and financial assumptions

The main assumptions considered in the model are:

- **Net Present Value estimated in 2020:** the reference year of estimate is 2020, considering that no migration project will begin before this date.
- **Project horizon from 2020 to 2045:** we consider that 2045 is a realistic horizon to consider that every stakeholder must have completed their migration to the Next Generation technology, and that no change to another technology would have begun.
- **Cost inflation rate:** 3,5% - in line with SNCF Réseau for maintenance and renewal of equipment cost index inflation rate, and considering it to be relevant for the rest of Europe. This last assumption is based on the fact that the telecommunication equipment market is relatively consistent Europe-wide. It is a Systra proposed assumption used for simulation.

- **Discount rate:** forecast at around 2% in line with ECB inflation target, considering that IM and RU are focused on public service and not on profit. The discount rate is aligned on inflation. It is a Systra proposed assumption used for simulation

- **GSM-R obsolescence impact on operation cost:** the assumption considered in the model is GSM-R operation cost on IM side doubles between 2030 and 2040. It is a Systra proposed assumption used for simulation. The target is to include the technology end of life and the risk that increasing maintenance cost due to supplier end of support.

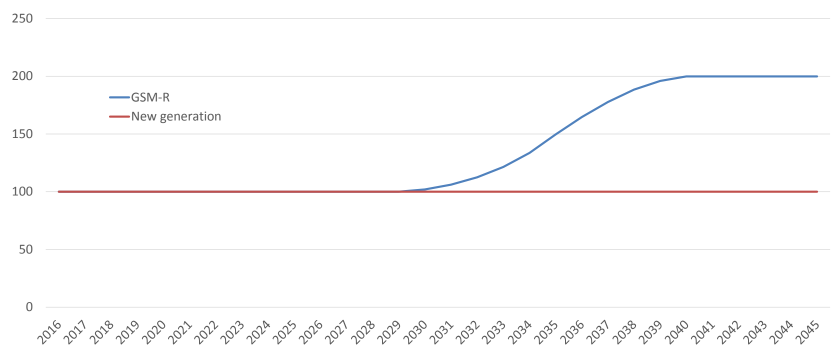

Figure 14. GSM-R VS Next Generation operation cost index evolution

- The obsolescence cost assumption for cab radios was discussed and it was agreed that we do not include such cost on RU side in this approach.

- GSM-R maintenance costs continue 2 more years after the end of CAPEX, for the operation set-up period.

7.3 Summary Assumptions

Assumptions for simulation are the following:

- No frequency change, no network sharing,

- IM investment lifetime 15 years for GSM-R and obsolescence curve on GSM-R cost after 2030.

- RU investment lifetime 12 years.

- For each country, only differences in term of volume (km of GSM-R line and number of cab radio) are considered.

- Same cost assumptions for all countries simulated (see following table).

Type	Technology	Freq Band	Value	Unit (€ 2016)
IM-CAPEX	GSMR-GSMR	FQ-I	**30 000**	€/km
IM-CAPEX	GSMR-NG	FQ-I	**30 000**	€/km
IM-CAPEX	NG-NG	FQ-I	**30 000**	€/km
IM-OPEX	GSMR	FQ-I	**3 300**	€/km/year
IM-OPEX	NG	FQ-I	**3 300**	€/km/year
RU-CAPEX	GSMR-NG	FQ-I	**18 000**	€/cab
RU-OPEX	GSMR	FQ-I	**1 000**	€/cab/year
RU-OPEX	NG	FQ-I	**1 000**	€/cab/year

Table 10. Cost assumptions for simulation

Country		Quantity		Part of		Part per year	
Name	Abb.	Km ol GSM-R line	Number of Cab Radio	EDOR	Crossborder trains	Train retrofit	Cab radio retrofit
Country A	**A**	3 100	2 400	20%	20%	3,3%	8,3%
Country B	**B**	3 200	2 300	20%	20%	3,3%	8,3%
Country C	**C**	16 000	9 500	20%	20%	3,3%	8,3%
Country D	**D**	29 700	12 000	20%	20%	3,3%	8,3%
Country F	**F**	5 400	2 500	20%	20%	3,3%	8,3%
European Union	**EU**	163 000	64 000	20%	20%	3,3%	8,3%

Table 11. Volume assumptions

7.4 Simulation results

In this section, we present the main result and conclusions of the simulation with the chosen parameters and scenarios.

This simulation results refer to previous Chapter 6 Migration Scenario and Chapter 7 Economic Model.

7.4.1 Scenarios at EU Level

Based on the simulation, we present in the following the all Europe scenarios results for the Net Present Value (NPV in € 2016). The different charts allow the comparison in values (€) and also in proportion for the final one. Note that all NPV results are negative figures because we only consider in that simulation cost elements (i.e. no revenue). NPV figures can also be compared in absolute value.

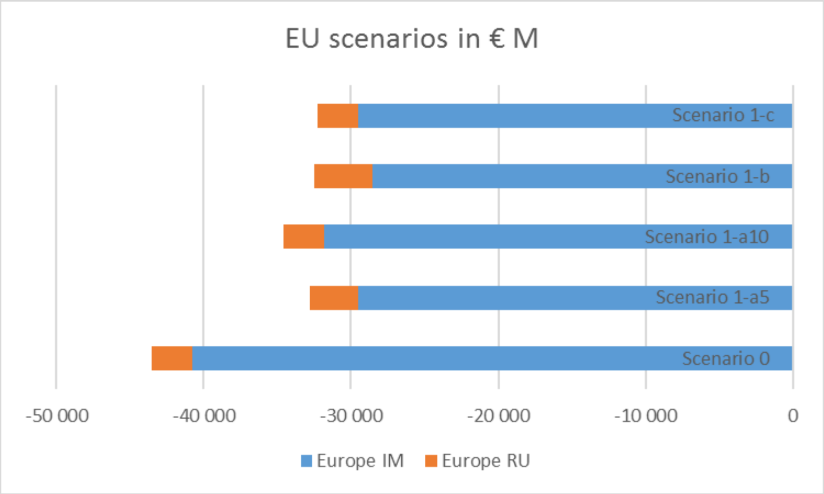

Figure 15. EU level NPV (2016 million of €) for each scenario.

In the total amount NPV (RU+IM) for the whole Europe case, Scenario 0 that is the most expensive (€ -44 billion), while the other four scenarios are less expensive and roughly comparable to one another (around €- 32 to -35 billion). However, by comparison, Scenario 1 a10 is most costly (€ -35 billion €). The remaining three are very similar (€ -32.3 to -32.8 billion).

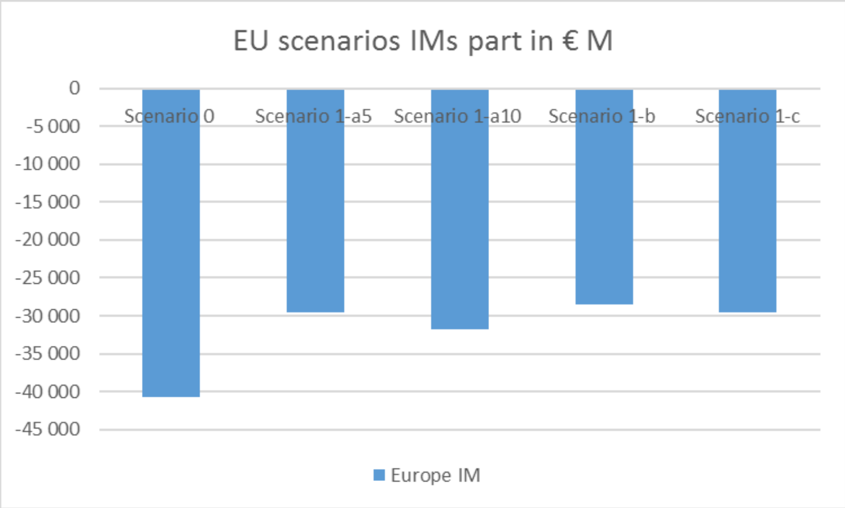

Figure 16. EU level NPV IMs part (2016 million of €) for each scenario.

For IMs, Scenario 0 that is the most expensive (€ -41 billion), while the other four scenarios are less expensive and roughly comparable to one another (around € -28.5 to -31.8 billions). However, by comparison, Scenario 1 a10 is most costly (€ -31.8 billion € - €3.2 billion of difference). Scenario 1a5 and Scenario 1c are the same result (same deployment phase). Scenario 1b (€-28.6) is the least costly for IM.

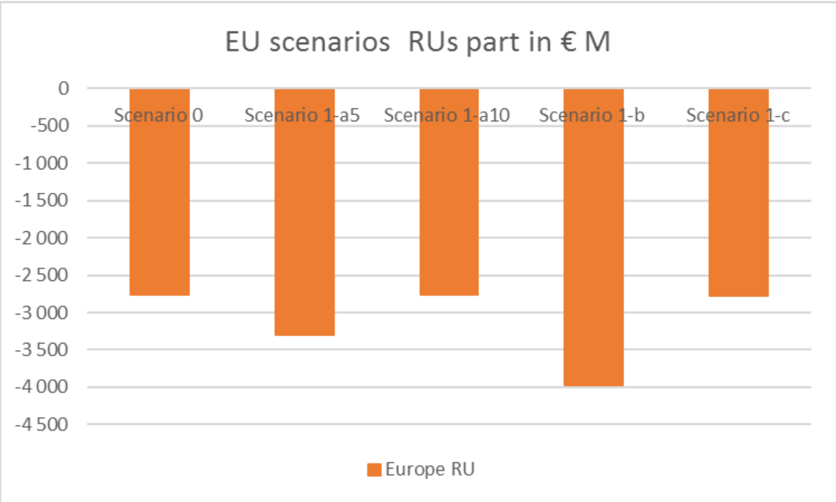

Figure 17. EU level NPV RUs part (2016 million of €) for each scenario.

For RUs, the results and comparison are very different. RU NPV are much less than IM NPV (between € 4.0 to €2.8 billion). The costliest scenario for RU is Scenario 1b where RU should rapidly change all cab radios. Scenario 1 a5 is less costly that 1b but higher than the three others (€3.3 billion). Scenarios 0, 1a 10 and 1c are similar or almost similar for RU in term of cost (€2.8 billion). These three scenarios benefit from natural renewal cycle.

Finally, that figures show the low amount of NPV for RUs compared to the NPV for IM. The NPV for RUs in that case represents between 5% to 13% of the total NPV according scenarios.

7.4.1 Scenarios at Member State Level

In this section, we present the result of certain European countries. Note that the difference between the countries is based on size of network and rolling stock fleet.

The previous conclusion on the optimal scenario for IM and RU are at first sight similar.

But a deeper analysis is necessary country by country according the size of rolling stock fleet compared to the network size. Some differences can exist.

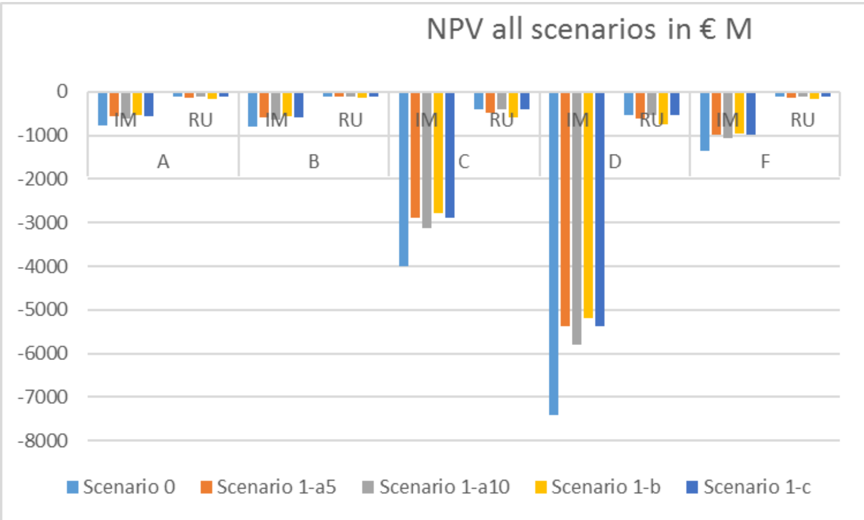

Figure 18. NPV per country

		Scenario 0	Scenario 1-a5	Scenario 1-a10	Scenario 1-b	Scenario 1-c
Country A	IM	-775	-562	-605	-543	-562
	RU	-104	-124	-104	149	-104
	IM+RU	-879	-686	-709	-394	-666
Country B	IM	-800	-580	-625	-561	-580
	RU	-99	-118	-99	-143	-100
	IM+RU	-899	-698	-724	-704	-680
Country C	IM	-3 999	-2 899	-3 123	-2 793	-2 899
	RU	-411	-489	-411	-592	-412
	IM+RU	-4 410	-3 388	-3 534	-3 385	-3 311
Country D	IM	-7 422	-5 380	-5 796	-5 204	-5 380
	RU	-519	-618	-519	-744	-520
	IM+RU	-7 941	-5 998	-6 315	-5 948	-5 900
Country F	IM	-1 350	-978	-1 054	-946	-978
	RU	-108	-129	-108	-155	-108
	IM+RU	-1 458	-1 107	-1 162	-1 101	-1 086

Europe	IM	-40 736	-29 529	-31 811	-28 561	-29 529
	RU	-2 767	-3 296	-2 767	-3 970	-2 773
	IM+RU	-43 503	-32 825	-34 578	-32 531	-32 302

Table 12. MS Level scenarios results comparative summary – Net Present Value for each stakeholder in Millions of € 2020

7.4.2 Analysis on scenarios at Member State Level

The comparative analysis of the project provides the following findings:

For IM:

- The costliest scenario for IM is Scenario 0 due to the renewal cost and also impact of obsolescence. The impact of obsolescence in operation costs should be reassessed with industry to confirm or not this conclusion. Until now, the simulation does not include obsolescence in renewal costs, this point of view needs to confirm. In this simulation, NPV of Scenario 0 is more than 40 % higher than the most economic one (Sc. 1b).
- The costliest scenario including migration for IM is Scenario 1-a with a long overlap (10 years). It is costly because the IM should operate a dual network for a long period. But there is only 5.5% of NPV between migration scenarios that is quite low to conclude according the limits of the economic model.
- Scenario 1a with 5 years overlap, Scenario 1b and Scenario 1c are most of the time comparable from an IM point of view. These scenarios offer the most economic scenarios for IM with limited cost of GSM-R OPEX. Scenario 1a with 5 years and Scenario 1c are similar from IM cost effective.
- In all case (here simulated countries) Scenario 1b is the most cost effective for IM (3 or 4% less) compared Scenario 1a with 5 years or Scenario 1c. But due to low differences, IM can accept to choose Scenario 1a with 5 years or Scenario 1c.

For RU :

- For RU, the most expensive scenario is Scenario 1-b with a short time to migrate for RUs that do not benefit from natural lifecycle renewal of equipment. This scenario is evaluated to be more than 40% (or even higher) than the most economic scenarios.
- For RUs, the most economic scenarios are Scenario 0, Scenario 1-a 10 years, Scenario 1-c because RUs benefit from natural life cycle renewal (cab radio and train). Scenario 0 and Scenario 1-a 10 years are at the same level of NPV and Scenario 1c very similar (less than 1% difference).
- Scenario 1-a (dual network) with an overlap of 5 years is intermediate scenario for RU. It is around 20% higher than the most economic one. It is still may acceptable for RUs but after discussion and exchange.

For RU versus IM:

STAKEHOLDER	Most advantageous scenarios	Least advantageous scenarios
IM	1a5 - 1b - 1c	0 - 1a10
RU	0 - 1a10 - 1c	1a5 - 1b

Table 13. IM and RU scenarios comparison

- Scenario 1c seems to be the most cost effective scenario both for IM and RUs. In terms of technical feasibility and practicality, this scenario can be the most difficult to achieve and can present some risk because RUs would need to install their equipment in advance. It will be possible only if technology is ready and fully tested in advance for all features. Software modification could however easily be done in the event that modifications are needed. This approach would need to be discussed with manufacturers in advance. This scenario also requires important discussion and coordination on the schedule.
- Between Scenario 1-a (dual network) with an overlap of 5 years, and Scenario 1-a with an overlap of 10 years, the difference is that the first option (Sc. 1a5) generates an additional cost for the RU (+20% of RU NPV). But, it is interesting to note that the second option (Sc. 1a 10) generates an increase of operating cost much higher in volume for the IM to maintain dual network enough time (+5.5% of IM NPV). By comparison, the model shows that it is always more expensive for IM (Sc. 1a5) than for RU (Sc. 1a10). This difference is evaluated from +10 M€ (scenario Country A or Country B) to more than €180 M (scenario Country D). For all Europe, it is evaluated to €1 000 M. We can conclude that after deployment IMs would prefer to rapidly stop operating the former network. In that way, IM can find advantages to help financially RUs to migrate.
- Scenario 1b is the most efficient for IMs but costly for RUs. In some countries (especially smaller countries), this scenario might present some advantages in term of project planning and project organization. This scenario requires discussion in advance to convince RUs to choose a rapid migration.

7.4.3 Scenarios including cross border

In this section, we present the result of certain European countries 2 by 2 in a cross border situation. The aim is to evaluate the impact of cross border and coordination. Here, we compare the Net Present Value (NPV in € 2016) that we obtain with simulations.

		Scenario 2 (A/B)	Scenario 3 (A/B)	Scenario 2 (A/D)	Scenario 3 (A/D)	Scenario 2 (D/C)	Scenario 3 (D/C)	Scenario 2 (D/F)	Scenario 3 (D/F)
Country A	IM	-590,8	-561,6	-590,8	-561,6				
	RU	-123,6	-123,6	-123,6	-123,6				
	IM+RU	-714,4	-685,2	-714,4	-685,2				
Country B	IM	-653,2	-653,2						
	RU	-119,9	-120,1						
	IM+RU	-773,1	-773,3						
Country C	IM					-3 266,0	-3 266,0		
	RU					-495,3	-496,0		
	IM+RU					-3 761,3	-3 762,0		
Country D	IM			-6 062,4	-6 062,4	-5 659,9	-5 380,5	-5 659,9	-5 380,5
	RU			-625,6	-626,6	-618,1	-618,1	-618,1	-618,1
	IM+RU			-6 688,0	-6 689,0	-6 278,0	-5 998,6	-6 278,0	-5 998,6
Country F	IM							-1 102,3	-1 102,3
	RU							-130,3	-130,5
	IM+RU							-1 232,6	-1 232,8

Table 14. International scenarios result comparative summary – Net Present Value for each stakeholder in Millions of € 2020

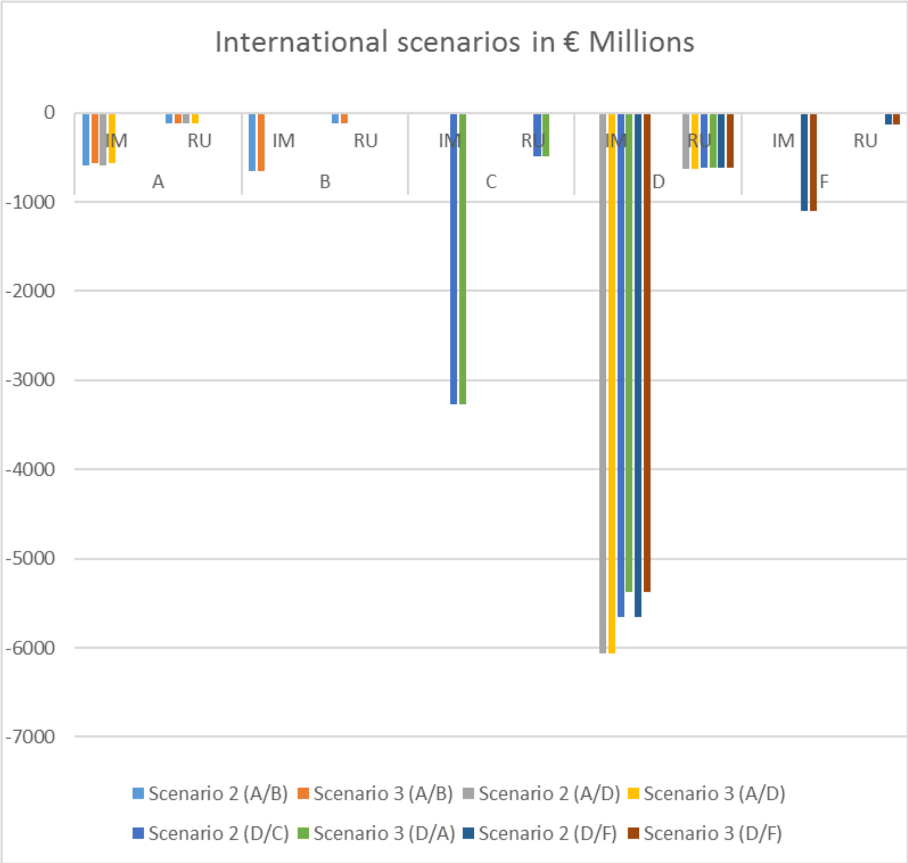

Figure 19. Cross border scenarios

We notice Scenario 2 and scenario 3 are almost similar for IMs and very similar for RUs in term of result. On IM side, scenarios results differ only about 5% in the disadvantage early adopter countries in Scenario 2. It is due to additional cost due to dual network operation (GSM-R and NG). On the other hand, Scenario 3 is slightly costly for RUs as late adopter. By comparison, in the case (D/F) D is a large country and F a small one, then IM will expense additional € +279.4 million in Scenario 2 and in country F, RU will expense only € 0.2 million in Scenario 3. For medium size countries such as case (A/B), IM will expense additional € 29.2 million compared to € 0.2 million for RUs.

We can conclude that discussion and coordination will help to decrease the cost. A solution is to install dual mode cab with GSM-R and Next Generation for train crossing borders if a country migrates before another one. In that case, the country that migrates can stop to maintain and operate GSM-R and then save OPEX cost (Scenario 3). This solution ensures interoperability and does not oblige the country that has already migrated to keep operating the former GSM-R network only for cross-border trains.

Summary

- Scenario 1c seems to be the most cost effective scenario both for IM and for RUs. In terms of technical feasibility and practicality, this scenario can be the most difficult to achieve and can present some risk because RUs would need to install their equipment in advance. It will be possible only if technology is ready and fully tested in advance for all features. Software modification could however easily be done in the event that modifications are needed. This approach would need to be discussed with manufacturers in advance. This scenario also requires important discussion and coordination on the schedule for migration.
- Between Scenario 1-a (dual network) with an overlap of 5 years, and Scenario 1-a with an overlap of 10 years, the difference is that the first option (Sc. 1a5) generates an additional cost for the RU (+20% of RU NPV). But, it is interesting to note that the second option (Sc. 1a 10) generates an increase of operating cost much higher in volume for the IM to maintain dual network enough time (+5.5% of IM NPV). By comparison, the model shows that it is always more expensive for IM (Sc. 1a5) than for RU (Sc. 1a10). We can conclude that IM would like after deployment rather rapidly stop operating the former network. In that way, IM can find advantages to help financially RUs to migrate.
- Between Scenario 1-a (dual network) with an overlap of 5 years, and Scenario 1-a with an overlap of 10 years, the difference is that the first option (Sc. 1a5) generates an additional cost for the RU (+20% of RU NPV). But, it is interesting to note that the second option (Sc. 1a 10) generates an increase of operating cost much higher in volume for the IM to maintain dual network enough time (+5.5% of IM NPV). By comparison, the model shows that it is always more expensive for IM (Sc. 1a5) than for RU (Sc. 1a10). We can conclude that after deployment IM would prefer to rapidly stop operating the former network. In that way, IM can find advantages to help financially RUs to migrate.
- Scenario 1b is the most efficient for IM but costly for RUs. In some countries (particularly smaller countries), this scenario might present some advantages in terms of project planning and project organization. This scenario requires discussion in advance to convince RUs to choose a rapid migration.
- We can conclude that discussion and coordination will help to decrease costs for ccross border or international scenarios. A solution would be to install dual mode cab radios with GSM-R and Next Generation for train crossing borders in order to ensure interoperability.

8. FINDINGS

The principal findings of the survey and the economic model are presented below.

8.1 Criteria and business drivers for decisions

What may be criteria and business drivers (IM/RU/MS) for decisions on starting the migration for RU's and IM's in the different MS (include CCS TSI functionality and all other usages)?

For Infrastructure Managers, the most significant conclusions from the survey relate to the drivers and reasons for migration from GSM-R to a Next Generation system. When asked to rate in order of importance migration drivers, the single most important factor mentioned was obsolescence of GSM-R technology. Obsolescence relates to when GSM-R is no longer supported by the manufacturers the cost of keeping these networks increases and the possibility of deploying new GSM-R equipment on new lines becomes almost impossible. This driver will most impact the migration end date.

Other major drivers included EU regulation (new European directives resulting in a requirement to migrate to a new system or even a new frequency band) and relationship with other plans such as introducing ETCS or new lines.

When given the opportunity to provide their own reasons for migration, obsolescence again topped the list followed by EU regulations, traffic capacity and the desire to introduce new services to staff and passengers.

There is a consensus that IMs will envisage starting to migrate to the Next Generation system in 2025 and that the network infrastructure will be owned by the IM.

The preferred migration method from GSM-R to Next Generation from the perspective of IMs is based on the installation of dual-mode cab radios.

As GSM service is eventually withdrawn by public operators, this may force IMs and RUs to migrate to a new public technology for low traffic lines and/or for lines that do not critical services, i.e. where there is no intention to deploy GSM-R.

For Railway Undertakings, the most significant conclusions from the survey relate to the drivers and reasons for migration from GSM-R to a Next Generation system. When asked to rate in order of importance migration drivers the RUs were unanimous in citing EU regulation indicating that RU are not pushing for a Next Generation technology and think that this will occur only if there is a legal requirement to do so.

As far as the migration method is concerned, it appears that RUs have yet to make up their minds on the matter and are awaiting confirmation on how infrastructure will be deployed.

Broadband applications for staff and passengers were mentioned by almost all of the RUs.

Other observations

The lack of significant detail in the responses of the IMs and in particular the RUs make drawing definitive conclusions difficult.

Information available today indicates that there is no pressing need to bring forward or push back the migration start date, but it is important to underline the following points:

- Due to the fact that there is little data currently available on OPEX, currently IMs do not see cost savings as driver. However, this position could change as more information becomes available, and might dramatically affect the drivers for migration. Additionally, industry is unclear on the support of GSM-R equipment and on the renewal of contracts The fact that public operators will give up GSM in the next few years reinforces that risk. The analysis carried out in this study is based on a snapshot (i.e. today's situation), and as a consequence, the detailed findings may be less relevant in future years.

- The cab radio market is a niche market for industry with only few manufacturers; hence, there is a risk on the availability and maintenance of such products especially when it is only a renewal phase. As a result of this uncertainty regarding future developments, RUs do not have sufficient information to carry out a risk analysis on the availability of equipment. This could change if support from industry changes.

A thorough risk analysis on the two areas highlighted above will be a main condition for successful migration.

8.2 Interaction with MS decisions on network models

<u>How does this interact with MS decisions on network models (i.e. relationship with MS decisions on network models)?</u>

The business drivers on network models for IM and RU are cost and functionality; however, these drivers may be strongly influenced by decisions at a Member State level on items such as sharing of network resources, and by decisions on spectrum.

The need for having a dedicated network was challenged, although there was no specific justification provided on the pros and cons; decisions at Member State level on this subject may also have a strong influence. Previous studies such as "Evolution of GSM-R" from IDATE in 2015 and the "Study on use of commercial mobile networks and equipment for 'mission-critical' high-speed broadband communications in specific sectors" from SCF in 2013 presented initial views, but we do not discuss this topic further since there is very little new information available since the publication of these reports.

Concerning the network model itself, it would be interesting to have a deeper understanding as to why the IM want to own their own networks, or to have a dedicated network. The questionnaire answers provide only limited insights in terms of quality of service and availability.

The rollout of ERTMS Level 2 or Level 3 in Member States (as per the European Deployment Plan referenced in the CCS TSI) may also have an impact on migration.

It is important to note that all of these items are still under discussion, and that MS decisions are not expected in the short term.

We can conclude that there is a direct link between MS decisions on network models; however, given that there is very little known about MS decisions, we are unable to provide answers to this question. We recommend that ERA review this situation as a possible next step.

8.3 Potential migration scenarios and planning

What are the potential migration scenarios and planning?

The migration scenarios considered in the economic model are:

- Scenario 0: No migration from GSM-R to Next Generation. GSM-R technology is maintained until 2045 for the whole of Europe. This scenario is unrealistic but used as a reference in terms of cost evaluation.

- Scenario 1a: Dual network GSM-R and NG during a long overlap

- Option 5y: Dual Network approach - Long overlap period but limited to of 5 years.
- Option 10y: Dual network approach - Long overlap period i.e. at least of 10 years.

- Scenario 1b: Single network NG: Rapid transition from GSM-R to Next Generation at network side with limited overlap period (1 year). IM will deploy equipment in the same time that RU will install new on board equipment to prepare a single network operation.

Scenario 1c: Single network NG: Rapid transition from GSM-R to Next Generation at network side with limited overlap period (1 year). RU will install new on board equipment in advance to prepare a single network. IM and RU finish their installation at the same time.

-Scenario 2: Dual network GSM-R and NG during a long overlap (5 or 10 years) but NOT in the same time window (2 to 5 years) for two neighbors. (4 different cases).

-Scenario 3: Single network NG during a short overlap (1 year) but NOT in the same time window (2 to 5 years difference) for two neighbors. (2 different cases).

Note: Scenario 1a and 1b are national scenarios at Member State (MS) level. Scenarios 2 and 3 are cross border scenarios at European Level.

Concerning planning, IMs and RUs have no defined migration plans yet. The scenarios depend on a number of factors that are still uncertain for most of them.

Based on the experience of migration to GSM-R, there are different planning scenarios and time frames ranging from 7 to 19 years. But compared to the previous migration, we can expect that for the next migration several compatible assets exist and may be re-used partially at least. This situation will largely positively influence the planning and reduce the deployment duration. But these expectations depend on European and national decisions (spectrum, network sharing, …).

8.4 Significant cost drivers or cost savers

What can be significant cost drivers or cost savers for the different RU's, IM's and MS?

We have determined that costs for IMs are far higher than costs for RUs.

For IM:

The costliest scenario for Infrastructure Managers is Scenario 0 (i.e. no migration) due to renewal costs and also due to impact of obsolescence. In the simulation, NPV of Scenario 0 is more than 40% higher than the cheapest alternative. Following that the most expensive migration scenario for IM is Scenario 1-a with a long overlap (10 years). Scenario 1a with 5 years overlap, Scenario 1b and Scenario 1c are comparable from a cost point of view. These scenarios offer the most economic scenarios for IM, with limited cost of GSM-R OPEX. Scenario 1b presents a small advantage (3 or 4% less) compared to Scenario 1a with 5 years or Scenario 1c. But due to the low difference, IM can accept to choose Scenario 1a with 5 years or Scenario 1c.

Then for the IMs, the most significant cost drivers or cost savers that we have identified are the installation and maintenance of a dual mode infrastructure for a long period of time or for an extensive area (which raises costs), and the possibility to reuse the existing radio sites (which reduces costs).

For RU:

The most expensive scenario for Railway Undertakings is Scenario 1-b with a short time to migrate for RUs that do not benefit from natural life cycle renewal of equipment. The cost is evaluated to have NPV that is more than 40% higher than that of the most economic scenario. For RUs, the most economic scenario is Scenario 0, Scenario 1-a 10 years or Scenario 1-c since RUs benefit from natural life cycle renewal (cab radio and train). Scenario 0 and Scenario 1-a 10 years are at the same level of NPV and Scenario 1c very similar (less than 1% difference). Scenario 1-a (dual network) with an overlap of 5 years is an intermediate scenario for RUs. It is approximately 20% higher than the most economic one. It is still may acceptable for RUs but after discussion and exchange.

For RUs, the most significant cost drivers or cost savers found are the installation of dual-mode or even single equipment on board of the vehicles, and the possibility to do so taking advantage of the natural lifecycle renewal.

For IM/RU:

Scenario 1c seems to be the most cost effective scenario both for IM and for RUs. In terms of technical feasibility and practicality, this scenario can be the most difficult to achieve and can present some risk because RUs would need to install their equipment in advance. It will be possible only if technology is ready and fully tested in advance for all features. Software modification could however easily be done in the event that modifications are needed. This approach would need to be discussed with manufacturers in advance. This scenario requires also important discussion and coordination on the schedule.

Between Scenario 1-a (dual network) with an overlap of 5 years, and Scenario 1-a with an overlap of 10 years, the difference is that the first option (Sc. 1a5) generates an additional cost for the RU (+20% of RU NPV). But, it is interesting to note that the second option (Sc. 1a 10) generates an increase of operating cost much higher in volume for the IM to maintain dual network enough time (+5.5% of IM NPV). By comparison, the model shows that it is always more expensive for IM (Sc. 1a5) than for RU (Sc. 1a10). We can conclude that after deployment IM would prefer to rapidly stop operating the former network. In that way, IM may be able to find advantages to financially help RUs migrate.

Scenario 1b is the most efficient for IM but costly for RUs. In some countries (particularly smaller countries), this scenario might present some advantages in terms of project planning and project organisation. This scenario requires discussion in advance to convince RUs to choose a rapid migration.

In conclusion:

In all migration scenarios tested in the model, running a dual network is more expensive than dual-mode cab radios. In other words, dual networks for IMs are a significant cost driver.

The cost of GSM-R renewal and the cost of GSM-R OPEX in the case of a dual network could however be mitigated or avoided in scenarios imply coordination with national and international RUs.

A short deployment time of the new network for IM, i.e. 5 years rather 10 years, can also reduce the total amount of migration cost. It is therefore recommended to seek to avoid a long migration period.

It should be noted that cost savers are not on the same scale for IMs as for RUs inasmuch as IM investments are significantly higher than those for RUs.

IMs expect to achieve cost savings in Next Generation equipment compared to GSM-R.

An important cost saver for RUs would be to benefit from the natural lifecycle renewal for traction units and cab radios. With sufficient forward planning, RUs would be able to take advantage of existing maintenance schedules to install Next Generation cab radio equipment rather than take rolling stock out of service specifically for this installation. The deployment of dual-mode cab radios in this manner is considered to be the most efficient solution. RUs would need to be made aware that they need to prepare the migration as early as possible since late adopters may not have access to dual-mode cab radios (due for instance to possible GSM-R chipset shortages).

National scenarios (at Member State level) are not very different for IMs, but they are different for RUs.

Based on these considerations, it is recommended to initiate coordination between IMs and RUs first on a national basis, and then with international RUs.

8.5 Interoperability during the migration

How to ensure interoperability during the migration?

If technology, equipment and systems are standardised and mature, then interoperability during migration will be a coordination issue.

We conclude that communication of migration plans well in advance is a basic requirement. This allows the IMs and the RUs to plan ahead and to avoid getting into situations where the interoperability that has been achieved to date can be temporarily jeopardised. It will be important during coordination to announce well in advance and also to provide a national level way of expertise. We can refer to the filtering discussion on GSM-R that occurred at an MS level between IMs and RUs.

The IMs should work on the identification of the date of the “switch-off” of GSM-R or of the time period where they plan to have a dual network.

The RUs should start installing dual mode solutions as soon as possible, to minimise costs and to allow a better synchronisation of migration activities. Additionally, by beginning to upgrade early RUs can benefit from the natural renewal and maintenance cycle and not wait for the end of date of GSM-R.

To facilitate communication and migration planning, an exchange of data on the status of equipment in rolling stock would be extremely useful. The existing register of rolling stock could be used, as has already been done for example for Gothard line migration on ERTMS.

With this in mind, procedures will be needed to substantially improve the quality of data in the register of rolling stock. Today, data provided by the Member States is often incomplete or incorrect. A mechanism that might be considered would be to condition any State Aid to the RUs for the upgrade to GSM-R and the RU providing good, timely and accurate information on the status of rolling stock upgrades to ERA for inclusion in the rolling stock register (see also Section 8.6).

For migration a legal framework needs to be established because up to now, there is no mechanism to introduce a new technology and force RUs to migrate or at least there are no tools to facilitate that.

The present legal framework that are the Railway Interoperability Directive and TSI do not address this type of migration and do not allow the switching-off of GSM-R.

In that case, only National Technical Rules and Derogation Requests allow IM (if accepted by the EC) to switch off GSM-R. If an IM would like to migrate, it should request that to MS and the MS will ask for a derogation at European level.

We note that currently the Rail Interoperability Directive applies to new vehicles or renewals, but not to changes.

A next step might be to implement a mechanism for IMs and RUs to agree on plans for migration. One existing example of a mechanism that might be suitable is the Network Change Notice in Great Britain, where the IM funds the deployment of on-board equipment when the change is initiated by the IM (and not by a TSI change, for example). Modifications however would be required to legislation restricting state aid in order to make ensure that the threshold for the amount IM can compensate RU for changes is not a hindrance to the migration process.

For cab radio equipment (ERTMS), it proposed that there:

- Are no new mandatory functions on top of existing requirements.
- Is a financial framework is need to protect on-board investments i.e. a fair compensation scheme shall be applicable between IM and RU when new functions would globally improve the railways business case.

8.6 Tools to create well balanced and acceptable migration scenarios

Which tools can be used to create migration scenarios that are well balanced and acceptable for RU and IM, on MS as well as on EU scale?

There is no precedent of a legal framework that imposes two systems at the same time. Lessons will have to be learnt from the previous migrations (such as from Class B to Class a Signalling systems, from analogue radio to GSM-R, and so on) on the legal tools that should be developed, within the framework of the Railway Interoperability Directive (where retrofits cannot be imposed, and changes only apply to new/updated/renewed lines).

The establishment of well informed and accurate databases with information on the fitting that vehicles have, in which areas they are authorised to run and what are the radio systems available on those areas will help enormously the coordination and the decision making for both RUs and IMs.

The use of the European vehicle and infrastructure register databases (such as European Centralised Virtual Vehicle Register (ECVVR)) is deemed to be an important step to ensure that migration planning is as optimal. It is therefore essential that this data is accurate and up-to-date.

It will also be useful for all stakeholders to have a wide as possible supplier base for Next Generation equipment which will help to keep CAPEX down. The simplest way to achieve this would be to ensure that the Next Generation technology is a commercially available off-the-shelf technology that is used by private and public operators.

Finally, the creation of a financial framework to ensure a fair allocation of benefits, costs and risks between IMs and RUs appears to be essential in order to improve the railways' business case, and can be seen as a tool to encourage the migration. This is key policy implications that flows from our finding that costs for the RUs are nearly the opposite of those for IMs, in the sense that scenarios with a long migration period are better for the RUs than shorter migration periods. The reason is that a longer migration period enables the RUs to replace existing cab and handheld equipment with dual-mode equipment at such time as it would have been due for replacement anyway. This finding needs to be understood in conjunction with other key findings of this study:

- IMs and RUs agree that the preferred migration scenario involves upgrading of all cab and hand-held equipment to dual-mode. This needs to happen *before* the IM discontinues GSM R operation.
- As previously noted, the RUs see little immediate benefit in migration. They have little interest in migrating before they are required to migrate.
- The TSI will presumably be enhanced at some point in time to reflect a requirement for Next Generation technology; however, the current legal framework does not explicitly require RUs to upgrade equipment that conformed to the TSI that was in effect when the equipment was most recently put in service, upgraded or renewed[4].

The misalignment of incentives means that RUs are likely, in the absence of some public policy intervention, to delay the migration beyond the date is globally optimal. The cost to IMs of this delay would be substantially greater than the savings to the RUs; moreover, it would complicate the migration, especially in regard to cross-border rail traffic (since some IMs might migrate, while others might be unable to migrate). This misalignment of incentives could easily lead to deployment delays, thus substantially increasing costs for the IMs and also increasing the complexity of the migration as a whole[5].

Financial compensation to the RUs would seem to be the most natural way to address this concern. It appears at first blush that all costs of migration are potentially eligible for State Aid as interoperability

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[4] See Article 5(2) of the Railways Interoperability Directive: "Subsystems shall comply with the TSIs in force at the time of their placing in service, upgrading or renewal, in accordance with this Directive; this compliance shall be permanently maintained while each subsystem is in use."

[5] If incentives were aligned, the migration would represent a Pareto improvement, where at least one person is made better off and nobody is made worse off. In practice, the migration appears instead to potentially represent a Kaldor–Hicks improvement, where those that are made better off (Member States and IMs) could hypothetically compensate those that are made worse off (RUs) and thus lead to a Pareto-improving outcome.

aid under existing guidance from the European Commission[6]; however, only 50% of the eligible costs would be automatically presumed to be consistent with principles of necessity and proportionality.[7]

Based on the foregoing considerations, it is possible that 50% compensation to the RUs is not sufficient to ensure timely migration. We suggest, at such time as the costs of migration are more fully predictable, that the ERA carefully consider whether compensation in excess of 50% might possibly be warranted. The Member State in question would need to judge whether it is willing to make the expenditure, and would have to demonstrate the need and proportionality of financial compensation in excess of the default 50%[8]; however, we assume that a general determination by ERA would carry weight when the European Commission's DG Competition judges the appropriateness of a particular State Aid request in light of the totality of circumstances.

If the ERA were to make such a recommendation, it could do so subject to conditions that the RU self-certify that all relevant equipment will be upgraded by a certain date, and associate it with a date (for instance, 2028) by which all RU upgrades must be completed in order to quality. This provides for simple administration, and also helps to ensure timely migration. No changes to existing regulation are required.

Bibliography

References.	**Document Title**

[6] European Commission (2008), Community guidelines on State aid for railway undertakings, 2008/C 184/07, paragraph 106. "As regards interoperability aid, the eligible costs cover, to the extent to which they contribute to the objective of coordinating transport, all investments relating to the installation of safety systems and interoperability (3), or noise reduction both in rail infrastructure and in rolling stock. In particular they cover investment associated with the deployment of ERTMS (European Rail Traffic Management System) and any like measure which can help to remove the technical barriers in the European rail services market."

[7] Ibid., paragraph 107.

[8] Ibid., paragraph 108.

1. IDATE Evolution of GSMR - FINAL Report for ERA – April 2015.

2. SCF Report Study on use of commercial mobile networks and equipment for "mission-critical" high-speed broadband communications in specific sectors smart_2013_0016_final_report_8211.

3 PWC Report ERTMS: Study to develop tailor-made solutions for use of innovative financing to support deployment of ERTMS, in particular along nine core network corridors Draft Final Report 2 Oct 2015.

4 Survey on operational communications (study for the evolution of the railway communications system) Final report for the European Railway Agency - 25 February 2014-Analysis Mason.

5 UIC International Union of Railways Future Railway Mobile Communication System User Requirements Specification FU-7100 version 2.0 29th of March 2016.

6 ETSI Term of Reference relating to TC RT Working Group on Next Generation Radio for Rail.

9. ANNEXES

9.1 ANNEX A - Results of the economic model

9.1.1 Selected scenarios

The selected scenarios defined to cover those situations are described in the table below.

As indicated in the study, criteria for that simulation are estimated and common for all countries. In that simulation only the size of the network (GSM-R number of line km and cab radio number estimation) are different and based on assumptions.

Note that only a part of possible scenarios is presented in the following text. Due to similar assumptions on cost data, the conclusions are more and less similar for all of them more. A parameter that can modify this analysis is the importance of number of cab radio related to the number of km covered in GSM-R.

Scenario 0 – Reference scenario	
No migration from GSM-R to NG: Maintain GSM-R until end of time for the whole of Europe	
Scenario 1a5 or 1a10	**Scenario 1b or Scenario 1c**
Dual network (long overlap e.g. 5 or 10 years) with GSM-R + NG: • Evaluation for different countries such as A, B, C, D, F and all Europe. • Evaluation for whole of Europe in the same time window	**Single network (limited overlap e.g. 1 year) with GSM-R + NG:** • **Scenario 1b**: RUs and IM deploy very quickly (2 years in same time window). • **Scenario 1c**: RUs start to deploy in advance /IM and they both finish in same time. ○ Evaluation for different countries such as A, B, C, D, F and all Europe. ○ Evaluation for whole of Europe in the same time window.

Scenario 2 – Dual network	Scenario 3 – Single Network
Dual network (5/10 years' overlap) NOT in the same time-window (2/5 years' difference) for two neighboring countries: • Evaluation for different countries such as A, B, C, D, F and all Europe.	**Single network (1-year overlap) NOT in the same time-window (2/5 years' difference) for two neighboring countries:** • Evaluation for different countries such as: A, B, C, D, F and all Europe.

Table 15. Summary presentation of studied scenarios

9.1.2 Simulation scenarios at MS Level: Country A case

In this Section, a complete simulation results for scenarios at MS level are presented. As an example of results, we present the case of Country A.

The dedicated assumptions for Country A are 3 100 km of line for the network size and an estimation of 2 300 cab radios.

For IM and RU, CAPEX and OPEX evolution are presented. Additionally, there are also Cash Flow evolution for each of them.

9.1.2.1 Scenario 0 – no migration

The overall Cash Flow for IM and RU only includes GSM-R OPEX. In the case of the IM, this cost is directly impacted by the impact of technological obsolescence.

In that case, we include a renewal cost of equipment based on a GSM-R renewal each 15 years. For the time being, that cost is included in the OPEX cost.

Note: *Concerning NG cost renewal, the model itself lets the possibility to include this additional CAPEX but it is not done in the following scenarios due to too important uncertainty on technology.*

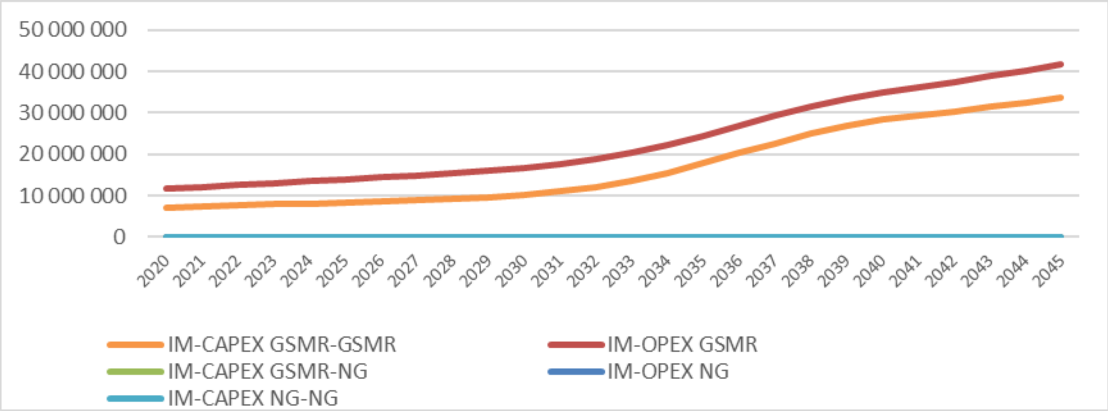

Figure 20. Scenario 0 – Country A – IM Cash flow at current price

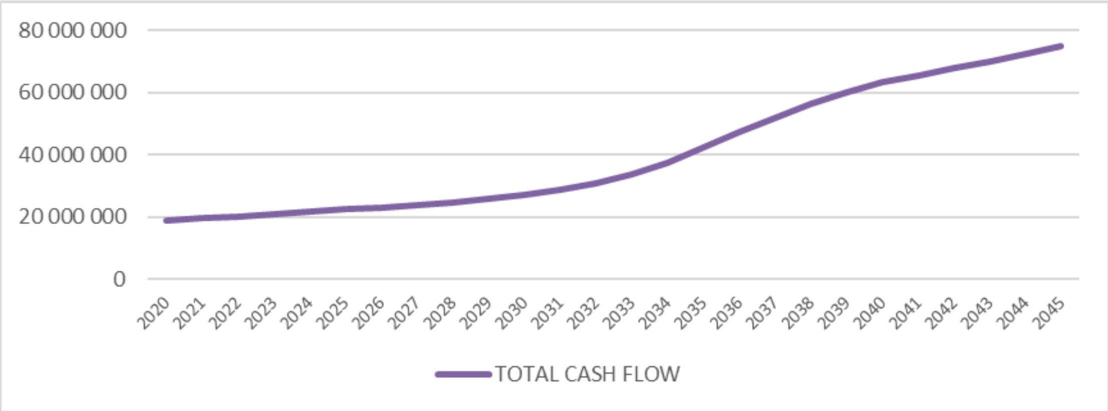

Figure 21. Scenario 0 – Country A – IM Total Cash flow at current price

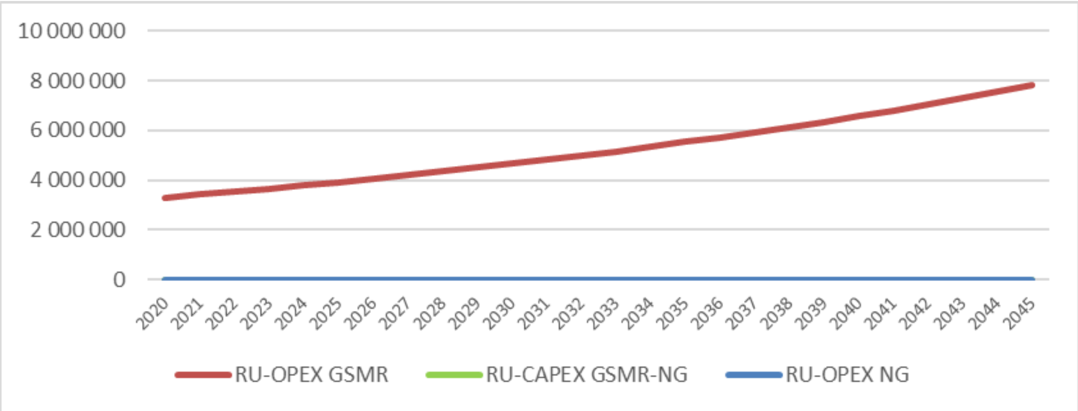

Figure 22. Scenario 0 – Country A – RU Cash flow at current price

Based on our costs ratios, the Net Present Value (NPV) of the project for the IM of Country A is €-775 M. The NPV for the RU is €-104 M.

9.1.2.2 *Scenario 1-a5 – dual network, overlap of 5 years*

The time line of the scenario is:

- From 2020 to 2024: only GSM-R Operation;
- From 2025 to 2030: GSM-R operation and investment in new technology for the IM and the RU;
- From 2030 to 2032: NG Operation set-up;
- From 2030 to the end of time: only NG Operations.

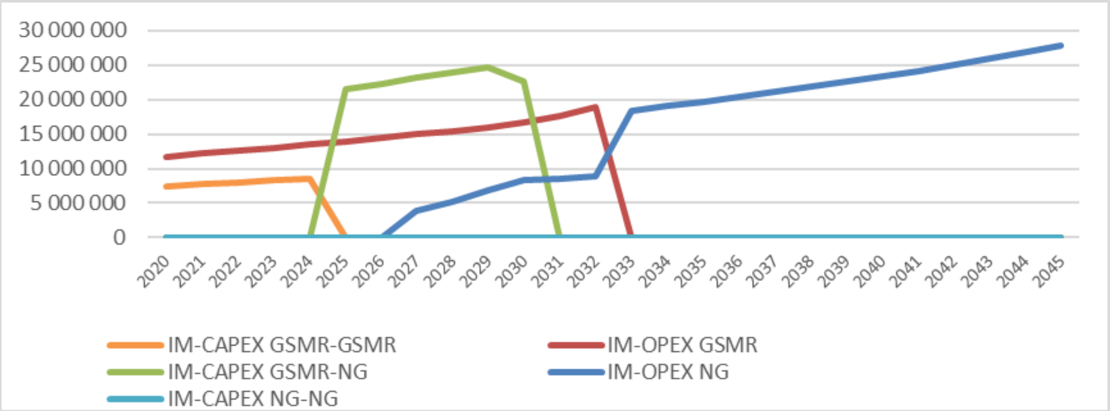

Figure 23. Scenario 1-a5 – Country A – IM Cash flow at current price

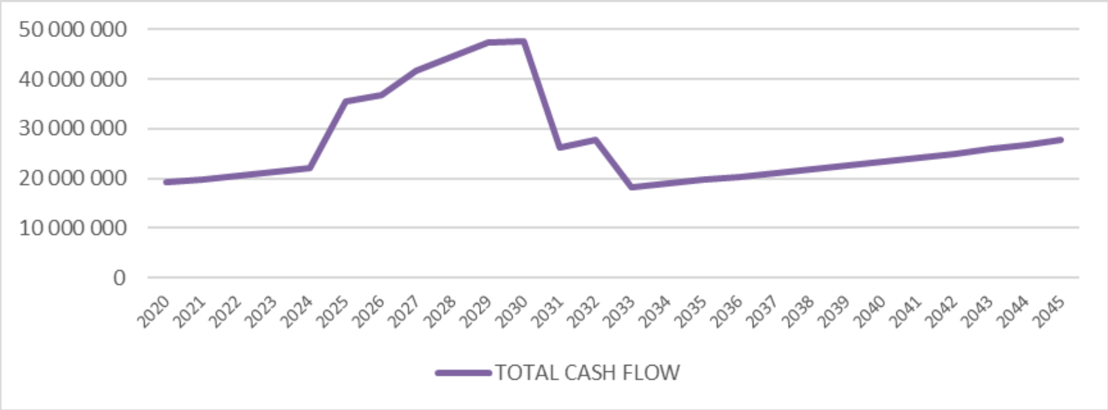

Figure 24. Scenario 1-a5 – Country A – IM Total Cash flow at current price

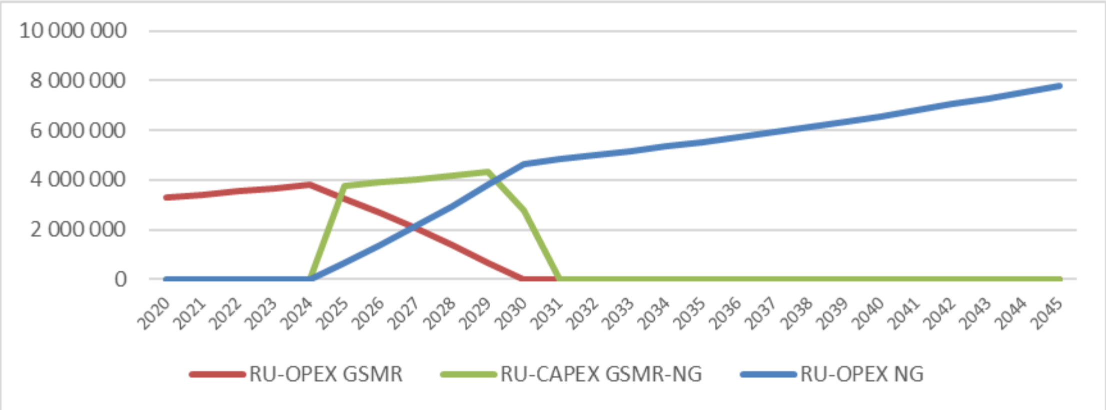

Figure 25. Scenario 1-a5 – Country A – RU Cash flow at current price

Based on our costs ratios, the Net Present Value (NPV) of the project for the IM of Country A is €-562 M. The NPV for the RU is €-124 M.

9.1.2.3 Dual network, overlap of 10 year

Based on the previous scenario, this one includes the following modifications:

- From 2020 to 2024: no change, only GSM-R Operation;
- From 2025 to 2030: GSM-R operation and investment in new technology for the IM;
- From 2030 to 2032: NG Operation set-up for the IM;

- From 2032 to 2035: The IM maintain a dual network to allow the RU to finish their transition;
- From 2025 to 2035: The investment in NG for the RU is covered by OPEX, considering business as usual train and cab radio retrofit life-cycle;
- From 2035 to the end of time: only NG Operations.

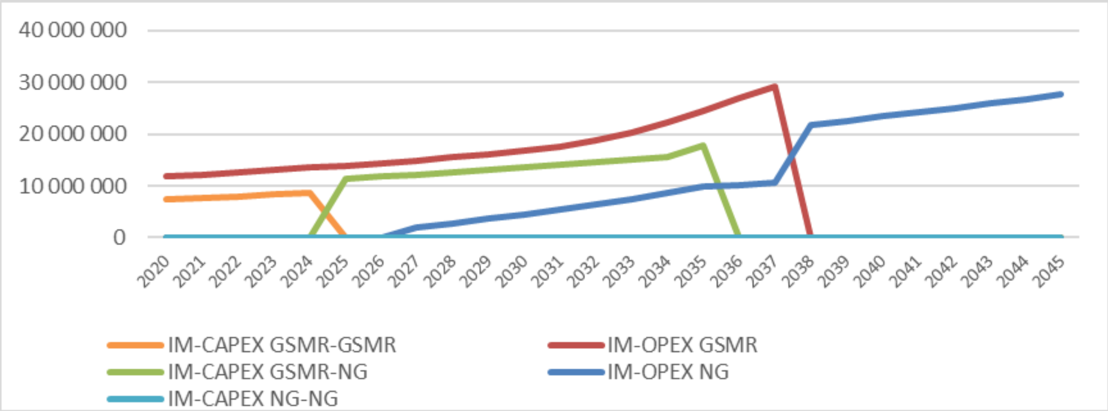

Figure 26. Scenario 1-a5 – Country A – RU Cash flow at current price

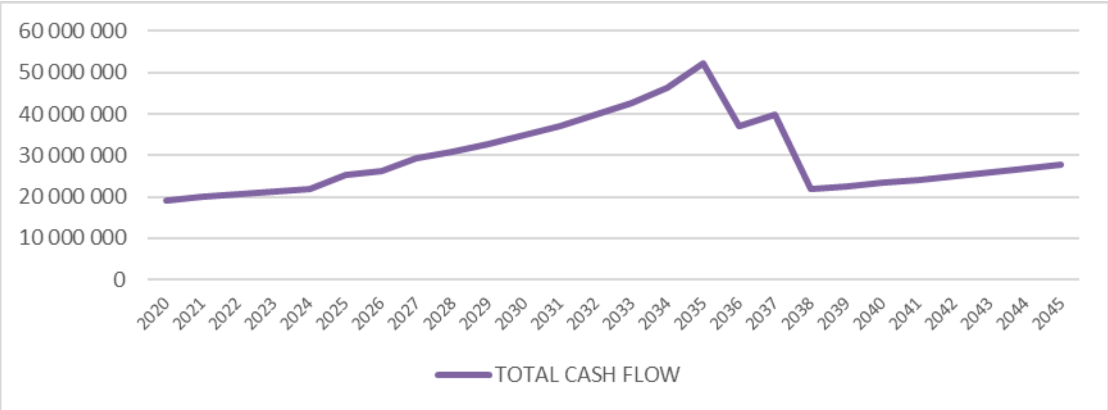

Figure 27. Scenario 1-a10 – Country A – IM Total Cash flow at current price

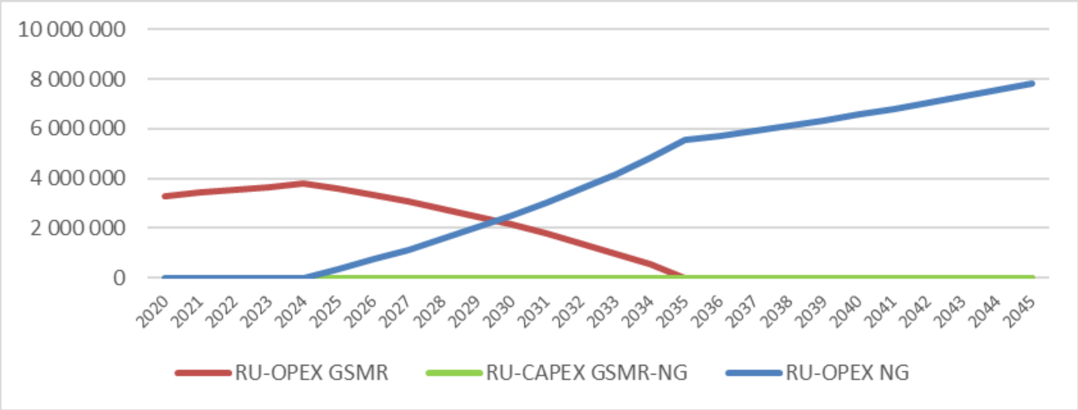

Figure 28. Scenario 1-a10 – Country A – RU Cash flow at current price

Based on our costs ratios, the Net Present Value (NPV) of the project for the IM of Country A is €-605 M. The NPV for the RU is €-104 M.

9.1.2.4 Scenario 1-b – single network, overlap of 1 years

The transition is concentrated on very short period (IM deployed in 2 years and RU also in 2 years).

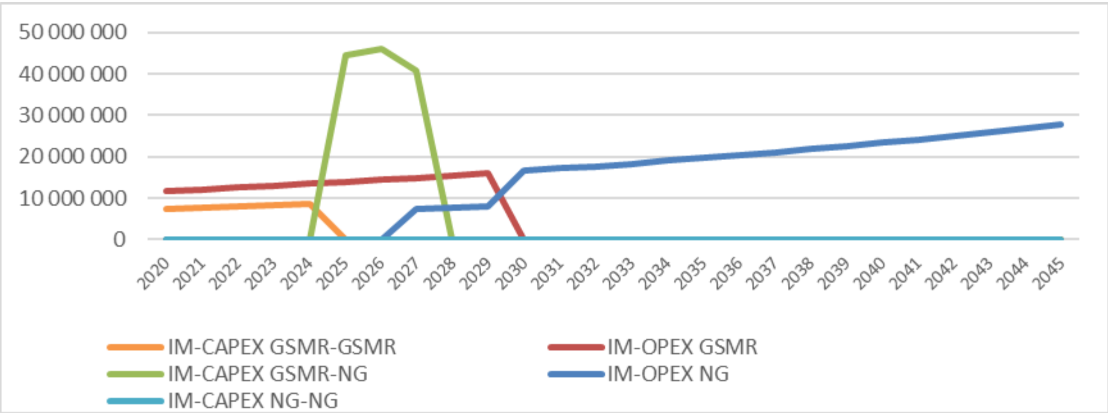

Figure 29. Scenario 1-b – Country A – IM Cash flow at current price

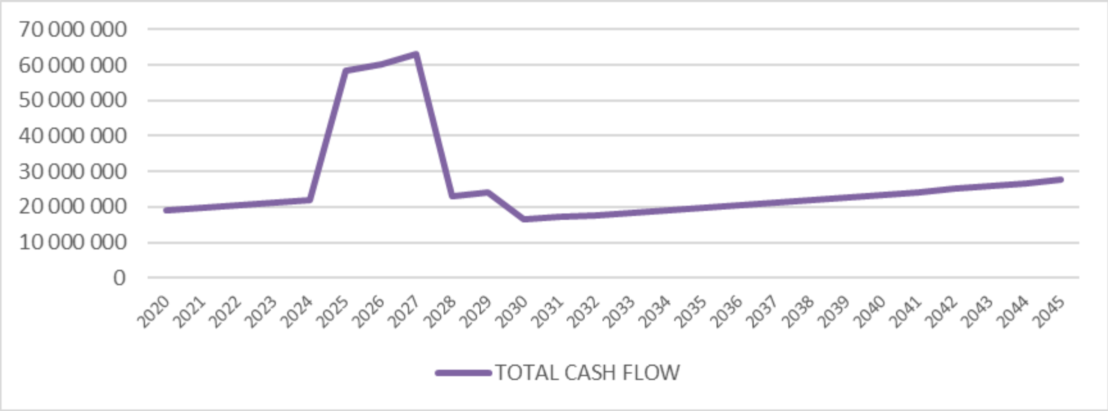

Figure 30. Scenario 1-b – Country A – IM Total Cash flow at current price

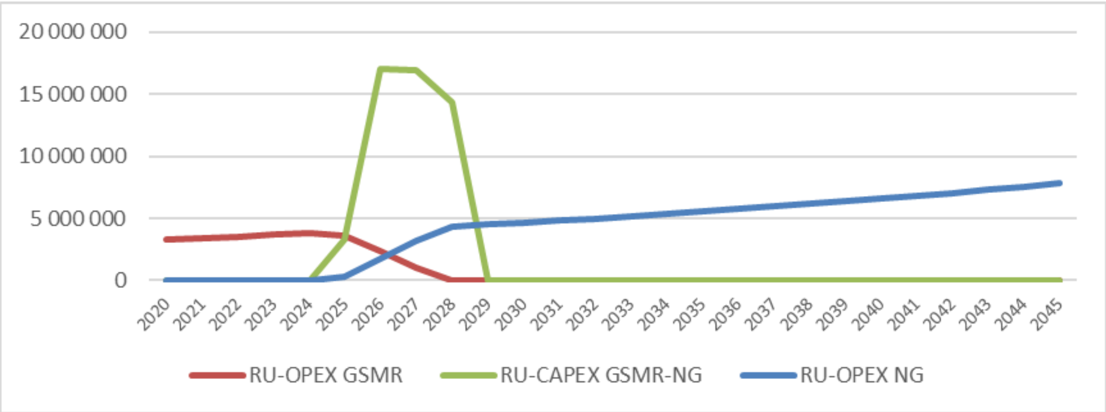

Figure 31. Scenario 1-b – Country A – RU Cash flow at current price

Based on our costs ratios, the Net Present Value (NPV) of the project for the IM of Country A is €-543 M. The NPV for the RU is €-149 M.

9.1.2.5 Scenario 1-c – long deployment but short overlap of 1 years

IM deploy in a relative long period of 5 years but RU starts to deploy 3 years in advance. They both finish in the same time.

The transition is concentrated on very short period.

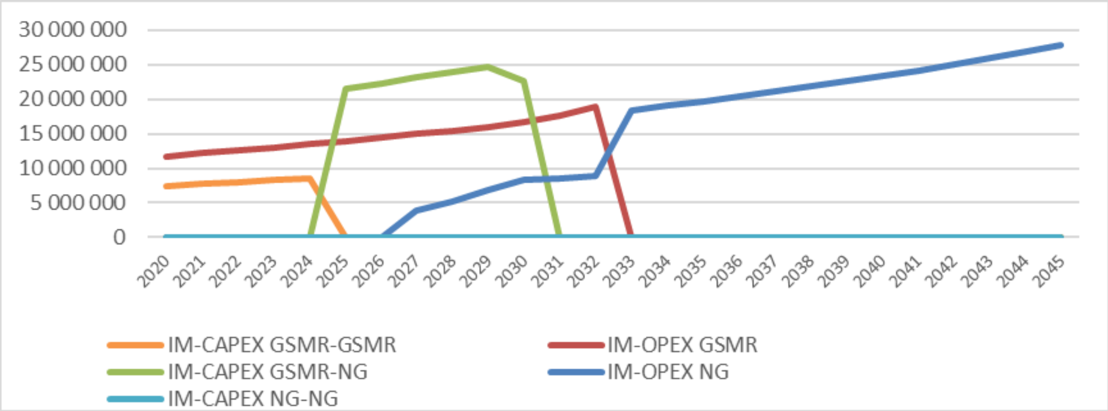

Figure 32. Scenario 1-c – Country A – IM Cash flow at current price

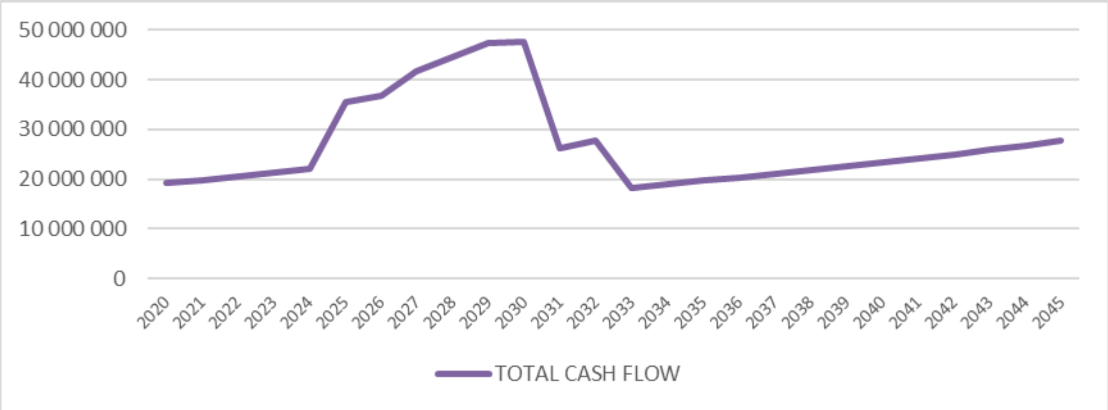

Figure 33. Scenario 1-c – Country A – IM Total Cash flow at current price

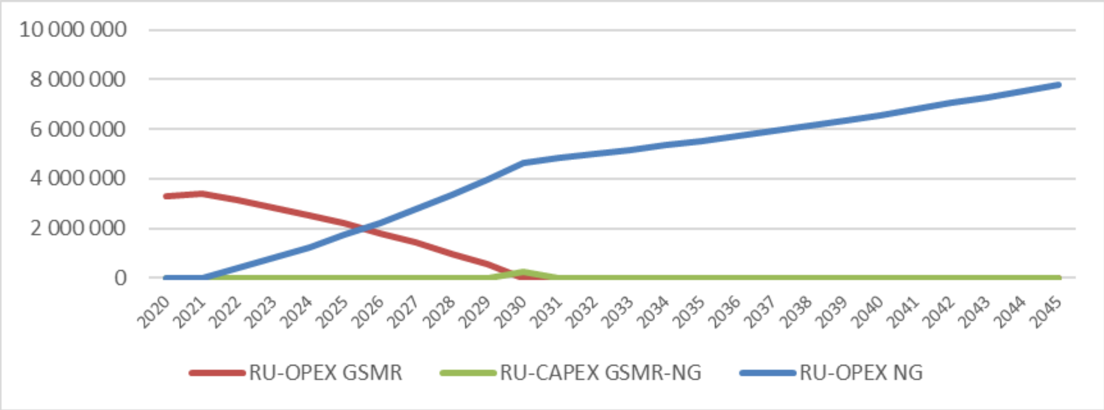

Figure 34. Scenario 1-c – Country A – RU Cash flow at current price

Based on our costs ratios, the Net Present Value (NPV) of the project for the IM of Country A is €-562 M. The NPV for the RU is €-104 M.

9.1.1 Cross border scenarios at European Level

In this section, cross border simulation results are presented with 2 cases. First case, 2 countries that are comparable in term of network size and rolling stock fleet: Country A: Country B (Country A as first adopter for NG and Country B, 5 years later in this scenarios). The second case is 2 countries that are different in term of size and fleet: Country D-Country F (Country D as first adopter - Country F, 5 years later).

9.1.1.1 Scenario 2 – dual network

9.1.1.1.1 Country B-Country A

Country A: first adopter – Country B: 5 years later

The time line of the scenario is:

- From 2020 to 2024: only GSM-R Operation in both countries;
- From 2025 to 2030: GSM-R operation and investment in new technology for the IM and the RU of Country A; only GSM-R Operation in Country B;
- **From 2030 to 2032: NG Operation set-up in Country A;**
- From 2032 to 2035: IM in **Country A operate dual network** to allow Belgian trains to operate on it;
- From 2030 to 2035: GSM-R operation and investment in new technology for the IM and the RU of Country B;
- From **2035 to 2037: NG Operation set-up in Country B IM network;**
- From 2037 to the end of time: only NG Operations in both countries.

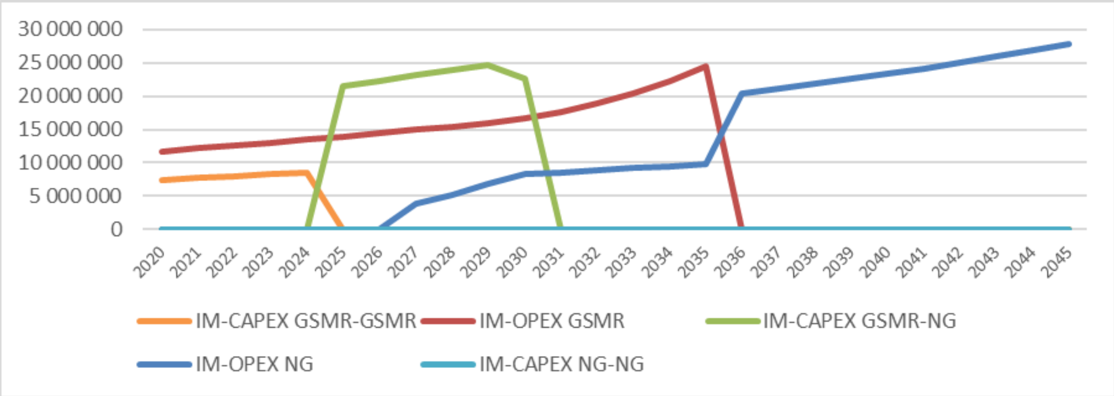

Figure 35. Scenario 2 – Country A IM Cash flow at current price

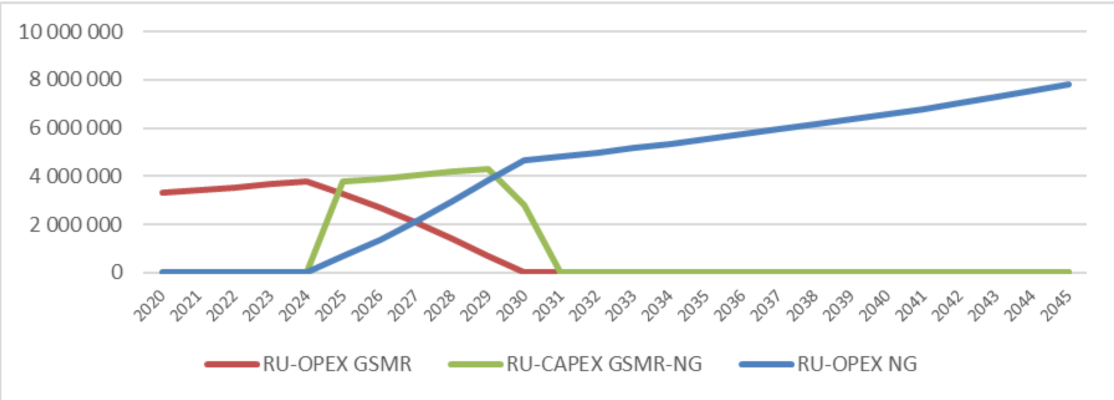

Figure 36. Scenario 2 –Country A – RU Cash flow at current price

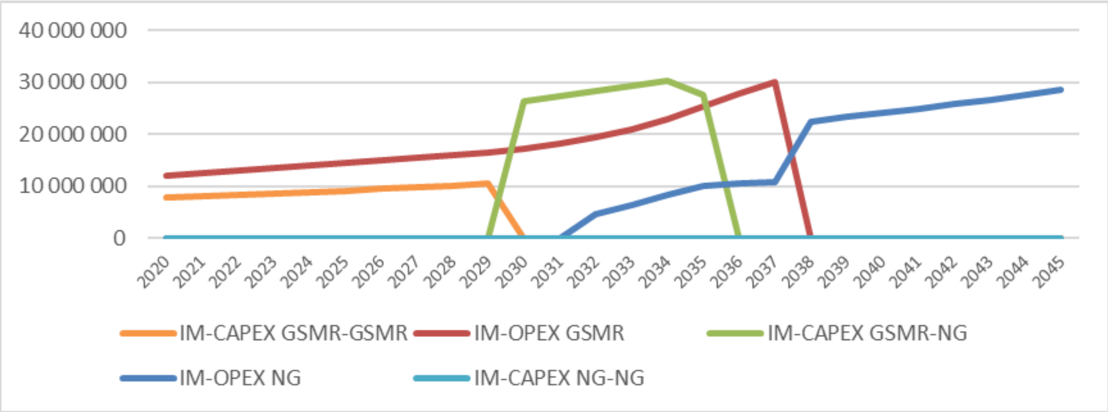

Figure 37. Scenario 2 – Country B – IM Cash flow at current price

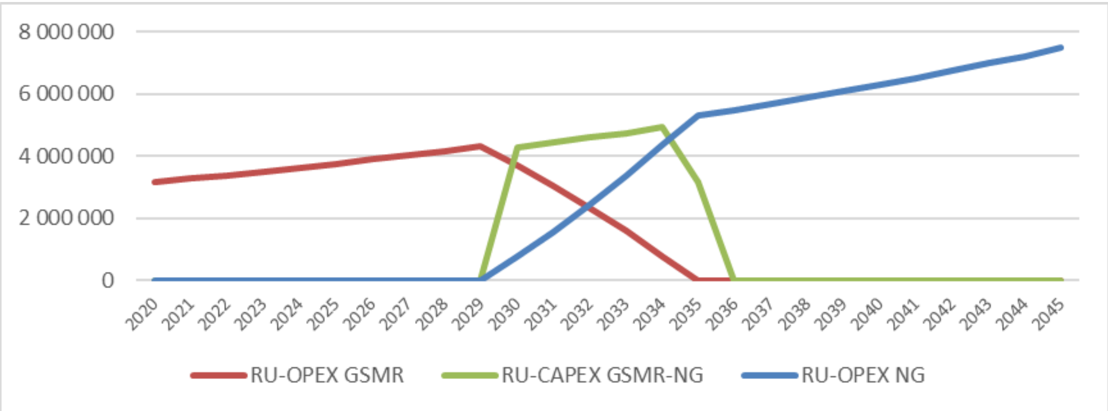

Figure 38. Scenario 2 – Country B – RU Cash flow at current price

Based on our costs ratios, the Net Present Value (NPV) of the project for the IM of Country B is €-653.2 M. The NPV for the Country B RU is €-120.1 M. The NVP of the project for the IM of Country A is €-590.8 M. The NPV for Country A RU is €-123.6 M.

9.1.1.1.2 Country D-Country F

Country D: first adopter - Country F 5 years later

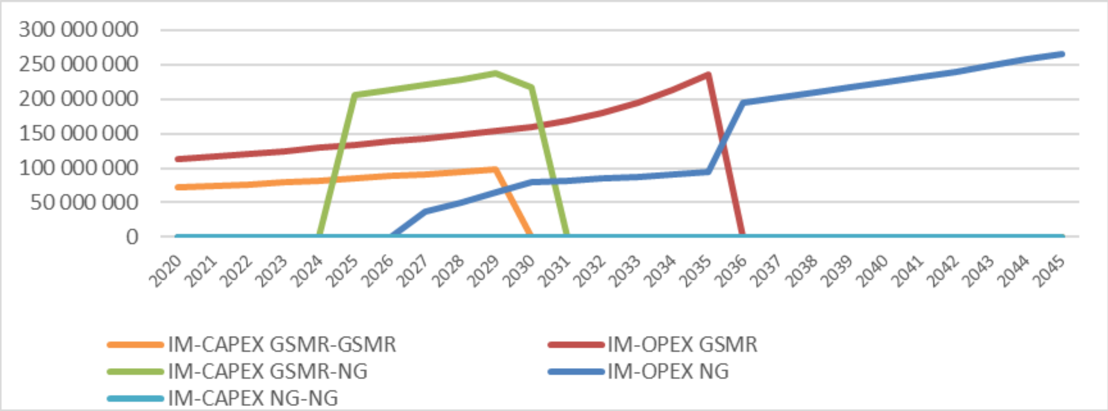

Figure 39. Scenario 2 –Country D – IM Cash flow at current price

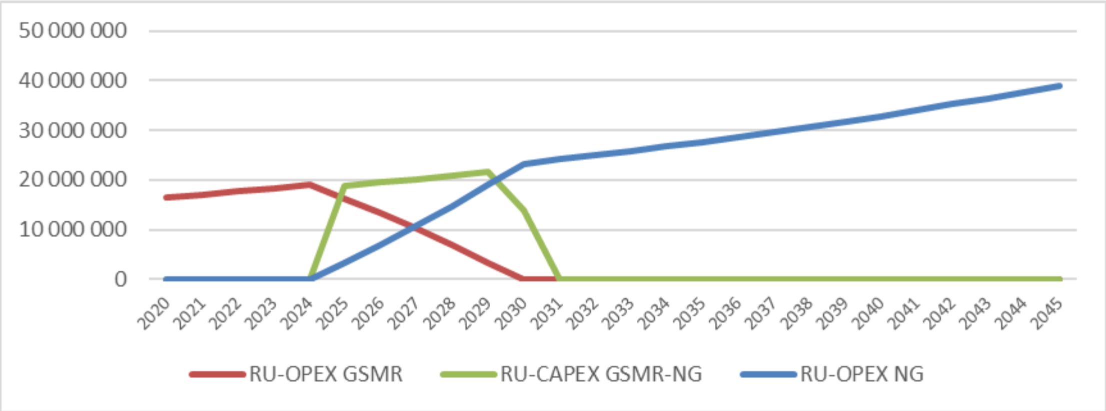

Figure 40. Scenario 2 – Country D – RU Cash flow at current price

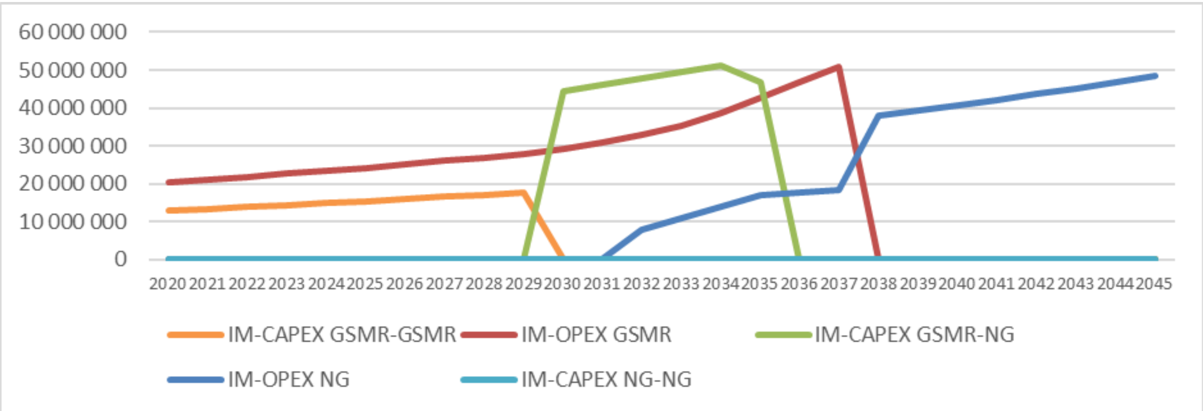

Figure 41. Scenario 2 – Country F IM Cash flow at current price

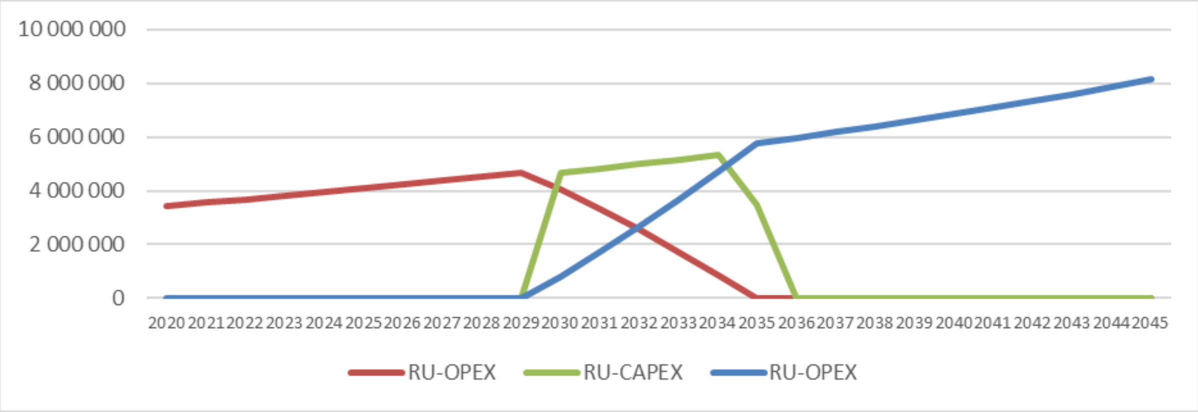

Figure 42. Scenario 2 – Country F – RU Cash flow at current price

Based on our costs ratios, the Net Present Value (NPV) of the project for the IM of Country D is €-5 659.9 M. The NPV for the Country D RU is €-618.1 M. The NVP of the project for the IM of Country F is €-1 102.3 M. The NPV for the Country F RU is €-130.5 M.

9.1.1.2 Scenario 3 – single network

9.1.1.2.1 Country B-Country A

Country A: first adopter – Country B: 5 years later

The time line of the scenario is:

- From 2020 to 2024: only GSM-R Operation in both countries;
- From 2025 to 2030: GSM-R operation and investment in new technology for the IM and the RU of Country A for all its fleet, and for the RU of Country B for its international cross-border trains; only GSM-R Operation in Country B;
- **From 2030 to 2032: NG Operation set-up in Country A;**
- **From 2032 to 2035: IM in Country A operate single network on NG technology;**
- **From 2030 to 2035: GSM-R operation and investment in new technology for the IM and the RU of Country B for its remaining fleet;**
- From 2035 to 2037: NG Operation set-up in Country B IM network;
- From 2037 to the end of time: only NG Operations in both countries.

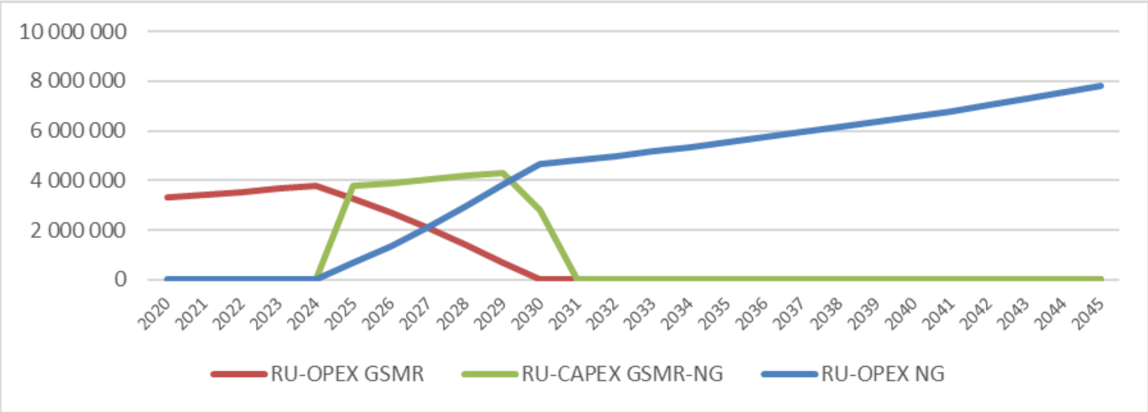

Figure 43. Scenario 3 –Country A– IM Cash flow at current price

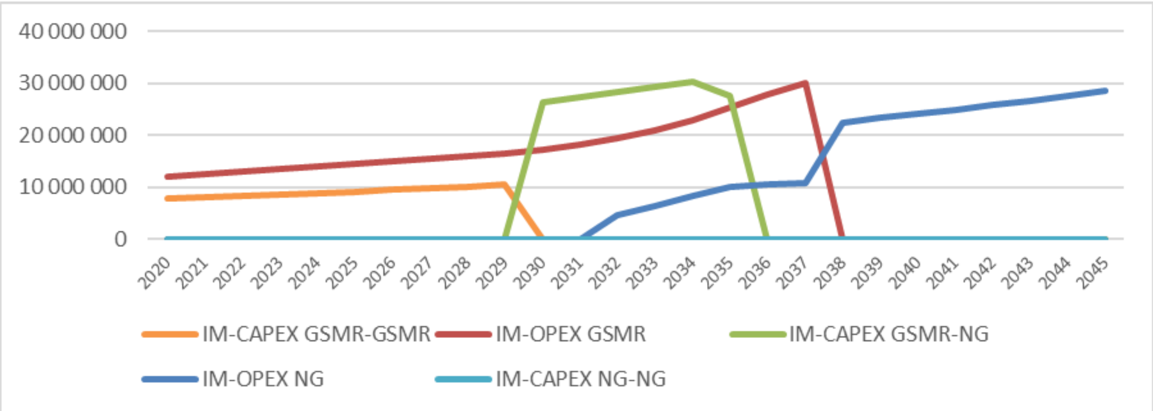

Figure 44. Scenario 3 – Country A RU Cash flow at current price

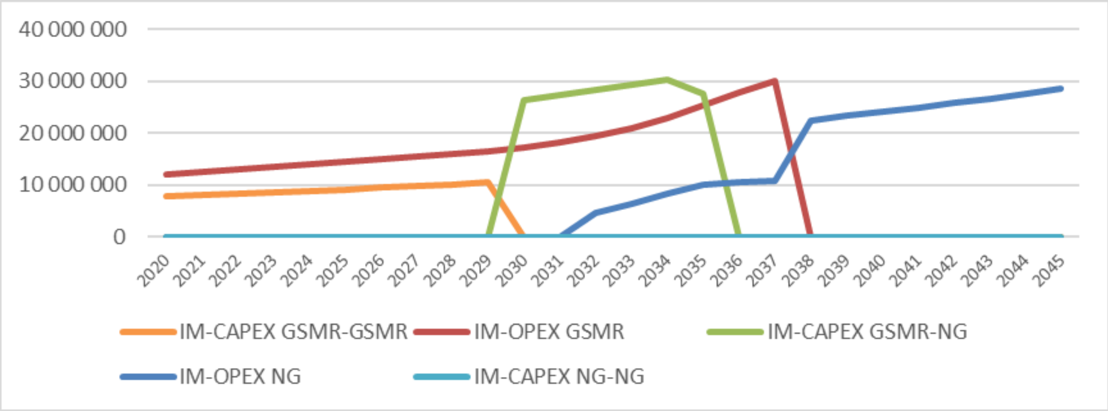

Figure 45. Scenario 3 – Country B – IM Cash flow at current price

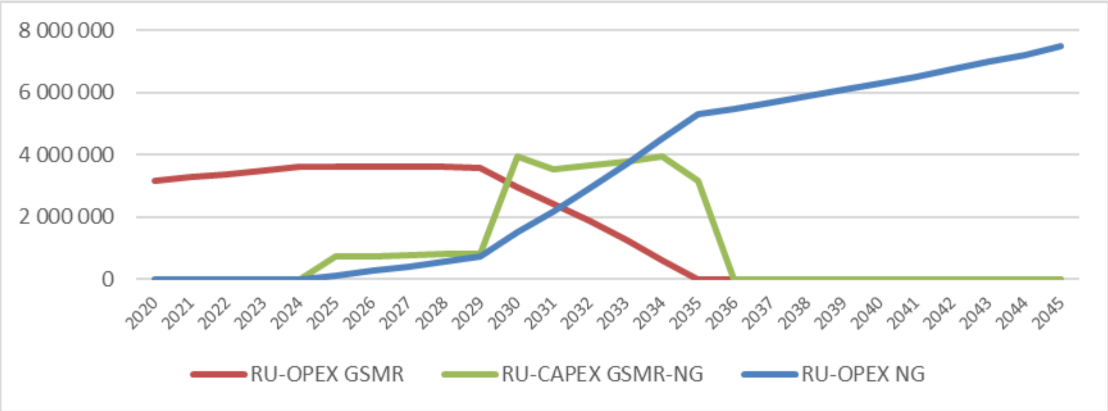

Figure 46. Scenario 3 – Country B – RU Cash flow at current price

Based on our costs ratios, the Net Present Value (NPV) of the project for the IM of Country B is €-653.2 M. The NPV for the Country B RU is €-120.1 M. The NVP of the project for the IM of Country A is €-561.6 M. The NPV for Country A RU is €-123.6 M.

9.1.1.2.2 Country D- Country F

Country D: first adopter – Country F 5 years later

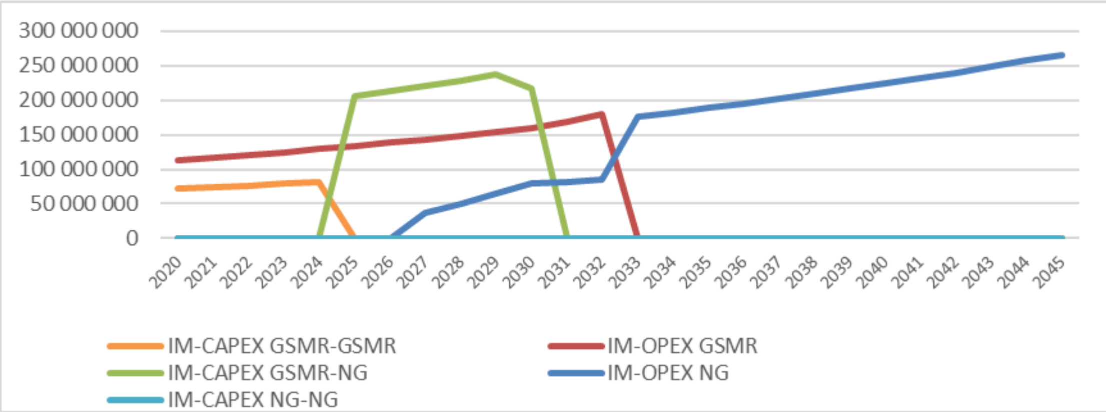

Figure 47. Scenario 3 –Country D IM Cash flow at current price

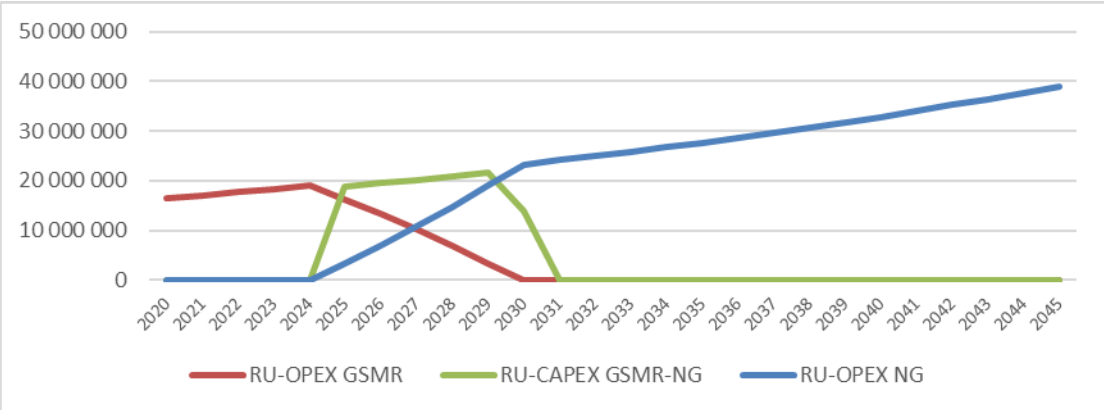

Figure 48. Scenario 3 – Country D – RU Cash flow at current price

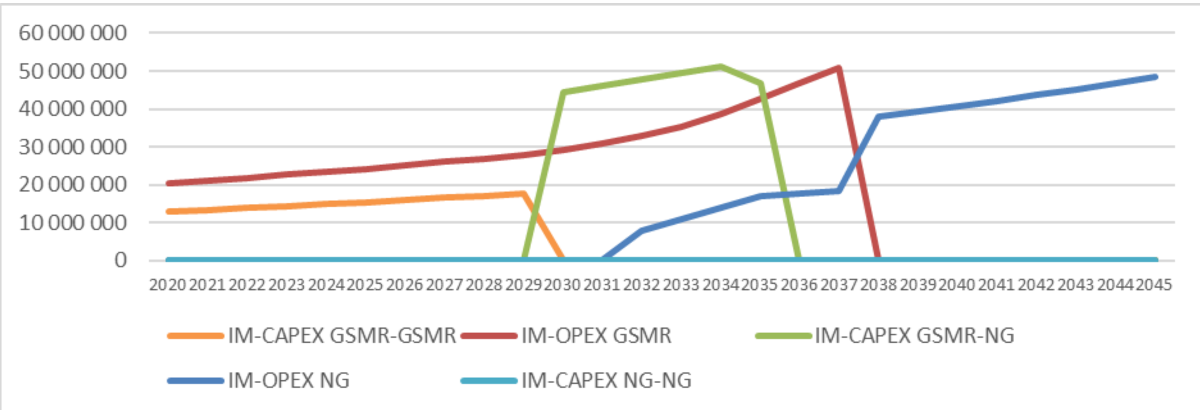

Figure 49. Scenario 3 –Country F IM Cash flow at current price

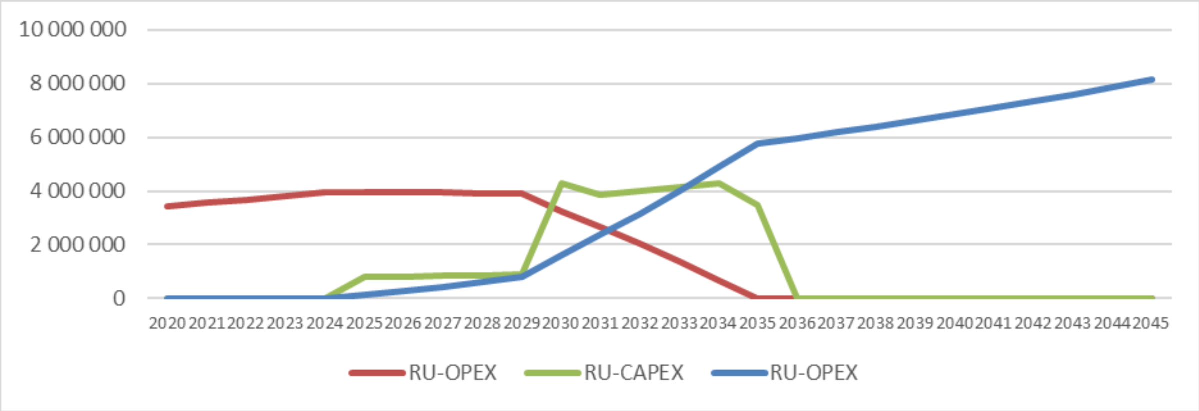

Figure 50. Scenario 3 – Country F – RU Cash flow at current price

Based on our costs ratios, the Net Present Value (NPV) of the project for the IM of Country D is €-5 380.5 M. The NPV for the Country D RU is €-618.1 M. The NVP of the project for the IM of Country F is €-1 102.3 M. The NPV for the Country F RU is €-130.5 M.

9.2 ANNEX B – Questionnaire

The questionnaire was available online (through Voice tool) and in Word version. It was sent with an internet link and also in word version as attached document. An introduction letter from ERA is available and was also sent.

The questionnaire was send the 18 of January 2016 to different group representatives (12 persons). Three representatives of the CER group (The Community of European Railway and Infrastructure Companies, 6 representatives of EIM group (European Rail Infrastructure Managers), one representative of ERFA (European Rail Freight Association), one representative of EPPTOLA (The European Passenger Train and Traction Operating Lessors' Association). These representative were requested to distributed the questionnaire.

9.2.1 Results of questionnaire

The following companies sent answers.

COMPANY	COUNTRY	IM/RU	SURVEY
Banedanmark	Denmark	IM/RU	Y
Infrabel	Belgium	IM	Y
Trafikverket IT	Sweden	IM	Y
SNCF Réseau	France	IM	Y
CFR	Romania	IM	Y
NS Netherlands Railways	The Netherlands	RU	Y
RFI	Italy	IM	Y
LR Lithuanian Railways	Lithuania	IM/RU	Y
ATOC	Great Britain	RU	Y
Network Rail	Great Britain	IM	Y
SBB	Switzerland	IM/RU	Y
Prorail	The Netherlands	IM	Y
DB Netz AG	Germany	IM	N

9.2.2 Introduction letter

"The European Railway Agency (ERA) is currently undertaking a study dealing with the evolution of railway radiocommunications systems.

You or your organization, EPPTOLA, may have already contributed to these studies in the past. In this next step, ERA aims to analyse in greater depth the conditions of migration from GSM-R to other solutions.

As part of this process, Systra, on behalf of ERA, is conducting a study to provide guidance on the optimal timeline of migration from GSM-R to its successor(s) and the conditions to make it successful across Europe.

In order to collect relevant information and data from different sources, we would appreciate direct participation of Railway Undertakings, Infrastructure managers and fleet owners by means of a questionnaire.

For this purpose, we kindly request you to ask your individual members for their help, to provide answers in the following questionnaire:

http://na2.se.voxco.com/se/?st=Te7pBHJH0jZHI6WczXQYJC%2f2M8aIKL%2fgsT2l4a3JzSU%3d

It is possible to complete this online questionnaire in stages. Of course the attached questionnaire in word may be used instead, to be send by email to me (cmaton@systra.com).

*We would like to receive the answers by **Mid of February 2016**.*

The information provided will be used in the study and will be framed in the reports that will be published by ERA in Q2 2016. We are aware of the confidential character of some information asked in the questionnaire, so individual or detailed figures on e.g. costs will not be published and kept for internal analysis.

You will find attached an introduction letter from ERA.

Thank you for your help and your time.

Best regards. "

9.2.3 List of questions

ERA 2015 04-a, b and C Framework Contract

ERA 2015 04 1 RS: "Study on migration of Railway radio communication system from GSM-R to other solutions"

Questionnaire Study

ERA revision marks and comments included

Summary	
Title	Study on migration of Railway radio communication system from GSM-R to other solutions
European Railway Agency Reference	ERA 2015 04 1 RS
Subject	Questionnaire Study
Authors	
SYSTRA Reference	FR01T15H49_ERA_RS1_DLV_008
Versioning	Rev1.2
Confidentiality	Intermediate

Approval

Version	Name	Date
1.2	**Author :** B Vanheeghe / C Maton	11/01/16
	Checked : L Pushparatnam	13/01/16
	Approved : Chiel Spaans	15/01/16

1. PURPOSE AND SCOPE

1.1. PURPOSE OF THIS DOCUMENT

A questionnaire study was carried out with the main purpose to collect information related to the migration of railway radio communication systems in different European countries.

1.2. SCOPE

The European Railway Agency (ERA) is currently leading a Program dealing with the evolution of the radio communication system for railways. You or your company may already contributed to these studies. In the next step, ERA aims at analysing more in depth the conditions of migration from GSM R to other solutions. As part of this next step, Systra, on behalf of ERA, is carrying out a study for collecting information and providing guidance on the optimal timeline of the migration from GSM-R to its successor(s) and the conditions to make it successful across Europe. In order to collect relevant information and data from different sources, we request your participation in the following questionnaire. The information provided result will be used in the study and will be framed in the reports that will be published.

2. GENERIC INFORMATION

ID	RU	IM	QUESTIONS	ANSWERS
1.01			**What is your name?** *(e.g. John Doe)*	
1.02			**What is your company's name?**	
1.03	**X**	**X**	**What is your position or job title?**	
1.03b	**X**	**X**	**Please, indicate your email address**	
1.04			**Is your company is Infrastructure Manager (IM)**	

ID	RU	IM	QUESTIONS	ANSWERS
			or Railway Undertaking (RU)	
1.05		X	**Describe the railway network in terms of** • Total infrastructure size in track km: • How many km's covered by GSM-R today and in 5 years? • How many km ETCS L2/3 today and in 5 years? • How many radio sites? • How many core network sites?	
1.06	X		**Fleet information** • Total number of Traction Units (locomotives, trainsets): • Amount of TU's for national use only: • Amount of TU's used for international traffic and in which countries (e.g. 100 TU's, of which 50 in F, DE, BE, NL, 10 in F and CH, 15 in F and I).	
1.07	X		**Onboard equipment for the situation today and in e.g. 10 years** • Total number of cabradios: • Average number of radio modules per cabradio and per traction unit : • Total number of EDOR: • Average number of radio modules per EDOR and per traction unit:	

ID	RU	IM	QUESTIONS	ANSWERS
1.08		**X**	**Non on-board GSM-R equipment :** • How many trackside radio equipment (modems) are there? • How many handheld terminals for operational staff shunting, station staff, trackside staff, others) are there?	
1.08a	**X**		**Non on-board GSM-R equipment :** How many handheld terminals for operational staff (train staff, shunting, station staff, others) are there?	
1.09	**X**	**X**	**Non GSM-R equipment:** How many non GSM-R radio equipment handheld terminals for staff (smartphones, short range radio, tetra, etc) are used for traindrivers and other operational staff are there in the company?	
1.10		**X**	**Controller positions** • How many controller systems? • How many controller desks?	
1.11	**X**		**How many of your trains travel across European cross borders?**	

3. THE PAST SITUATION

ID	RU	IM	QUESTIONS	ANSWERS
2.01	X	X	**Have you already managed a Railway radio communication system migration (e.g. from analogue to GSM-R)?** • If yes, can you describe the start and end dates? • If yes, which one (e.g. from Analog Radio to GSM-R)?	
2.02		X	**How long did it take to prepare the migration?** *(in month)*	
2.03	X	X	**How long did you have parallel operation of old and new radio communication systems?** *(in month)* • Nationwide scale? • Railway line scale?	
2.04		X	**Did you prepare a migration plan/strategy?** **Could you please share it with us for informative purpose?**	
2.05	X	X	**How would you rank the complexity of this migration in your company?** *(from 1-Very low, 2-Normal, to 3-Very complex)?*	
2.06		X	**Have you split this migration project into multiple projects of lower complexity (i.e. area per area or**	

ID	RU	IM	QUESTIONS	ANSWERS
			line by line…).	
2.07	X	X	**What was the reason to perform this migration?** - Obsolescence, - OPEX++, - Equipment performance, - New services, - EU regulation, - Spectrum, - Others internal or external reasons	
2.08	X	X	**Provide lessons learnt from this migration if any**	

4. THE CURRENT SITUATION

ID	RU	IM	QUESTIONS	ANSWERS
3.01		X	**Please provide information on the following :** • Expected operational lifetime of your GSM-R network • - Planned big upgrades/exchanges.e.g. new NSS and/or new BSS, and when start/finish	
3.02	X		**Please provide information on the following :** • Expected lifetime of your onboard equipment:	
3.03		X	**Question on contracting aspects:** • What is the current end date of contracted support for your GSM-R network? • Is this directly related to the economic/technical life time of your network? (Yes/No) • Do you see any risk for extension or re-contracting? If yes which one.	
3.04	X		**Question on contracting aspects:** • What are the current end dates of contracted support your onboard radio equipment? • Is this directly related to the economic/technical life time? • Do you see any risk for extension or re-contracting? If yes which one.	

<table>
<tr><th>ID</th><th>RU</th><th>IM</th><th>QUESTIONS</th><th>ANSWERS</th></tr>
<tr><td>3.05</td><td></td><td>X</td><td>
Overall costs of GSM-R per km of track

• Choose a Range for CAPEX CApital EXpenditure GSM-R in € per km of track

<table>
<tr><th>Range €/km</th><th>Min</th><th>Max</th></tr>
<tr><td>1</td><td></td><td><20 000 €</td></tr>
<tr><td>2</td><td>20 000 €</td><td>30 000 €</td></tr>
<tr><td>3</td><td>30 000 €</td><td>45 000 €</td></tr>
<tr><td>4</td><td>45 000 €</td><td>60 000 €</td></tr>
<tr><td>5</td><td>60 000 €</td><td>75 000 €</td></tr>
<tr><td>6</td><td>>75 000 €</td><td></td></tr>
</table>

Indication on what what is included in the figures above:

• Radio Site (equipment, installation and test) : Y/N.
• Core network (equipment, installation and test) : Y/N.
• Transmission : Y/N
• Decommissioning :Y/N
</td><td></td></tr>
</table>

<table>
<tr><th>ID</th><th>RU</th><th>IM</th><th>QUESTIONS</th><th>ANSWERS</th></tr>
<tr><td></td><td></td><td></td><td><u>OPEX Operation and Maintenance Expenditure</u>

• Can you indicate a cost (in €) per km of track and per year or possibly a percentage of CAPEX per year?

• Is it Operation and maintenance costs only or is it including investment /installation /depreciation?</td><td></td></tr>
<tr><td>3.06</td><td>X</td><td></td><td>Overall costs of GSM-R per Traction Unit

• Choose a range for <u>CAPEX CApital EXpenditure</u> GSM-R per Traction Unit

<table>
<tr><th>Cost range</th><th>Min</th><th>Max</th></tr>
<tr><td>1</td><td></td><td><10 000 €</td></tr>
<tr><td>2</td><td>13 000 €</td><td>20 000 €</td></tr>
<tr><td>3</td><td>20 000 €</td><td>27 000 €</td></tr>
<tr><td>4</td><td>27 000 €</td><td>34 000 €</td></tr>
<tr><td>5</td><td>>34 000 €</td><td></td></tr>
</table>

Indication on what it is included for cab radio :

• Equipment: (Y/N)</td><td></td></tr>
</table>

ID	RU	IM	QUESTIONS	ANSWERS
			• Number of equipment (transceiver) per unit: • Installation and test : (Y/N) • Others such as time of withdrawn of service : (Y/ N -details) **<u>OPEX Operation and Maintenance Expenditure</u>** • Can you indicate a cost (in €) per Traction Unit and per year? • Is it Operation and Maintenance costs only or is it including investment /installation /depreciation?	
3.07		**X**	**Others** • Please indicate with which other countries roaming agreements exist today and indicate the situation in 5-10 years. • Please indicate the number of km of track covered by public GSM instead of GSM-R, the intended duration of this solution and the operational costs per km of track of this solution.	
3.08	**X**		**Others** • Is there a dependency between installation and maintenance of cabradio and edor, or can their life cycle be considered as independent?	

5. THE FUTURE:

ID	RU	IM	QUESTIONS	ANSWERS
4.01	X	X	**Do you have already plans to implement a successor to GSM-R? Yes or No** If no, on a scale of priority from 1 (lowest) to 5 (highest): Do you think your organization will start to replace GSM-R within the next 10 years?	
4.02		X	**What would be the drivers to migrate? Please classified the following *(range 0 to 5 -0 "not a drivers" to 5 "high drivers importance"):*** • Equipment reliability decrease • Increase of maintenance cost • Cost reduction • Introduction of new services, new applications • Product end of life, end of support for GSM-R assets • EU regulation • Relationship with other plans, e.g. Introducing ETCS, new lines, etc. • New technology standard and equipment availability • Other reasons (such as national requirement or network infrastructure sharing ...)	

ID	RU	IM	QUESTIONS	ANSWERS
4.03	X		**What would be the drivers to migrate?** Please classified the following from the highest importance to the lowest: • On board equipment reliability? • Increase of maintenance cost, • Introduction of new services • Cost reduction • Product end of life, end of support of GSM-R assets • Relationship with other plans, e.g. Introducing ETCS, rolling stock renewal or upgrade • EU regulation • Other reasons	
4.04		X	**Related to ownership and control:** • Do you envisage owning this new network? • Would you consider sharing this new network with other parties (e.g. emergency services) or using? • Would you consider using radio services provided by a third party private or public operator? If yes in what proportion? • What could be the driver(s) for sharing or third party services?	

ID	RU	IM	QUESTIONS	ANSWERS
4.05	**X**	**X**	Do you plan or already use applications which cannot be supported by GSM-R and require broadband radio networks And which are these?	
4.06		**X**	Do you plan to introduce new (public standard) technologies like 4G for specific non-interoperability related applications for these applications? If yes and you indicate it.	
4.07	**X**	**X**	**Do know how much will it cost to maintain this future radio system?** **Do you expect cost reduction compared to GSM-R technology?**	
4.08		**X**	• Is there any coordination with the Ministry for introduction of new radio technology? • Does this coordination also include the potential need for additional spectrum?	
4.09	**X**	**X**	**If you are planning a replacement for GSM-R what would your preferred solution,** • Install dual-mode (or multi-mode) radios in all trains to allow them to travel over GSM-R and new-technology covered infrastructure. • Deploy new network infrastructure in parallel to GSM-R allowing single mode trains fitted with GSM-R or with a new technology to travel over the same line.	

ID	RU	IM	QUESTIONS	ANSWERS
			• A mixture of both scenarios, e.g. line or area dependent; please indicate what lines or areas could be candidate for what scenario.	
4.10	**X**	**X**	**What are your reasons for migrating to a new network?**	
4.11	**X**	**X**	**Would you be willing to be contacted to discuss further details?** ***(Y or N)***	