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Executive Summary

This is the Executive Summary of the draft Final Report for the study “Evolution of GSM-R”, which was conducted by IDATE and WIK-Consult GmbH for the European Railway Agency (ERA).

Operational rail communications play a key role in ensuring continuous, safe and interoperable railway transportation. This study (and further ERA work based on it) is inspired by the need to ensure that this continues to be the case as technology evolves.

The need for a successor to GSM-R

Some studies have assessed the operational communication needs of the European rail sector in recent years. All have found that the current operational system, GSM-R, is a good fit for current needs, and that functional needs are evolving only gradually.¹ Bandwidth requirements for rail operations and signalling systems are growing only very slowly today.² GSM-R technology can evolve to accommodate mid-term needs.

A successor to GSM-R is required primarily due to the expected obsolescence of GSM-R. GSM-R builds on existing GSM mobile standards, using the frequency bands 876-880 MHz (uplink) and 921-925 MHz (downlink) that are harmonised within CEPT for the operational communication of railway companies (GSM-R) in accordance with current mobile technology. GSM is a second generation mobile technology, but the industry is already moving to LTE³ (arguably a fourth generation [4G] technology) and is expected to evolve to fifth generation (5G) technology after 2020. The ability of the rail industry to continue to support GSM-R beyond roughly 2030 is doubtful. Given the long procurement cycles in the rail sector, planning for a successor needs to begin now.

Stakeholders also seek cost reductions, especially in operational expense (OPEX), which could be also a driver in some cases to look for other communication solutions.

Impact assessment as a tool for assessing Options going forward

Our approach throughout is inspired by European Impact Assessment methodology. Among the European institutions, Impact Assessment provides a useful means of analysing costs and benefits of prospective policy interventions. Impact Assessment, as defined by the European Commission,⁴ is conducted by (1) clearly identifying the Problem to be addressed; (2) identifying a series of General and Specific Objectives that should be achieved in doing so; (3) identifying several plausible Options constituting policy interventions that might

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² This view is not universal. Some rail stakeholders argue that bandwidth limitations of GSM-R are a cause, not a result, of the lack of new applications. Others argue that the emerging developments will have greater impact than has been assumed. In this report, however, we have taken the slow evolution of functional requirements, as found in the previous studies, as a point of departure.

³ LTE corresponds to the radio access part (or eUTRAN) and EPC, Evolved Packet Core, the core network of the 3GPP mobile broadband standard.

achieve the desired Objectives; and (4) assessing the likely Impacts, both positive and negative, of each of the Options (see section 3.3 for details on the options).

Properly applied, Impact Assessment serves not only to assess impacts of decisions already reached, but also to assist in the proper formulation of policies in the first place.

**A multidimensional problem**

Arriving at a solution is complex. In order to make progress, it is necessary to decompose the problem into multiple Problems and multiple decisions to be taken, each of which must reflect (1) evolving functional requirements on the part of the users of the relevant service; and (2) evolving technology:

- A set of European cross-sectoral decisions that must be taken as to (1) whether to handle PPDR, rail, intelligent highway transport, and energy together, (2) the degree to which a solution could be common among these sectors (and possibly common with commercial mobile networks), and (3) how such a cross-sectoral approach might work if it were desired;
- A set of European rail-specific decisions; and
- A set of Member State decisions.

**A cross-sectoral European view**

The Problem for European policymakers (and not just for the rail sector) is to identify technical, spectrum management, and policy measures to be undertaken to enable continued provision of mission critical services, however defined, to the European public protection and disaster relief (PPDR), energy and transport sectors (including rail) as technology and markets evolve going forward.

The decision-makers at this level are the European institutions. The decision-makers span multiple sectors – these are not just rail decisions.

A recent study on behalf of the European Commission\(^5\) claimed that the cost of a cross-sectoral network based on commercial mobile services for *Public Protection and Disaster Relief (PPDR)* and rail might well be somewhat less than that of the private networks used

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today, even after allowing for the costs of hardening the network to provide reliability and expanding its coverage. There is, however, considerable uncertainty about this claim. Their analysis was primarily relative to existing PPDR networks, and only tangentially relevant to operational rail network requirements; moreover, their analysis rests on the assumption that a various reliability, coverage, management and practical requirements can be met that, in practice, quite possibly cannot be met.

**A Member State view**

Many decisions will ultimately be taken at different times in different Member States (bearing in mind that a number of European countries that are not Member States of the EU or EEA apply the CCS TSI).

The decision-makers at this level are Member State governments. The decision-makers span multiple sectors – these are not necessarily just rail decisions. The ministry of transport, however defined, will typically play a role, as will the rail Infrastructure Manager (IM). The Member State spectrum management authority (SMA) will also play a decisive role. These are complex decisions involving many stakeholders.

Coverage requirements can differ greatly among different wireless applications. For rail operational networks, they differ as well as a function of speed and traffic of the lines.

There could be enormous value in re-use of the existing trackside GSM-R locations by a future replacement system. This does not necessarily imply that the same ownership and control model be carried forward. As long as future successors to GSM-R were to operate in frequency bands similar to or slightly lower than the frequency band of GSM-R, the same route kilometres could be covered using the same sites.

Multi-technology support has potential value. Current geosynchronous satellites are subject to substantial latency, but could nonetheless be better than lack of coverage in remote areas. In the future (post 2030), use of MEO satellites to cover remote areas might bring considerable benefits.

**A view from the perspective of the European rail sector**

Decisions at this level are core to the current study. The decision-makers are European rail authorities: the European Commission (DG MOVE), with support from the European Rail Agency (ERA), and the national authorities at each Member State. Many contributors from the sector influence these decisions with their expertise, including, the Union Internationale des Chemins de Fer (UIC), a worldwide organisation, and other representative groups, such as CER, EIM, ERFA, and EPTTOLA.

Under the Option that we deem to be preferred, European specifications (in the CCS TSI,) would be revised to permit or require, in suitable configurations bearer independent applications in support of a small, well-chosen range of technologies, potentially including current and future LTE; possibly Wi-Fi or successor technologies; and possibly satellite networks (for lines where conditions are suitable). When specifications are sufficiently mature, 5G will be a strong candidate for inclusion.

We assume that it is mandatory to solve this transition issue for mission critical train functionality, primarily for train operation. The possible ability however of the same solution to meet additional rail business requirements, or perhaps even passenger entertainment needs, is not a mandatory requirement; however, meeting these additional needs could be factored in as a possible price/performance optimisation.

The detailed impacts will depend on myriad decisions; however, it is fairly clear that a failure on the part of European rail authorities to expand specifications so as to accommodate a practical evolution of the GSM-R system would result in a proliferation of inconsistent and possibly non-interoperable solutions at Member State level, thus reducing interoperability, ability to roam, and economies of scale at European level.

Conversely, even if Member State decisions are far in the future, a coordinated standards-based approach at European level can generate substantial benefits.
Recommendations

Based on our analysis, our recommendations to the ERA and to the European rail sector are as follows.

Recommendation 1. The relevant specifications need a serious overhaul in order to ensure that the rail operational functionality that operates above GSM-R is properly de-coupled from its underlying transport and is future proof. .........................................................62

Recommendation 2. ERA and the European rail sector should study the degree to which necessary rail voice communications functionality could be provided by a “lowest common denominator” network (such as a purely IP-based radio network) that contains no special support at all for rail-specific voice communications functionality such as Rail Emergency Call and Group Call. (Application and end-to-end performance and reliability requirements might still be relevant.) .........................................................63

Recommendation 3. A successor to GSM-R could support more permissible configurations than are possible today, but care must be taken to ensure that the number of supported configurations is no greater than is truly necessary, sustainable, and regularly reviewed.64

Recommendation 4. As new bearers are introduced, continued interoperability with GSM-R as deployed must be maintained. .................................................................64

Recommendation 5. ERA and the European rail sector should consider carefully European certification requirements for operational rail communications. A more granular and flexible certification of operational rail communications equipment would appear to be in order. There should be as few national specificities in the systems as possible (ideally none at all) with the goals of achieving a single certificate in Europe and thereby optimising costs. ...........................................................................64

Recommendation 6. The rail sector would be well advised to ensure that rail communications experts participate in 3GPP SA6 standards activities in order to ensure that these potentially crucial standards fully and appropriately address rail communications needs. ...............65

Recommendation 7. Planning should begin incorporating 3GPP LTE-based standardised solutions into a successor to GSM-R. This should be done, as much as possible, in a manner that is independent of specific LTE releases. .........................................................66

Recommendation 8. ERA should consider initiating a study on the use of 3GPP LTE in the existing 4 MHz GSM-R uplink and downlink bands, and possible coexistence with GSM-R in the band. The possible role and relevance (if any) of the E-GSM-R extension bands (873-876 MHz (Uplink) and 918-921 MHz (Downlink)) should also be reviewed at that time. 66

Recommendation 9. ERA and the European rail sector should monitor the evolution of radio technologies, such as 5G mobile services, and should consider incorporating support into a successor to GSM-R once the standards are sufficiently mature. ........................................67

Recommendation 10. The ERA, the European Space Agency (ESA), and the European rail sector should continue to study the degree to which the use of satellite is feasible and practical for operational rail communications. Current GEO (and possibly LEO) satellites might possibly be acceptable for lines in remote areas with suitable traffic characteristics. Future MEO satellites are likely to have still greater applicability. ........................................67

Recommendation 11. ERA and the European rail sector should consider whether the inclusion of Wi-Fi (and/or some other low bandwidth optimised radio bearer) into standards for a successor to GSM-R is warranted. The prime motivations to do so would be to increase capacity in train stations and shunting yards, and also to reduce the cost of communication infrastructures. Coexistence with consumer Wi-Fi would need to be assessed, as well as the planned migration schedule to successors to today’s GSM-R. .......................68
Findings

Finding 1. The need for a successor to GSM-R is motivated by anticipated eventual obsolescence of GSM, capacity limitations in GSM-R, and a desire to reduce costs. Previous studies have found that functional requirements and bandwidth demand are evolving only slowly; however, not all stakeholders agree. ................................................................. 14

Finding 2. Multiple studies have assessed possible ways forward for operational rail communications (and for other mission critical networks). .................................................................................. 15

Finding 3. It is exceedingly difficult to express clear, non-overlapping Options with which to address this Problem. .................................................................................................................. 20

Finding 4. We find it useful to distinguish among three interrelated sets of decisions: (1) A cross-sectoral decision at European level to as how to handle PPDR, energy, intelligent highway transport, and rail communications overall; (2) a rail-specific decision; and (3) Member State (national) decisions. ................................................................. 21

Finding 5. Public Protection and Disaster Relief (PPDR) forces hope to upgrade their communications capabilities using broadband technology. ................................................................. 22

Finding 6. Needs for the energy sector are driven primarily by smart metering and smart grid applications; these have, however, different network implications. ................................................................. 22

Finding 7. Railway functional requirements for train operational communications have been found in previous studies to be evolving only slowly; however, needs may increase in the medium-far future. ........................................................................................................... 23

Finding 8. There are commonalities between rail and other mission-critical applications for voice and data radio services, but also important differences such as speed. .......................................... 23

Finding 9. Technology is evolving in ways that provide many new opportunities going forward. ............ 24

Finding 10. We are analysing European cross-sectoral Options and Sub-Options from least active intervention to most active intervention. A range of solutions are possible, with different implications in terms of cost and ease of implementation. .................................................. 28

Finding 11. For reasons outlined in SCF (2014), the cost of a cross-sectoral network based on MNO services for PPDR and rail might well be somewhat less than that of the private networks used today, even after allowing for the costs of hardening the network to provide reliability and expanding its coverage. At the same time, it is necessary to bear in mind that their analysis was primarily relative to existing PPDR networks, and only tangentially relevant to operational rail network requirements; moreover, their analysis rests on the assumption that a various reliability, coverage, management and practical requirements can be met that, in practice, quite possibly cannot be met. Further study is needed .... 35

Finding 12. Taking migration costs into account (which is not fully possible until far more is known about the migration) an Enhanced Business as Usual approach (with private rail networks using modernised technology) might well be comparable in efficiency to the various network sharing sub-Options that we have considered. .................................................. 35

Finding 13. If the GSM-R bands can eventually be released, the opportunity cost for the European Union as a whole of up to roughly €2.5 billion could be freed. This number rests however on many assumptions, and must be interpreted with caution. .................................................. 36

Finding 14. Coverage requirements can differ greatly among different wireless applications. For rail operational networks, they differ as well as a function of speed and traffic of the lines. Stations, depots and shunting yards tend to require coverage at greater bandwidth than is needed elsewhere. ........................................................................................................... 39

Finding 15. There could be enormous value in re-use of the existing trackside GSM-R locations by a future replacement system. This does not necessarily imply that the same ownership and control model be carried forward. As long as a future successor to GSM-R were to operate in frequency bands similar to or slightly lower than the frequency band of GSM-R, and assuming no radical growth in bandwidth demands, the same route kilometres could be covered using the same sites. .................................................................................. 40

Finding 16. Multi-technology support has potential value. Current geosynchronous satellites are subject to substantial latency, but could nonetheless be better than lack of coverage in remote areas, and are in use for operational rail communications in other parts of the world. In the future (post 2030), use of MEO satellites to cover remote areas might bring considerable additional benefits. .................................................................................. 42

Finding 17. At Member State level, Options differ largely on the degree to which private networks, unmodified commercial networks, or commercial networks with modifications for mission critical services are use. Many hybrids are possible. .................................................. 45
Finding 18. At this level of analysis, it is necessary to distinguish between voice requirements and (ETCS) data requirements. ........................................................................................................58

Finding 19. Key elements of the Preferred Option for European rail authorities would appear to be to add specific capabilities to the relevant specifications to enable bearer independent applications in support of a small, carefully chosen range of bearer technologies, potentially including current and future LTE; possibly Wi-Fi or successor technologies; and possibly satellite networks (for lines where conditions are suitable). When specifications are sufficiently mature, 5G will be a strong candidate for inclusion. ........ 61

Finding 20. The use of GPRS or EDGE to carry ETCS traffic is a positive development that is already ongoing .........................................................................................................................66

Finding 21. Even if Member State decisions are far in the future, a coordinated standards-based approach at European level can generate substantial benefits................................................. 70
1. Introduction

This is the draft Final Report for the study “Evolution of GSM-R”, study ERA/2014/04/ERTMS/OP, which is being conducted by IDATE and WIK-Consult GmbH for the European Railway Agency (ERA).

The document is published in the interest of soliciting feedback from interested parties, and to support future planning on the part of the ERA in particular and the European rail sector in general.

Operational rail communications play a key role in ensuring continuous, safe and interoperable railway transportation. This study (and further ERA work based on it) is inspired by the need to ensure that this continues to be the case as technology evolves.

1.1. The need for a successor to GSM-R

The need for a successor to GSM-R is driven primarily by the eventual obsolescence of the underlying GSM technology on which GSM-R is based. GSM-R can be viewed as being in the middle of its life-cycle, with a remaining lifetime of at least 15 years from now. Since its introduction, GSM-R technology has been continuously evolving. There are various opportunities to Railway Undertakings (RUs) and Infrastructure Managers (IMs) to cope with their mid-term needs. Increase of capacity for voice and for data applications, packet switching, support of IP data communication, increased protection against interference, and increased availability by means of geo-redundant network core solutions could potentially address current and near-future requirements. Further enhancements to provide additional functionality and improved quality of service are under investigation.

The operational communication needs of the European rail sector have been assessed multiple times in recent years (see Section 1.2). These studies found that the current operational system, GSM-R, is a good fit for current needs, and that functional needs are evolving only gradually. Bandwidth requirements for rail operations are growing only very slowly today.7

In the course of this study, a number of stakeholders challenged these previous findings. Some argued that bandwidth limitations of GSM-R are a cause, not a result, of the lack of new applications. One Infrastructure Manager (IM) argued that lack of bandwidth in GSM-R is a serious and immediate problem.8 Some argue that ongoing work conducted in the UIC project on Future Railway Mobile Communication Systems (FRMCS)9 is likely to result in new functional requirements. Automated Train Operation (ATO) was mentioned,10 as well as video for maintenance11 and for level crossing supervision.

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6 The terms of reference can be found at http://www.era.europa.eu/The-Agency/Procurement/Documents/TOR%20ERA%202014%2004%20ERTMS%20OP.pdf
8 There are huge differences among the different countries as to the volume of voice and data applications. In some cases, the capacity limits of GSM-R are apparently being reached.
10 Driver Advisory Systems (DAS) and other applications as indicated in Shift2rail were also mentioned.
11 For instance, video from stationary locations or drones could be used to monitor level crossing, to observe bridges and viaducts for cracks and structural problems, and to protect against theft.
Consistent with the Terms of Reference specified by ERA, we have taken the slow evolution of functional requirements, as found in the previous studies, as a point of departure. Under this assumption, a successor to GSM-R is required primarily due to the expected obsolescence of GSM-R. GSM-R builds on existing GSM mobile standards, using the frequency bands 876-880 MHz (uplink) and 921-925 MHz (downlink) that are harmonised within CEPT for the operational communication of railway companies (GSM-R) in accordance with current mobile technology, together with the possibility to use the 873-876 / 918-921 MHz band (if available, when needed). GSM is a second generation mobile technology, but the telecommunication industry is already moving to LTE (arguably a fourth generation [4G] technology) and is expected to evolve to fifth generation (5G) technology after 2020. The ability of the rail industry to continue to support GSM-R beyond roughly 2030 is doubtful. Given the long procurement cycles in the rail sector, planning for a successor needs to begin now.

Stakeholders also seek cost reductions, especially in operational expense (OPEX). Some expressed interest in capital expense (CAPEX) reduction through convergence with other networks (such as TETRA, commercial mobile networks, and/or Wi-Fi networks).

Stakeholder input and previous studies have also identified a strong desire to cleanly separate rail operational communication applications from the underlying radio bearer in order to facilitate smooth transition as the radio system continues to evolve.

Finding 1. The need for a successor to GSM-R is motivated by anticipated eventual obsolescence of GSM, capacity limitations in GSM-R, and a desire to reduce costs. Previous studies have found that functional requirements and bandwidth demand are evolving only slowly; however, not all stakeholders agree.

1.2. Precursors to the current study

This study needs to be understood as part of a line of inquiries that have been launched by the ERA and the European Commission (see also Section 2.1, and the Annex to this report).

In 2013, the ERA launched a project to analyse the current situation with respect to the communication system used for voice and data for rail traffic management. The possible evolution of the communication needs and different network ownership models were described. The resultant study (Analysys Mason (2014)), based on extensive interviews and including a SWOT analysis of strengths and weaknesses of various approaches, was published in February 2014. The study evaluated six Options: (1) retain GSM-R; (2) new technology – same band; (3) new technology – new band; (4) new technology – with third party; (5) multiple prescribed technologies; and (6) multiple technologies – no prescription.

Meanwhile, the ERA itself conducted an extensive Ex-Post Evaluation of GSM-R as part of their programme. The results, again based on extensive stakeholder interaction, provide a valuable source of guidance as to perceived needs for railway operational radio communications.

In addition, the European Commission launched a study to consider alternative ways of implementing “mission critical” communications in Europe, including not only rail but also energy and public protection and disaster relief (PPDR). The resultant study (SCF (2014)), which in the end dealt primarily with PPDR and only tangentially with rail communications, identified significant opportunities for commercial Mobile Network Operators (MNOs) to meet mission critical communication needs, provided however that several rigorous requirements

were fully met (which in the view of many experts are not at all likely to be met). Moreover, it is far from clear that this list of requirements is either correct or exhaustive:

- First the behaviour of commercial MNOs must be constrained to provide the services needed by mission critical users while preventing the use of “lock in” techniques to take unfair advantage of this expansion of the MNOs’ market power and social responsibility. Such changes include not just stronger commitments to network resilience, but the acceptance of limits on price increases and contract condition revisions, ownership continuity assurances, and a focus on quality of service for priority mission critical traffic. …
- Commercial networks have to be “hardened” from RAN to core and modified to provide over 99% availability – with a target of “five nines”. Geographic coverage must also be extended as needed for mission critical purposes and indoor signal penetration improved at agreed locations.
- All this network hardening and extended coverage, along with the addition of essential mission critical functions and resilience, must be accomplished at reasonable cost. …
- Hardened LTE networks must be able provide the different types of service required by each of the three sectors. Each sector uses broadband in quite different ways. …
- However, there is a further high barrier: will commercial mobile networks be able to overcome ingrained Member State preferences for state controlled networks for applications that implicate public safety? This is not simply a legal, regulatory or economic question. …

This study identified the following policy Options, which do not precisely align with those of the Analysys Mason study: (1) dedicated networks and dedicated specialised 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, perhaps regional in scale.

Finding 2. Multiple studies have assessed possible ways forward for operational rail communications (and for other mission critical networks).

1.3. Goals of the current study

The European Railway Agency (ERA) is in charge of the maintenance of the TSI Control Command and Signalling (CCS TSI), and is the system authority for ERTMS (that includes both the ETCS and the GSM-R parts). The agency is to ensure that the TSI is adapted to technical progress, market trends, and social requirements, and is responsible for proposing any amendments to the TSIs which it considers necessary to the European Commission.

The ERA established this study in order to evaluate the Options to address the evolution of operational rail communications, in light of the challenges identified in Section 1.1, in terms of:

- methodology for their assessment;
- feasibility of the options presented;
- selection of the most suitable options;
- possible operator concepts for railways according to the options selected;
- frequency availability for railways; analysis for the different applications and possible use of a common bandwidth for different services, as presented in the different options;
- possible evolution of the terminals and network infrastructures according to the options selected; and
- highlights for the economic assessment of the options studied.

Ibid.
See Article 12 of Regulation (881/2004), which provides the basis for the ERA.
The study was specifically not intended:

- to identify a single, preferred Option;
- to develop a transition plan to a preferred Option; or
- to reassess future functional needs for a successor to GSM-R, which were already evaluated in the Ex-Post Evaluation (2014) and in the Analysys Mason (2014) study.¹⁷

The ERA anticipates that the results of the study will be used as appropriate to prepare the evolution to the future concept. A number of future studies are planned to deal with aspects not addressed in this study.

1.4. Goals of this Final Report

This Final Report seeks to provide stakeholders with the study team's assessment of the problem, to provide stakeholders with an opportunity to review our thinking and respond to it, and to provide a basis for further planning and actions on the part of the ERA (see Section 1.5).

1.5. The way forward

This study is neither the beginning of the process (see Section 1.2) nor the end; rather, it is a significant milestone along a fairly long road.

The ERA presented its vision of the way forward during the final public workshop for this project, which took place in Lille on 11 February 2015. The ERA distinguishes between functionality, technology, spectrum management, and migration aspects of the broader problem. They seek to integrate specifications of next generation communication system(s) integrated into a CCS TSI revision in 2018. Specific elements would include:

- Technology dimension (chapter 4 of CCS TSI);
- Migration dimension (chapter 7 of CCS TSI); and
- An Impact Assessment in support.

A number of past, current and future activities support this vision.

- Functionality dimension
  - The ex-post analysis of operational radio requirements (2014)
  - UIC FRMCS

- Network/Technology dimension
  - The Analysys Mason study (2014)
  - This study (2014)
  - Further studies focusing on remaining points in defining the appropriate network and technology suitable options

- Migration dimension
  - A transition study to start in H2 2015

These activities need to be viewed as part of a longer planning and specification cycle. Consider, for instance, the anticipated sequence of cab radio evolution depicted in Figure 1.

1.6. Our methodology

Our approach throughout is inspired by European Impact Assessment methodology. Among the European institutions, Impact Assessment provides a useful means of analysing costs and benefits of prospective policy interventions. Impact Assessment, as defined by the European Commission, is conducted by (1) clearly identifying the Problem to be addressed; (2) identifying a series of General and Specific Objectives that should be achieved in doing so; (3) identifying several plausible Options constituting policy interventions that might achieve the desired Objectives; and (4) assessing the likely Impacts, both positive and negative, of each of the Options.

Properly applied, Impact Assessment serves not only to assess impacts of decisions already reached, but also to assist in the proper formulation of policies in the first place.

In this case, use of standardised Impact Methodology also assists ERA in communicating results to the European Commission, and assists the Commission (if necessary) in communicating results to the European Parliament and the Council.

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Our overall approach is comprised of four steps:

- **Step 1**: Building an evidence base by means of desk research, extensive interviews, and three public workshops.
- **Step 2**: Framing the problem, using the vocabulary of European Impact Assessment.
- **Step 3**: Assessing the likely impact of each candidate Option for addressing the Problem.
- **Step 4**: Formulating recommendations.

**Figure 2: Study methodology**

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Tools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formulate likely evolutionary patterns of GSM-R</td>
<td>Study performed by Analysys</td>
</tr>
<tr>
<td>Make a clear statement of the problem to be solved</td>
<td>Desk research</td>
</tr>
<tr>
<td>Refine the list of options</td>
<td>Interviews</td>
</tr>
<tr>
<td>Assess the likely effects of proceeding with no change</td>
<td>Desk research</td>
</tr>
<tr>
<td>For each option, perform a comparison with the baseline.</td>
<td>Interviews</td>
</tr>
<tr>
<td>Sum up main findings, and provide recommendations</td>
<td>Desk research</td>
</tr>
</tbody>
</table>

### 1.7. Structure of this document

Chapter 2 explains that the problem to be addressed is really comprised of multiple problems. On the one hand, there are European and Member State aspects; on the other, there are cross-sectoral aspects that relate not only to rail, but also to other mission-critical services such as public protection and disaster relief (PPDR) and energy.

Chapter 3 analyses possible cross-sectoral approaches that could be taken at European level, while Chapter 4 explores possible approaches at Member State level.

Finally, Chapter 4.5 explains the decisions that appear to be needed for the rail sector at European level, based on the analysis undertaken in Chapters 3 and 4.
2. Multiple problems call for multiple solutions

Key Findings

- It is exceedingly difficult to express clear, non-overlapping Options with which to address this Problem.
- We find it useful to distinguish among three interrelated sets of decisions: (1) A cross-sectoral decision at European level as to how to handle PPDR, energy, intelligent highway transport, and rail communications overall; (2) a rail-specific decision; and (3) Member State (national) decisions.
- Public Protection and Disaster Relief (PPDR) forces hope to upgrade their communications capabilities using broadband technology.
- Needs for the energy sector are driven primarily by smart metering and smart grid applications; these have, however, different network implications.
- Railway functional requirements for train operational communications have been found in previous studies to be evolving only slowly; however, needs may increase in the medium-far future.
- There are commonalities among these sectors, but there are also important differences.
- Technology is evolving in ways that provide many new opportunities going forward.

For purposes of our study, we are distinguishing between three interrelated sets of decisions: (1) A cross-sectoral decision at European level as to how to handle PPDR, energy, intelligent highway transport, and rail communications overall; (2) a rail-specific decision; and (3) Member State (national) decisions.

2.1. The analysis done to date

Both of the previous studies (Analysys Mason (2014) and SCF (2014)) used sets of Options that failed to convince rail stakeholders in the course of our Workshops to date, and that we also find insufficient for our purposes.

The Analysys Mason (2014)\(^{19}\) study used the following Options:

- retain GSM-R;
- new technology – same band;
- new technology – new band;
- new technology – with third party;
- multiple prescribed technologies; and
- multiple technologies – no prescription.

The SCF (2014)\(^{20}\) used the following Options:

- dedicated networks and dedicated specialised equipment;

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\(^{19}\) David Taylor, Nils Lofmark, Maria McKavanagh (2014), “Survey on operational communications (study for the evolution of the railway communications system)”. 25 February 2014, Ref: 37760-496v04.


- commercial MNO networks and commercial equipment;
- dedicated networks with commercial networking equipment;
- hybrid networks; and
- a common multi-purpose network, perhaps regional in scale.

Comparing these Options, it is immediately clear that the Options are not aligned between the two studies.²¹

Second, it becomes clear that it is exceedingly difficult to express clear, non-overlapping Options. Options could potentially differ from one another according to:
- ownership and control model;
- technology;
- spectrum band(s);
- whether multiple ownership and control models are accommodated within or among the Member States;
- whether multiple technical and/or spectrum management models are accommodated within or among Member States.

The choices made interact with one another, but they do not uniquely determine one another. A dedicated rail operations network could, for example, be single technology or multi-technology.

For analogous reasons, great care must be taken in analysing “hybrid” solutions, because solutions could be hybrid across any of these dimensions, or indeed across more than one. In this study, we have attempted to more clearly delineate what we mean by “hybrid” in each specific instance where we use the term.

Finally, and most problematic from our perspective, the previous work (both Analysys Mason (2014) and SCF (2014)) has analysed Options as if there were a single decision to be made. There will in practice be multiple decisions. These decisions will in practice be made at quite different times, at different administrative levels (national versus European), and by different sets of decision-makers.

Finding 3. It is exceedingly difficult to express clear, non-overlapping Options with which to address this Problem.

2.2. A multi-layered decision process

We believe that it is necessary instead to decompose the problem into multiple Problems and multiple decisions to be taken,²² as shown in Figure 3:

- A set of European cross-sectoral decisions that must be taken as to (1) whether to handle PPDR, rail, intelligent highway transport, and energy together, (2) the degree to which a solution could be common among these sectors (and possibly common with commercial mobile networks), and (3) how such a cross-sectoral approach might work if it were desired;
- A set of European rail-specific decisions; and
- A set of Member State decisions.

Different aspects of the broader problem are addressed at different decision levels. Wherever new harmonised spectrum might be required, for instance, this would necessarily addressed at European level, and generally with consideration of impacts on sectors other than rail. Decisions of what to deploy, and where, and how, tend by contrast to be dealt with at Member State level, albeit subject to rules and guidelines established at European level.

²¹ Indeed, the SCF study appears to make no reference whatsoever to the earlier Analysys Mason (2014) study.
²² For that matter, there is also an interaction with worldwide spectrum policy (consider the World Radiocommunication Conference 2015 (WRC-15)); however, the linkage is not crucial to the point where it needs to be explicitly modelled.
Each of these decisions must reflect (1) evolving functional requirements on the part of the users of the relevant service; and (2) evolving technology.

The EU level rail sector decision influences, but does not control, the cross-sectoral decision; conversely, the EU rail sector more or less controls the decision for its sector, but the cross-sectoral decision (together with Member State decisions) bounds the frontier of possibilities within which the rail sector decision can be taken.

Member States will make their own decisions, within a framework that is set at European level. The European framework should facilitate, or at least not hinder, sensible decisions at Member State level.

The complex interdependencies among these decisions cannot be ignored.

**Finding 4.** We find it useful to distinguish among three interrelated sets of decisions: (1) A cross-sectoral decision at European level as to how to handle PPDR, energy, intelligent highway transport, and rail communications overall; (2) a rail-specific decision; and (3) Member State (national) decisions.

### 2.3. Drivers for these decisions

The decisions to be taken are driven (as shown in Figure 3) in large measure by (1) evolving PPDR and energy functional requirements, (2) evolving railway functional requirements, and (3) evolving technology.

#### 2.3.1. Evolving PPDR and energy functional requirements

Public Protection and Disaster Relief (PPDR) forces continue to rely on mission critical voice services, which are expected to continue to be carried by the existing dedicated voice and narrowband TETRA and TETRAPOL networks for some ten to fifteen years.\(^{23}\) At the same time, PPDR users are increasingly looking to upgrade their communications capabilities

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\(^{23}\) CEPT ECC Report 199 (2013), “User requirements and spectrum needs for future European broadband PPDR systems (Wide Area Networks)”. 

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21
using mobile broadband technology. Video is of particular interest as a means of enabling commanders to see what is happening in the field (and it is for this reason that bandwidth requirements are great for upload than for download). Firefighters are interested in seeing building plans, and need indoor coverage.24

It is fairly common for PPDR forces from one Member State to assist in the event of a disaster in another,25 consequently, interoperability and roaming issues are becoming highly relevant to PPDR, just as they are in the rail sector.

The energy sector is seeing possible increasing demand for radio communications if smart metering increases. Smart meter communications use a wide range of bearers, including signalling over the power line (power-line communications (PLC), long range UHF radio, unlicensed mesh radio and GPRS. Smart metering is an application which is not critical; smart grid, on the other hand, is a critical application that requires a fine level of control with a fast response time. The proliferation of many power generation sources, such as solar generation on houses and wind farms, connected to an electricity grid which was designed to feed power from a few large power stations to many users, is giving rise to a situation where there has to be a fine level of control with a fast response time, otherwise there is a significant risk of instability, which in turn can lead to large power outages. Latency times of between 5 and 10 milliseconds are required.26

Intelligent highway transport was not a specific target of our study, but stakeholders have rightly noted that highways and railways sometimes follow the same routes, and that potential synergies with communications for intelligent highway transport need to be considered.

Finding 5. Public Protection and Disaster Relief (PPDR) forces hope to upgrade their communications capabilities using broadband technology.

Finding 6. Needs for the energy sector are driven primarily by smart metering and smart grid applications; these have, however, different network implications.


26 David Taylor, Nils Lofmark, Maria McKavanagh “Survey on operational communications (study for the evolution of the railway communications system)” (Analysys Mason, 2014)
2.3.2. Evolving railway functional requirements

In terms of train operations, our working assumption based on previous studies is that railway functional requirements are evolving only slowly (see Section 1.1). We have assumed that functional requirements, even in 2030, are not radically different from functional requirements today.\(^\text{27}\) Coverage requirements, however, change as new (high speed) lines are brought into service.

There are no final documents available today that indicate or justify new applications or additional needs. On the other hand, several activities in the railway sector are ongoing which may require robust wireless (data) communication. Some examples are the inclusion of ATO (automatic train operation) in ETCS, studies on NGTC (next generation train control, with investigation of commonalities between “heavy rail” and “urban rail”), activities in the S2R (shift to rail) program and UIC activities on User requirement Specifications in the FRMCS project.

Finding 7. Railway functional requirements for train operational communications have been found in previous studies to be evolving only slowly; however, needs may increase in the medium-far future.

There are commonalities among these sectors, but there are also important differences. Economies of scale are important in all of these sectors. Interoperability and roaming are important in most of these sectors, but not in all, and moreover they do not have the same meaning in all sectors. The need to support movement at speeds in excess of 400 km/h is a rail-specific requirement.

Finding 8. There are commonalities between rail and other mission-critical applications for voice and data radio services, but also important differences such as speed.

2.3.3. Evolving technology

Technology is evolving in many different directions, some fairly predictable, others less so. This technological evolution provides many new opportunities going forward:

- **Internet Protocol (IP):** IP is being used as the foundation for nearly all data traffic, and increasingly for voice and video as well. This trend is unambiguous, and is unlikely to change by 2030.
- **Increasing transmission efficiency:** The migration from 3G mobile technologies to LTE is bringing an increase in spectral efficiency (e.g. bits/Hz), and the migration to LTE Advanced will take this evolution to the next step. The anticipated evolution to 5G in the coming years can be expected to lead to further improvements.\(^\text{28}\)
- **Increasing focus on spectrum sharing:** There is a gradual evolution away from purely exclusive spectrum assignments, and toward increasing use of various forms of shared or collective use. A particularly noteworthy trend is the potential use of Licensed Shared Access (LSA), also known as Authorised Shared Access (ASA), to enable more flexible sharing of spectrum than has been possible to date.\(^\text{29}\)
- **Increased focus on active network sharing:** Enhanced active network and equipment sharing as defined in 3GPP TS 23.251, 22.852 and 22.951 could enable


\(^\text{28}\) To the extent that these newer technologies lend themselves to larger contiguous spectrum bands, however, there may also be a tendency toward inefficiency for applications that do not require much bandwidth.

\(^\text{29}\) The GSM Association (GSMA) defines LSA/ASA as complementary way of authorising and accessing spectrum, in addition to licensed (exclusive) and license-exempt (unlicensed), which enables the sharing of spectrum between a limited number of licensed users. Based on a commercial agreement and under an adequate regulatory framework, a non-mobile incumbent could allow part of their assigned spectrum to be used by a LSA/ASA user (such as a mobile operator).
several network operators to share hardware and control of a joint network. This could be relevant to a number of the scenarios considered in this report.

- **Increasing flexibility in spectrum usage:** A number of technological trends, including the ability of LTE to aggregate multiple bands, together with the emergence of asymmetric downlink (ADL), are providing substantially greater flexibility in the use of spectrum. This can facilitate for instance the operation of LTE in licence-exempt bands.

- **Heterogeneous Networks (HetNets):** HetNets is part of the LTE-Advanced standard and enables smooth interworking between macro-cells and small-cells in a LTE network. It is increasingly common for “hot spots” to support both small cell mobile operations and Wi-Fi. Many experts expect 5G technology to craft a seamless wireless network out of multiple, highly diverse forms of transmission, including for instance mobile and Wi-Fi networks.

- **Software Defined Radio (SDR):** It is increasingly feasible to reconfigure the operation of radio devices dynamically. Given the long procurement cycles for rail communications (and also for the PPDR and energy sectors), this could offer important operational flexibility.

- **5th generation wireless systems (5G):** A new generation of wireless services is expected to emerge by 2020 or soon thereafter. Many anticipate that it will offer substantial advantages beyond greater speed and spectral efficiency than current mobile technologies. Mesh networking, smooth integration with technologies such as Wi-Fi, and support for frequencies above 6 GHz are possible capabilities, but great uncertainty remains as to what will actually constitute 5G (see also Section 5.4.5).

### Finding 9
Technology is evolving in ways that provide many new opportunities going forward.

### 2.4. Relationship to the structure of the remainder of this document

The remainder of this document discusses the three interrelated decisions in turn, starting with the European cross-sectoral level in Chapter 3), continuing with the Member State level in Chapter 4, and concluding in Chapter 4.5 with decisions to be taken at European level by the rail sector (since this is the issue that is of direct concern to this study).

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3. The European cross-sectoral level

**Key Findings**

- We are analysing European cross-sectoral Options and Sub-Options from least active intervention to most active intervention. A range of solutions are possible, with different implications in terms of cost and ease of implementation.

- For reasons outlined in SCF (2014), the cost of a cross-sectoral network based on MNO services for PPDR and rail might well be somewhat less than that of the private networks used today, even after allowing for the costs of hardening the network to provide reliability and expanding its coverage. There is, however, considerable uncertainty about this claim. Their analysis was primarily relative to existing PPDR networks, and only tangentially relevant to operational rail network requirements; moreover, their analysis rests on the assumption that a variety of reliability, coverage, management and practical requirements can be met that, in practice, quite possibly cannot be met. Further study is needed.

- Taking migration costs into account (which is not fully possible until far more is known about the migration) an Enhanced Business as Usual approach (with private rail networks using modernised technology) might well be comparable in efficiency to the various network sharing sub-Options that we have considered.

- If the GSM-R bands can eventually be released, the opportunity cost for the European Union as a whole of up to roughly €2.5 billion could be freed. This number rests however on many assumptions, and must be interpreted with caution.

This chapter deals with the European cross-sectoral level, as described previously in Chapter 2. First, we present the Problem at the European cross-sectoral level of analysis. We then explain how we distinguish the Options and Sub-Options from one another (Section 3.2), explain the Options and Sub-Options that we have derived (Section 3.3.2), and discuss how the various Options and Sub-Options differ from one another in terms of their expected respected impacts (Section 3.4). The Options describe different possibilities for providing radio network bearer services and the related technologies.

The Commission’s release note to the SCF (2014) study notes that “… the Commission does not intend to adopt any legally binding measures related to the harmonisation of dedicated spectrum or obliging Member States to use commercial networks.” Nonetheless, European policymakers will be obliged to take a number of relevant decisions or to choose not to take them (which is also a decision).

The decision-makers are the European institutions – the European Parliament, the Council, and especially the European Commission. The decision-makers span multiple sectors – these are not just rail decisions.

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32 European Commission (2014), “Use of commercial mobile networks and equipment for mission-critical high-speed broadband communications in specific sectors (SMART 2013/0016)”, 15 December 2014, at: [https://ec.europa.eu/digital-agenda/en/news/use-commercial-mobile-networks-and-equipment-mission-critical-high-speed-broadband](https://ec.europa.eu/digital-agenda/en/news/use-commercial-mobile-networks-and-equipment-mission-critical-high-speed-broadband). This is consistent with the oral remarks of a senior Commission official, Andreas Geiss (DG CNECT, Head of Unit B4), who at the Final Presentation Workshop for the SCF (2014) study noted the Commission’s interest in establishing “… EU guidelines … for managing a commercially based mission critical network successfully. These EU guidelines would not be legally binding but should be based on subsidiarity principles, with the aim of offering guidance to MS and NRAs in drawing up both their regulatory framework for operating such networks with MNOs and their contract conditions.” (as reported in Appendix E to SCF (2014)).
In this chapter, we progress as is customary in an Impact Assessment, from a definition of the Problem (Section 3.1), to a short list of Objectives (Section 3.2), to a list of Options (Section 3.3), and to an assessment of the Impacts of each of the Options (Section 3.4).

3.1. The Problem at the European cross-sectoral level

The cross-sectoral problem at European level is in principle the central theme of the SCF (2014) study, not of this study. That study defines their objectives, but does not appear to provide a statement of the cross-sectoral Problem that Europe needs to address.

We propose the following cross-sectoral Problem statement at European level:

- Identify technical, spectrum management, and policy measures to be undertaken to enable continued provision of mission critical services, however defined, to the European public protection and disaster relief (PPDR), energy and transport sectors (including rail) as technology and markets evolve going forward.

3.2. The Objectives

In an Impact Assessment, a clear view of the Objectives is essential in order to understand the Impacts of a proposed policy. In this report, we are decomposing the broader Problem into three distinct levels; consequently, it is necessary to distinguish Objectives for each of them. In practice, it is not altogether appropriate for this study (which deals specifically with the rail sector) to concern itself with non-rail objectives; nonetheless, in order to be able to proceed with meaningful analysis, we put forward the following General Objectives for the rail-specific Problem at Member State level:

- Support all current and anticipated future mandatory functionality for the “mission critical” sectors of rail, Public Protection and Disaster Relief (PPDR), and energy, at reasonable cost using modern, supportable technology.
- Enable continued operation without disruption during a transition period from existing modes of use to new modes of use. (In the case of the rail sector, this means that interoperability and roaming continue to be crucial during an extended transition period where GSM-R coexists with whatever succeeds it.)

3.3. Options

3.3.1. Key dimensions along which Options and Sub-Options differ from one another

Each of the Options and Sub-Options, both for the cross-sectoral problem and for the rail-specific problem, is distinguished from the others along multiple axes of choices, including:

- The policy instruments by means of which the European Union both supports and enforces the approach taken, and promotes harmonised approaches where they are warranted.
- The ownership and control models that are permitted within the scope of the policy framework.
- The technologies that are permissible.
- The spectrum management decisions that should or must be taken in support of the approach.

These relationships are not any-to-any. Only certain constellations of choices appear, at this point, to be sensible and internally consistent. Some choices of policy instrument, and of the ownership and control model, for instance, seem to imply the need for a dedicated spectrum band, while others do not.
3.3.2. Options for European overall cross-sectoral policy

We are analysing European cross-sectoral Options and Sub-Options from least active intervention to most active intervention.

The options at the top and bottom of the list seem less likely than those in the middle; nonetheless, it is useful to analyse them:

- For methodological completeness; and
- To enable comparisons to the Options and Sub-Options that seem more promising.

The choice of Option and Sub-Options influences the choice of technology and spectrum bands, but does not necessarily uniquely determine them.

With that established, we have defined the following initial set of Options and Sub-Options in terms of the first decision, i.e. the European cross-sectoral policy decision:

1. Business as usual
2. Member State actions subject to European support and coordination
   a. Require network operators to deploy and operate (akin to universal service)
   b. Impose spectrum licence obligations on network operators
   c. Use of State Aid mechanisms to promote private networks, or enhancement of commercial networks
3. Direct European sponsorship
   a. Strong coordination
   b. European implementation (“We do it all”)

The creation and/or continuation of private networks are very much on the table, and they appear explicitly as an Option at Member State level in Chapter 3. In fact, they are possible here under both sub-Options of the Business as Usual Option, and would likely continue to be supported under all of the other Options as well.

Table 1 lists and summarises the Options and Sub-options, and describes the policy approach and technical approach implicit in each. Table 2 shows how the Options and Sub-options might possibly interact with or drive spectrum management decisions, and with decisions to integrate rail communications with commercial mobile networks (MNOs), with PPDR, or with energy networks.

These options also interact with the likely migration and time scale. Under Options 2 and 3, deployment of a network capable of supporting operational rail communications would be likely to begin circa 2020 driven by PPDR needs for broadband video services (which appear to be emerging more rapidly than new operational rail requirements).

It may be helpful at the outset to consider each of the Options and Sub-Options in turn.

- **Business as usual**: This Option assumes a continuation of present trends, with rail operations over private networks that are distinct from commercial mobile networks, and also distinct from other mission critical networks. Two sub-Options can be distinguished.
  - **Business fully as usual**: This Option/sub-Option is effectively required in any Impact Assessment. It reflects the most likely trajectory if no additional actions were undertaken to deal with the Problem beyond those already in motion or foreseeable today. It thus provides a baseline against which any other policy interventions can be judged. This Option assumes no greater activity at European level than exists today (or will predictably exist based on initiatives already in progress) in order to prepare for future needs of PPDR, energy, and/or rail networks; however, Member States may undertake as much (or as little) as they may choose to foster the further evolution of train operational communications (and the other mission critical sectors). Member States would have the right to deploy private networks.

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33 In case of continuation of private network, a European cross-sectoral action for spectrum allocation should be required
under this Option (and the others), as they do today; no new European policy measures are needed to enable them to do so.

- **Enhanced business as usual**: In this sub-Option, rail continues to operate over private networks that are distinct from commercial mobile networks, and also distinct from other mission critical networks (see also Section 4.4.1); however, the technology might be modernised to enable (for instance) the use of 3GPP technologies such as LTE (see for instance Section 5.4.3). Corresponding changes to the CCS TSI would be needed. Whether this is feasible in the existing GSM-R bands (and possibly E-GSM-R bands) or would require a new band harmonised at European level would need to be studied.

- **European support and coordination for the use of (commercial) wireless services**: The next three sub-Options reflect active European support and coordination, but assume that actual implementation rests largely with the Member States. Each of the sub-Options includes mechanisms that seek to ensure that networks, primarily commercial wireless networks in Member States that wish to do so, would deploy with sufficient coverage, reliability and robustness to meet rail operational needs. We tacitly assume that pure commercial incentives alone would be unlikely to produce the necessary service deployments. We also assume that GSM-R becomes difficult if not impossible to support after 2030, which is consistent with statements from market players.
  - **Require selected wireless network operators to deploy and operate the service**: The assumption here is that Member States would impose suitable obligations on some or all Wireless Network Operators. The obvious policy model is universal service, where the Member State designates one (or more) network operators to provide the service in each geographic portion of the national territory, using an objective procedure (e.g. a competition or auction). The Member State may compensate the network operator for the net cost that it incurs. The overall institutional structure is defined at European level, but implementation is left to the Member States.
  - **Use of Spectrum licence obligations**: Instead of a general mandate, a Member State might impose an obligation to support rail operations as a licence condition for some attractive block of spectrum. This has somewhat the same effect as the previous Sub-Option, in that it effectively auctions off the obligation; however, the obligation entails costs that may possibly depress the value of the spectrum block in question. US experience with this approach is not altogether promising.
  - **Use of State Aid mechanisms to motivate wireless network operators to deploy and operate mission critical networks**: State Aid rules at European level once again provide for the service provider to be chosen on an objectively valid basis such as an auction, and define permissible means and levels for compensation by the Member State government.

- **Direct European sponsorship**: These Sub-Options are associated with a far more active European role. We consider these approaches less likely, but they are included for completeness.
  - **Strong coordination**: In this Sub-Option, the European Union would directly fund and coordinate European mission-critical networks, but would still leave implementation to the Member States.
  - **European implementation (“We do it all”)**: In this (perhaps unlikely) thought model, the European Union actively provides a network for mission-critical services, probably including PPDR, rail, and possibly energy.

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Finding 10. We are analysing European cross-sectoral Options and Sub-Options from least active intervention to most active intervention. A range of

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34 The allocation, assignment and usage conditions of the band would have to be suitable for use by GSM-R, and it would have to be defined as a supported band in the CCS TSI. This does not necessarily require full, exclusive harmonisation of the band at European level.
solutions are possible, with different implications in terms of cost and ease of implementation.
### Table 1. Proposed Options for European overall cross-sectoral policy.

<table>
<thead>
<tr>
<th>Number</th>
<th>Option Name</th>
<th>Sub-Option Name</th>
<th>Policy Approach</th>
<th>Technical Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Business as usual</td>
<td>Business fully as usual</td>
<td>No new policy initiatives.</td>
<td>GSM-R continues to be used to 2030 and beyond. Other complementary technologies also continue to be used to 2030 and beyond.</td>
</tr>
<tr>
<td>1b</td>
<td>Business as usual</td>
<td>Enhanced business as usual</td>
<td>Rail continues to operate over private networks that are distinct from commercial mobile networks, and also distinct from other mission critical networks; however, the technology of the private networks can be refreshed.</td>
<td>GSM-R usage declines, and becomes rare or non-existent after 2030. New technology is deployed, presumably forms of 3GPP/LTE, enhanced to reflect any UIC/ETSI requirements.</td>
</tr>
<tr>
<td>2a</td>
<td>European support and coordination for the use of (commercial) wireless services</td>
<td>Require wireless network operators to deploy and operate mission critical networks</td>
<td>E.g. revisions to the Universal Service Directive empower Member States to require MNOs to deploy and operate mission critical networks; require Member States to choose one or more providers; and enable them to compensate MNOs for the net cost.</td>
<td>GSM-R usage declines, and becomes rare or non-existent after 2030. Any new technology must be consistent with whatever the network operator is deploying, presumably forms of 3GPP/LTE, enhanced to reflect any UIC/ETSI requirements.</td>
</tr>
<tr>
<td>2b</td>
<td>European support and coordination for the use of (commercial) wireless services</td>
<td>Facilitate the use of Spectrum licence obligations</td>
<td>The Member State (NRA) would auction a new block of desirable spectrum such that the winner accepts the obligation to deploy a network with suitable coverage that can support (PPDR and) rail.</td>
<td>GSM-R usage declines, and becomes rare or non-existent after 2030. Advantageous to permit the technology to be consistent with whatever the MNO is deploying, presumably forms of 3GPP/LTE, enhanced to reflect any UIC/ETSI requirements.</td>
</tr>
<tr>
<td>2c</td>
<td>European support and coordination for the use of (commercial) wireless services</td>
<td>Employ State Aid mechanisms to motivate wireless network operators to deploy and operate mission critical networks</td>
<td>Use State Aid rules to determine a provider (e.g. by an RFP). Conditions are set by contract rather than by regulation.</td>
<td>GSM-R usage declines, and becomes rare or non-existent after 2030. Technical standards developed by UIC/ETSI, probably based on LTE or 5G. EU conducts a procurement to establish a list of prequalified suppliers, with discounted prices, available to the Member States.</td>
</tr>
<tr>
<td>3a</td>
<td>Direct European sponsorship</td>
<td>Strong coordination</td>
<td>EU funds a multi-purpose public critical services network. Member States implement the network. Those Member States that accept funding accept associated conditions. Other Member States must build (or procure commercial services) to interoperable standards, and with equal or greater quality.</td>
<td>GSM-R usage declines, and becomes rare or non-existent after 2030. Technical standards developed by UIC/ETSI, probably based on LTE or possibly 5G. EU conducts a procurement to establish a list of prequalified suppliers, with discounted prices, available to the Member States. MS must procure equipment that meets standards, not necessarily from the list.</td>
</tr>
</tbody>
</table>
Evolution of GSM-R/Draft final report

EU funds and implements a multi-purpose public critical services network in those Member States that accept it. Other Member States must build to interoperable standards, and with equal or greater quality. GSM-R usage declines, and becomes rare or non-existent after 2030. EU procures equipment to technical standards developed by UIC/ETSI, probably based on LTE or possibly 5G. Equipment procurement terms offered to EU must also be offered to Member States.

Table 2. Apparent implications of Options and Sub-Options for the approach to spectrum, and integration with commercial MNO services, PPDR, and/or energy.

<table>
<thead>
<tr>
<th>Number</th>
<th>Sub-Option Name</th>
<th>Spectrum Approach</th>
<th>Integration with MNOs, PPDR, ...</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Business fully as usual</td>
<td>No new spectrum allocation. E-GSM-R bands (873-876 MHz (Uplink) and 918-921 MHz (Downlink)) may also be used as extension bands for GSM-R on a national basis.</td>
<td>No more than today.</td>
</tr>
<tr>
<td>1b</td>
<td>Enhanced business as usual</td>
<td>Whether this is feasible in the existing GSM-R bands (and possibly E GSM R bands) or would require a new band harmonised at European level would need to be studied.</td>
<td>No more than today.</td>
</tr>
<tr>
<td>2a</td>
<td>Require network operators to deploy and operate mission critical networks</td>
<td>Probably no new spectrum allocation. Could operate in existing mobile bands. E-GSM-R bands (873-876 MHz (Uplink) and 918-921 MHz (Downlink)) may also be used as extension bands for GSM-R on a national basis.</td>
<td>Likely obligation to provide interoperable networks for PPDR and for rail, but not necessarily an obligation to integrate, nor a prohibition on the Member State choosing to operate the infrastructure itself.</td>
</tr>
<tr>
<td>2b</td>
<td>Facilitate the use of Spectrum licence obligations</td>
<td>Requires a new allocation, presumable in the 450 MHz or 700 MHz range. Should be harmonised, as much as possible, at European level.</td>
<td>Likely integration of PPDR and rail, with surplus capacity used for commercial services. No prohibition on the Member State choosing to operate the infrastructure itself.</td>
</tr>
<tr>
<td>2c</td>
<td>Employ State Aid mechanisms</td>
<td>Likely need for a new allocation, presumable in the 450 MHz or 700 MHz range. Should be harmonised, as much as possible, at European level.</td>
<td>Likely integration of PPDR and rail, with surplus capacity used for commercial services. No prohibition on the Member State choosing to operate the infrastructure itself.</td>
</tr>
<tr>
<td>3a</td>
<td>Strong coordination</td>
<td>A new harmonised band is allocated, but could be otherwise assigned in Member States that choose not to let the EU deploy. Cab equipment must in any event support the harmonised band, except perhaps in equipment that will never leave the Member State.</td>
<td>Common private network for PPDR, rail, and possibly energy. No prohibition on the Member State choosing to operate the infrastructure itself.</td>
</tr>
</tbody>
</table>

35 The use of licence exempt spectrum (e.g. for Wi-Fi) and/or spectrum in other suitable 5 GHz bands for sufficiently short range applications (e.g. in stations or yards) could be considered under any of the Options.
36 The spectrum license obligations would require the MNO to give first preference to mission critical services.
37 For example, the spectrum licensee might use LSA/ASA arrangements (see Section 2.3.3) to sublicense momentarily unneeded spectrum to a commercial MNO.
A new harmonised band is allocated, but could be otherwise assigned in Member States that choose not to let the EU deploy. Cab equipment must support the harmonised band, except perhaps in equipment that will never leave the Member State.

Common private network for PPDR, rail, and possibly energy. No prohibition on the Member State choosing to operate the infrastructure itself. No prohibition on the Member State choosing to operate the infrastructure itself instead of accepting the EU deployment.

The spectrum management decisions are likely to be particularly challenging. Due to rail sector requirements for interoperability and roaming, the key spectrum decisions will necessarily be made at European level rather than Member State level; however, as Table 1 and Table 2 demonstrate, these decisions are linked in complicated ways to the technological approach and the management and control model that are ultimately chosen, and also to the degree to which it is possible to integrate rail operational networks with either commercial mobile networks or with other mission critical networks. Moreover, any spectrum management decisions will need to carefully consider the risk of interference (e.g. with adjacent bands), and also opportunity costs relative to sectors for other than rail.

For these reasons, it would be premature (and also out of scope for this study) to prescribe a single, preferred spectrum management approach in this report. Those decisions need to be understood as part of the overall planning and specification process (see Section 1.5).

The spectrum management decisions are likely to be particularly challenging. Due to rail sector requirements for interoperability and roaming, the key spectrum decisions will necessarily be made at European level rather than Member State level; however, as Table 1 and Table 2 demonstrate, these decisions are linked in complicated ways to the technological approach and the management and control model that are ultimately chosen, and also to the degree to which it is possible to integrate rail operational networks with either commercial mobile networks or with other mission critical networks. Moreover, any spectrum management decisions will need to carefully consider the risk of interference (e.g. with adjacent bands), and also opportunity costs relative to sectors for other than rail.

For these reasons, it would be premature (and also out of scope for this study) to prescribe a single, preferred spectrum management approach in this report. Those decisions need to be understood as part of the overall planning and specification process (see Section 1.5).

The European Union in general and the Commission in particular have sufficient capability to resolve these questions when they are ripe, through the Radio Spectrum Policy Plan, interaction with the RSPG, and Commission mandates to CEPT and/or ETSI.

### 3.4. Assessment of impacts

Visualisation of qualitative assessment of impacts is often done in tabular format as in the simplified example in Table 3. Only fully elaborated Options that meet minimum functional requirements appear.

In such a table, the ratings that are routinely used are 0 (to denote impacts the same as those of the baseline), + (better than the baseline), ++ (much better than the baseline); or - (worse than the baseline), and -- (much worse than the baseline). For this analysis, we note that the process of determining who provides service in a given Member State is important, but (at this level of analysis) not necessarily the ultimate outcome. For instance, whether a given Member State will ultimately choose to have a network provided by, for instance, an MNO versus an MVNO is not something that needs to be decided at overall European level a decade in advance.

Benefits and costs are cross sectoral at European level; however, the Impacts to sectors other than rail are not fully analysed, since they are somewhat outside the scope of this study.

### 3.4.1. Definition of criteria

These criteria were collected during the first workshop and are grouped to align them with EU impact assessment methodology.

**Effectiveness**

Effectiveness must consider both normal operation and operation under stress (e.g. at times of bad weather, natural or man-made disasters …).
In our assessment, we take into account the following effectiveness criteria:

- Interoperability
- Coverage: geographical coverage of rail tracks, railway stations and tunnels
- Reliability and robustness (i.e. reliability in the face of stress)

**Efficiency**

Efficiency relates to achieving objectives at the lowest feasible cost. Efficiency thus reflects the (capital and operational) cost of implementing the chosen Option.

### 3.4.2. Qualitative assessment

Qualitative assessment is presented in this section. The assessments presented in Table 3 are tentative and directional, to the extent that they depend heavily on details of how the respective Options would be implemented. In particular, the relative merits among the different cross-sectoral approaches are not altogether clear (and may not be necessary for the current study, which is rail-specific). The thought process on which the assessments are based immediately follows the table.

#### Table 3: Assessment of impacts

<table>
<thead>
<tr>
<th></th>
<th>1. Business as usual</th>
<th>2. European support and coordination</th>
<th>3. Direct European sponsorship</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1a. Business fully as usual</td>
<td>1b. Enhanced business as usual</td>
<td>2a. Require operators to deploy and operate</td>
</tr>
<tr>
<td>Effectiveness overall</td>
<td>0</td>
<td>0</td>
<td>- to 0</td>
</tr>
<tr>
<td>Interoperability</td>
<td>0</td>
<td>0</td>
<td>- to 0</td>
</tr>
<tr>
<td>Coverage</td>
<td>0</td>
<td>0</td>
<td>- to 0</td>
</tr>
<tr>
<td>Reliability and Robustness</td>
<td>0</td>
<td>0</td>
<td>- to 0</td>
</tr>
<tr>
<td>Efficiency overall</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Cost</td>
<td>0</td>
<td>0 to +</td>
<td>+</td>
</tr>
</tbody>
</table>

**Effectiveness**

- **Interoperability:** Interoperability under sub-Option 1b can be expected to be similar to that of current GSM-R networks.

  Each of the Sub-Options 2a, 2b, and possibly 2c provide means under which commercial network operators would be motivated or required to provide required interoperability and coverage.

  Options 3a and 3b provide somewhat greater control than exists today, and therefore might possibly result in somewhat better cross-border and roaming interoperability than with today's networks. A key question is whether such a network might reduce the tendency to use different kinds of networks for different kinds of rail lines. On balance, however, we assume that interoperability would be similar to that experienced today.

- **Coverage:** Coverage under sub-Option 1b can be expected to be similar to that of current GSM-R networks. Each of the Sub-Options 2a, 2b, and possibly 2c provide means under which commercial network operators would be motivated or required to provide required interoperability and coverage. To the extent that MNOs provide the service, their existing geographic footprint does not meet needs for rail operations (nor, for that matter, for PPDR); however, for this Sub-Option to be workable, the cost of achieving additional coverage must be funded under one of the mechanisms in Sub-
Options 2a, 2b, or 2c, and therefore represents a difference in cost rather than a difference in coverage. (If the coverage is achieved through a spectrum licence obligation as in Sub-Option 2b, then the Member State is effectively paying by accepting reduced spectrum auction proceeds rather than with a direct cash transfer.) Meanwhile, Options 3b and possibly 3a might enable greater coverage, albeit at greater cost.

- **Reliability and robustness:** Similar considerations apply as with coverage. Reliability and robustness under sub-Option 1b can be expected to be similar to that of current GSM-R networks. Reliability and robustness under Sub-Options 2a, 2b, 2c could be expected to approach or reach levels currently experienced, but only to the extent that the Member State funds the network operator to enhance its capabilities. Once again, Options 3b and possibly 3a might enable greater coverage, albeit at greater cost.

**Efficiency**

- **Cost:** Under Cost, we consider steady state costs, not migration or transition costs; however, the migration costs are certainly relevant to overall Efficiency.

For reasons outlined in the study SCF (2014), the cost of a cross-sectoral network based on MNO services for PPDR and rail might well be somewhat less than that of the private networks used today, even after allowing for the costs of hardening the network to provide reliability and prioritisation and after expanding its coverage. There is, however, considerable uncertainty about this claim. Their analysis was primarily relative to existing PPDR networks, and only tangentially relevant to operational rail network requirements; moreover, their analysis rests on the assumption that a variety of reliability, coverage, management and practical requirements can be met that, in practice, quite possibly cannot be met (see Section 1.2).

For reasons noted in Section 4.1.2, the cost of coverage for rail for a new network whether operated by a commercial mobile network operator or as a private network might be considerably less than the “greenfield” cost if the spectrum used is slightly below the frequency of the GSM-R bands, and if the new network can operate from existing trackside locations. This could be true for any of the sub-Options, but is especially relevant to sub-Option 1b (Enhanced business as usual).

In respects other than coverage (such as reliability and robustness), wherever a PPDR broadband network is deployed (whether as a private network or else by a commercial network operator), the incremental cost of also carrying rail operational traffic will tend to be quite low. This is so because the bandwidth demands of operational rail networks are, under the assumptions we are working with for this study (including only modest traffic growth over time), minimal (but see also the discussion in Section 1.1).

Option 1b (Enhanced business as usual) would require initial capital expenditure (CAPEX) to swap out existing trackside and cabin equipment; however this will tend to be offset by the better price-performance of newer gear thanks to so-called Moore’s Law improvements, and to generally lower operating expense (OPEX) due to increased automation of management functions. With this in mind, we assume that the total cost of ownership over time for sub-Option 1b will be no greater than current GSM-R networks, and is likely to be a bit less.

Returning to the question of migration or transition costs, Options 1a and also 1b will tend to be far less complex and far less disruptive than the other sub-Options. For this reason, we assume that a sub-Option 1b is likely to be similar in overall efficiency, all things considered, to solutions based on sharing networks with a mobile operator or with a PPDR network. A more precise comparison is not possible today – there are too many uncertainties and too little data available on the existing GSM-R networks. For that matter, transition costs cannot be estimated when not even the rough outlines of a migration plan have been worked out.

In those Sub-Options where rail operations services are operated either by a commercial network operator or by a private network operating in spectrum bands other than the current GSM-R bands, the GSM-R spectrum might eventually no longer be needed (see also the discussion of spectrum management aspects in Section 3.3.2). The spectrum in
the current GSM-R bands\textsuperscript{40} that would eventually be freed can be viewed as a reduced opportunity cost,\textsuperscript{41} which thus reduces the net cost of network operation. Current spectrum auction results suggest that spectrum in roughly the range of the GSM-R bands has an economic value of somewhere between €0.40 and €0.80 per MHz/pop\textsuperscript{42}, with a reasonable current value being €0.50 per MHz/pop. Taking the population of the EU as roughly 500 million, this implies reduced opportunity cost for the European Union as a whole of roughly €250 million per MHz released, or €2.5 billion for the GSM-R band as a whole. We caution, however, that spectrum release could happen at very different times in different Member States; as a result, it might be a long time before a harmonised band is available for other purposes across the European Union.

These opportunity costs should be interpreted with caution, however, because (1) the GSM-R bands might possibly be re-purposed to support a successor technology; (2) assuming that the bands are not re-purposed, the time frame until the spectrum becomes available could be quite long, perhaps 2030 or later in many Member States; (3) the spectrum would not become available at the same time in all Member States, and might be in use much longer (perhaps indefinitely) in a few Member States; and (4) there would also be demand on whatever spectrum bands were used to provide successor services to GSM-R, which means that the net gain in terms of opportunity cost would be correspondingly reduced. If functional requirements and bandwidth demands are largely static, as we have assumed throughout this report, then the incremental opportunity cost in a successor band are likely to be small enough to ignore, provided that the successor band also supports some other application; however, if substantially more bandwidth is required than is needed for GSM-R today, the net gain in terms of opportunity cost will clearly be less than the €2.5 billion estimated here.

Furthermore, a €2.5 billion savings in opportunity cost does not represent nearly as large a savings as one might initially imagine. First, it is a figure for all of Europe, which might never be fully achieved. Second, it reflects one time auction value – on an annualised basis over the typical lifetime of auctioned spectrum, it is far less. Third, it is an opportunity cost savings that does not take into account the numerous real migration costs that would be incurred in order to fully achieve it.

Finding 11. For reasons outlined in SCF (2014), the cost of a cross-sectoral network based on MNO services for PPDR and rail might well be somewhat less than that of the private networks used today, even after allowing for the costs of hardening the network to provide reliability and expanding its coverage. At the same time, it is necessary to bear in mind that their analysis was primarily relative to existing PPDR networks, and only tangentially relevant to operational rail network requirements; moreover, their analysis rests on the assumption that a various reliability, coverage, management and practical requirements can be met that, in practice, quite possibly cannot be met. Further study is needed.

Finding 12. Taking migration costs into account (which is not fully possible until far more is known about the migration) an Enhanced Business as Usual approach (with private rail networks using modernised technology) might well

\textsuperscript{40}\textsuperscript{GSM-R share the UIC band with Defence in several Member States. Thus it is unlikely that this band could be heavily used by MFCN.}

\textsuperscript{41}\textsuperscript{Note that the opportunity cost is the cost relative to the highest valued use to which the resource (spectrum) could otherwise be applied, and is thus best reflected by the valuation implied by the price that the spectrum would fetch at auction. The opportunity cost is thus independent of any decisions as to alternative uses of the same spectrum.}

\textsuperscript{42}\textsuperscript{F. Pujol (IDATE), Spectrum Watch Service 2014.}
be comparable in efficiency to the various network sharing sub-Options that we have considered.

Finding 13. If the GSM-R bands can eventually be released, the opportunity cost for the European Union as a whole of up to roughly €2.5 billion could be freed. This number rests however on many assumptions, and must be interpreted with caution.
4. The Member State level

Key Findings

- In light of the substantial differences among the Member States, it is likely that they will reach different conclusions as to how best to proceed.
- European policy needs to recognise and accommodate the differences, but not at the cost of interfering with European goals (especially with interoperability and ability to roam with other dedicated/shared networks and commercial networks, all over Europe).
- Coverage requirements can differ greatly among different wireless applications. For rail operational networks, they differ as well as a function of speed and traffic of the lines. Stations, depots and shunting yards tend to require coverage at greater bandwidth than is needed elsewhere.
- There could be enormous value in re-use of the existing trackside GSM-R locations by a future replacement system. This does not necessarily imply that the same ownership and control model be carried forward. As long as a future successor to GSM-R were to operate in frequency bands similar to or slightly lower than the frequency band of GSM-R, and assuming no radical growth in bandwidth demands, the same route kilometres could be covered using the same sites.
- Multi-technology support has potential value. Current geosynchronous satellites are subject to substantial latency, but could nonetheless be better than lack of coverage in remote areas, and are in use for operational rail communications in other parts of the world. In the future (post 2030), use of MEO satellites to cover remote areas might bring considerable additional benefits.
- At Member State level, Options differ largely on the degree to which private networks, unmodified commercial networks, or commercial networks with modifications for mission critical services are use. Many hybrids are possible.
- At this level of analysis, it is necessary to distinguish between voice requirements and (ETCS) data requirements.

In this Chapter, we assess the decisions about rail communications to be taken at Member State level.43

Under the current legal framework, Member States have only limited discretion over technology, inasmuch as only one system and only one frequency band (plus an extension band) is allowed in the CCS TSI. Nonetheless, Member State decisions are crucial in determining which lines are covered (beyond those that are mandatory), and when (consider also Section 2.2). Member States also determine the operational and control model for rail operational communications, and provide funding.

Going forward, it is likely that a future CCS TSI will allow more than one technology and more than one frequency band. This is likely to effectively further expand the decision-making power of the Member States.

Member States also make decisions about other mission critical services, including PPDR and energy. The degree to which these networks are integrated with one another is therefore likely to also be largely or entirely a Member State decision (depending somewhat, however, on the approach taken at the European cross-sectoral level, as explained in Chapter 3).

43 We are taking liberties with the use of the term “Member State” here. A number of European countries that are not Member States of the EU or EEA apply the CCS TSI.
Member State decisions are not the primary focus of this study; rather, we are trying to formulate advice for rail communication decisions at European level. Nonetheless, it is clear that the choices that are likely to be interest to the Member States, some of which take into account not only rail transport but also other sectors including PPDR, set the framework within which European decisions need to be contemplated. European rail policy measures should support, or at least not make more difficult, the policies that the Member States are likely to want.

These decisions are likely to be taken at substantially different times in different Member States. The Member State decisions are likely to be taken years in the future, at a time when a great deal that is not known today about the technical evolution of commercial mobile networks has become clear. Moreover, the choices taken by the Member States might vary greatly from one Member State to the next based on valid considerations specific to each. For these reasons, it would be pointless to try to second-guess those decisions today. Nonetheless, there is a great deal that we can say about the considerations that are likely to shape those decisions.

A tacit assumption in this chapter, based on the assessment in Chapter 3, is that it is highly unlikely that the European Union will either build a massive pan-European network for rail operations, or will subsume all decision power over rail communications. We consider it far more likely that the current decision model will carry forward in some form, where the Union specifies requirements that ensure interoperability, permit roaming, and facilitate scale economies, while leaving it to the Member States to determine how best to fulfil those requirements within the national territory.

The decision-makers are Member State governments. The decision-makers span multiple sectors – these are not just rail decisions. The ministry of transport, however defined, will typically play a role, as will the rail Infrastructure Manager (IM). The Member State spectrum management authority (SMA) will typically also play a role.

We present this analysis prior to the chapter on rail communication decisions at European level (Chapter 5) because the content of this chapter largely drives the content of that chapter.

4.1. Differences in the respective positions of the Member States

The Member States differ greatly in terms of:

- The degree to which the existing GSM-R network already provides the necessary geographical coverage for rail operations, today and in the period up to roughly 2030;
- Largely as a consequence, the incremental cost that a dedicated network would require to achieve the desired coverage;
- The approach likely to be taken to mission-critical PPDR networking, and the willingness at Member State level to combine whatever approach is taken with a networking solution for rail operations.

In light of the substantial differences among the Member States, we consider it likely that they will reach different conclusions as to how best to proceed. Assuming that this is the case, European policy needs to recognise and accommodate the differences, to the extent that doing so does not interfere with European goals (especially with interoperability and ability to roam with other dedicated/shared networks and commercial networks, all over Europe).

4.1.1. Coverage requirements

Different kinds of mobile networks have very different geographical coverage requirements.

- Commercial mobile networks are generally interested in covering as much as possible of a country’s population, since it is the subscribers who generate the revenue.
• PPDR networks will also have greater interest in dense areas than in sparse, since that is where more of the incidents occur; however, they will want to coverage of the area of the national territory as possible, since an incident could occur anywhere.\textsuperscript{44}

• For a rail operations network, it is crucial to cover all of the \textit{route kilometres} of the rail network. At the same time, the quality of coverage could vary greatly depending on the speed of line and frequency of traffic over the line. It is already the case today that many low speed low frequency lines are covered by more limited communication services (provided e.g. by commercial MNOs)\textsuperscript{45} rather than GSM-R.\textsuperscript{46}

• Bandwidth demand tends to be particularly great in stations, depots, and shunting yards. These locations tend to require a high volume of concurrent communications. It is for this reason that technologies operating in licence exempt spectrum (such as Wi-Fi) or in somewhat higher frequencies (e.g. 5 GHz) may be particularly useful.

The coverage needs of the European rail network are evolving only slowly over time. New high speed lines take years to build. Thus, most high speed rail lines either already have GSM-R service, or can be expected to have GSM-R service long before a transition to a successor network is required. Thus, the cost of coverage of high speed rail lines by GSM-R can be viewed for our purposes as a \textit{sunk cost}.

Since there was no obligation to do so (before the extension of the scope of the CCS TSI in 2015), many countries have chosen not to extend GSM-R coverage to low speed, low frequency rail lines, especially in rural areas, but instead are using coverage provided by public networks and roaming (accepting reduced functionality). If countries were to choose to extend coverage (whether by means of GSM-R or of a successor technology) to lines that are not now covered by GSM-R, substantial additional investment would be required.

Finding 14. Coverage requirements can differ greatly among different wireless applications. For rail operational networks, they differ as well as a function of speed and traffic of the lines. Stations, depots and shunting yards tend to require coverage at greater bandwidth than is needed elsewhere.

\textbf{4.1.2. Cost implications}

GSM-R stakeholders consistently report that 80% to 90% of the capital cost of a GSM-R network is in the sites, in which they generally include not only buildings, but also masts, radio gear, back-haul arrangements, and any arrangements to ensure that an uninterruptible supply of power.\textsuperscript{47} It should be noted that the relative cost of equipment for radio and signalling in the vehicles is very low compared to the network cost.

Given the rather static geographic coverage that is required, \textit{there could thus be enormous value in re-use of the existing trackside GSM-R locations by a future replacement system.}

We assume here, as we have throughout, that bandwidth demand for operational rail communications is growing only slowly (see Section 2.3.2). If, however, throughput requirements were to grow, a more dense network might be needed. Depending on QoS requirements, the difference might be substantial.

Many have assumed that this would imply a continuation of the existing model of ownership and operation of GSM-R, but \textit{this does not necessarily follow.} As long as a future successor to GSM-R were to operate in frequency bands similar to or slightly lower than the frequency band of GSM-R, the same route kilometres could be covered using the same sites.\textsuperscript{48}

\textsuperscript{44} PPDR stakeholders express interest in covering rail routes, since they are potential areas for disasters; rail stakeholders note, however, that PPDR networks often do not cover rail lines today.

\textsuperscript{45} This is, for example, the case in France, Italy and Switzerland.

\textsuperscript{46} This can, however, vary greatly from one Member State to the next. In Germany, for example, commercial mobile networks reportedly cover some 99% of rail lines, and are used as a backup to GSM-R, and in lieu of GSM-R for rural lines with infrequent train movement.

\textsuperscript{47} The ability to achieve these savings in practice will depend on various factors, including the shape of the track, base station antenna characteristics, and the absence of obstacles.

\textsuperscript{48} A tacit assumption here, as throughout the report, is that traffic requirements are growing only slowly (see Section 1.1). If the traffic volume were to grow radically, the network design might need overall re-thinking.
Suppose, for instance, a Member State government (or its Infrastructure Manager (IM)) were to contract with an MNO to install LTE base stations, operating in the 800 MHz band, in the same locations where GSM-R operates today, using the same masts and the same reliable power arrangements. In principle, it should be possible to cover roughly the same route kilometres, since the propagation characteristics would be marginally better than those of GSM-R.

The MNO might choose to also serve public users from the same location (subject to careful arrangements to ensure that rail operations are not crowded out at times of high consumer demand and during incidents); however, service to consumers would tend to be uninteresting for long rural stretches of rail where few consumers live. As long as the network operator were serving only rail operations from the location in question, the existing back-haul arrangements would likely also be sufficient (since rail operational bandwidth requirements are at present growing very slowly if at all, as explained in Chapter 2). In some Member States today, licences for commercial spectrum include an obligation to provide coverage to areas where the commercial interest of the MNO would not otherwise lead it to provide coverage, such as railway lines.

If the Member State were interested in a PPDR network, similar considerations might apply. If PPDR spectrum were to become available in the 700 MHz band or in the range of 450-470 MHz (with some loss of efficiency, since more sites are deployed than are strictly needed), then once again the existing route kilometres could be served from the same locations, and the PPDR network could presumably use the same facilities to expand its own geographical coverage. Since bandwidth requirements for rail operations are minimal, there is little risk of rail operations interfering with PPDR needs; however, there is risk that PPDR traffic might interfere with rail operations traffic unless the traffic is carefully managed. The amount of spectrum needed, and also the backhaul capacity to the sites, would however need to reflect PPDR needs (which are presumably much greater than those for rail operations).

All of this implies that path dependencies play a huge role here. The position of the Member States will tend to vary based on (1) the degree to which they have already deployed GSM-R, or will have deployed it before a switch is needed; and (2) the degree to which they want or are required to support new rail lines (e.g. at lower speed or frequency) using the same infrastructure. The lowest cost alternative might be very different in one Member State than in its neighbours. This will tend to lead to different choices being taken.

Finding 15. There could be enormous value in re-use of the existing trackside GSM-R locations by a future replacement system. This does not necessarily imply that the same ownership and control model be carried forward. As long as a future successor to GSM-R were to operate in frequency bands similar to or slightly lower than the frequency band of GSM-R, and assuming no radical growth in bandwidth demands, the same route kilometres could be covered using the same sites.

4.1.3. Integration with PPDR capabilities

As noted repeatedly noted throughout, different Member States are likely to take different approaches to PPDR broadband networking. Some may choose to contract operation out to commercial MNOs, system integrators, or MVNOs (as the UK is currently attempting to do); others may continue to prefer dedicated PPDR networks, as is the case with TETRA and TETRAPOL.

Whatever approach is taken for PPDR broadband networking, the Member State should consider possible synergies and financial savings through joint operation with rail. The practicability of doing so, however, will vary greatly from one Member State to the next. Whenever operational rail networks share facilities with commercial or other mission critical networks, proper prioritisation of traffic is essential (see Sections 4.4.2 and 4.4.3).

There are also examples of coverage obligations for rural areas, e.g. in Germany.
4.1.4. Multi-technology networks

Work is already ongoing to provide a clean partition of function between the applications that run over GSM-R (including ETCS) and the underlying transport mechanism (see Section 5.4.1). This potentially enables multi-technology network models based upon several IP-based bearers. Various technologies such as GSM-R (GPRS/EDGE), LTE, future 5G, and satellite could be combined. In many cases, these multi-technology networks would also be hybrids, operating under more than one model of ownership and/or control. For instance, a Member State might choose to use a commercial satellite services provider to cover remote parts of the national territory served by lines with less stringent traffic requirements.

Solutions that incorporate Wi-Fi, satellite, or other technological platforms that do not include specific adaptations for mission critical services tend to pose challenges as regards (1) security (including both the integrity and the confidentiality of communications), (2) availability and robustness, and (3) ability to prioritise mission critical traffic over other traffic (see also Sections 4.4.2 and 4.4.3).

The potential benefits of multi-technology networks are manifest, but there are also costs that should not be forgotten. A more complex mix of technologies may imply increased cost for equipment suppliers. Roaming and interoperability potentially become more complex as the combinatorial complexity of configurations increases. This very likely increases the cost of certification and testing, and may possibly also have negative implications for reliability. It is thus important to avoid a needless proliferation of supported configurations (see also Section 5.4.2).

It is particularly likely that a mix of technologies will be needed during migration. Once again, it will be important to ensure that the number of supported configurations does not get out of hand, potentially ballooning costs.

Multi-technology networks are viewed in the context of our analysis not as an Option, but rather as a capability that a given Option may or may not be able to support. Multi-technology networks can, in principle, be supported under many of the Options, but not all.

**Satellite**

Satellite communication can be useful for bringing connectivity to remote areas which would otherwise be expensive or impractical to serve. To some extent, this is already the case today, but more so in other parts of the world than in Europe. There are two main opportunities:

- Current and future use of geosynchronous (GEO) satellites, or
- Future use of Medium Earth Orbit (MEO) satellites.

Signals transmitted by means of GEO satellites invariably experience high latency or delay. GEO satellites orbit the earth once per (sidereal) day, and thus appear to stay roughly stationary over a particular point on the earth. This simplifies the task of aiming an antenna at them. Such an orbit is possible only at an altitude of 35,786 km above mean sea level, which implies a round trip time for radio waves of roughly 250 milliseconds. Since this latency is a function of orbital mechanics and the speed of light, no technological enhancements can be expected to improve it.

This delay affects data services, especially delay sensitive data services such as ETCS. It does not outright prevent all voice communications, but two parties to a conversation are likely to start to speak at the same time because neither realises that the other has already begun to speak. For group calls, this could be a severe impediment.

Operational rail services depend both on voice services and, notably in the case of ETCS, data services. For satellite to be an attractive solution, it should ideally be able to support both.

The use of GEO satellites for rail operational data has been implemented in other parts of the world, and is being actively explored in Europe. The European Space Agency (ESA) is supporting the 3InSat project, an IP-based satellite scheme that is being tested in Sardinia. Based on this experience, project participants claim that GEO satellite latency can be
managed by the train control systems, especially for low traffic, regional or local lines. In the short term, use of geosynchronous satellites to cover remote parts of Europe that would otherwise be difficult to serve might bring considerable benefits. This may be particularly interesting for lines that, due to lower speed and lower density of traffic, have lower traffic demand.

Historically, Low Earth Orbit (LEO) communication satellites have often been subject to financial difficulties; nonetheless LEO communication systems such as Iridium exist, and are not subject to high latency (because they orbit much closer to the earth). ESA has expressed the view that GEO/LEO solutions could be found and deployed if the rail sector could provide clear requirements.

In the future, MEO (Medium Earth Orbit) satellite might represent a less problematic solution. MEO satellites operate closer to earth, and thus represent a better balance between on the one hand entailing much less latency, and on the other covering a substantial fraction of the earth with each MEO satellite. According to the preliminary results of the Satcom4Rail project, in the future, a possible candidate system could be a MEO satellite constellation in the C-band, but such a system could only become a reality in 2030 at the earliest. The Satcom4Rail project sees merit in MEO C-band solutions if existing satellite systems prove unable to meet rail requirements, and provided that the railway functionality remains stable.

The Satcom4Rail project explores the introduction and authorisation of satellite communications in support of railway critical safety and liability applications and services. The project has a limited scope, but preliminary results from the project suggest that GEO/L-band INMARSAT (with worldwide coverage) could provide a latency (i.e. transaction time, one-way) of around 242 milliseconds, and could also be supported in handhelds (but not for safety critical communications) for narrow band applications. GEO/Ku-band (with coverage in Europe) could provide a latency of around 256 milliseconds for broadband applications, but would not be supported by handhelds.

Satellites could play a useful role in a multi-technology network, potentially not only for rail but also for PPDR50.

### Wi-Fi

Wi-Fi, as standardised by IEEE, uses unlicensed frequency bands in the 2.4 and 5 GHz frequency bands. The latest technical improvements involve wider bandwidth and the use of MIMO to boost data rates. Given the limited range of Wi-Fi systems due to the use of unlicensed frequency bands and low power; it is expected that coverage of Wi-Fi systems would be limited to train stations and their immediate environs.

Finding 16. Multi-technology support has potential value. Current geosynchronous satellites are subject to substantial latency, but could nonetheless be better than lack of coverage in remote areas, and are in use for operational rail communications in other parts of the world. In the future (post 2030), use of MEO satellites to cover remote areas might bring considerable additional benefits.

#### 4.2. The Problem at the Member State (national) level

Within the European Union, we generally speak of the Member State level; however, it is important to remember that a number of the relevant countries here are not Member States (e.g. Switzerland).

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50 Antenna size is part of the conditions that may make the option of using satellite services successful. It should also be mentioned that satellite can also provide backhaul links between 3GPP network equipment.
In some Member States, there may be an attempt to deal with multiple mission-critical sectors in an integrated way; in others, however, different approaches are likely to emerge, e.g. keeping separated dedicated networks for each sector.

Sufficient for our purposes is to define a Problem statement at Member State level that is specific to the rail sector.

- Identify technical, spectrum management, and policy measures to be undertaken to enable continued provision of critical operational communications functionality to the rail sector within the Member State in question and in an interoperable way with the rest of Member States as technology and markets evolve going forward.

### 4.3. Rail-specific Objectives at Member State level

In principle, identifying Objectives is an exercise for the Member States; nonetheless, we put forward the following General Objectives for the rail-specific Problem at Member State level:

- Support all current and anticipated future mandatory rail operational functionality (including communications to and from the dispatcher, ETCS support, and Railway Emergency Call) at a reasonable cost using modern, supportable technology.
- Support additional rail functionality (possibly including business-supporting communications) to the extent that the same mechanisms can do so at reasonable cost.

As noted in Sections 1.1 and 2.3.2, railway functional requirements appear to be evolving very slowly. The Objective of this study is not to investigate the functionality that railways may require in the far future (see also Section 1.3). Based on the conclusions of the Ex-Post Evaluation of GSM-R conducted by ERA, there is no indication that new basic functionality for signalling and traffic operation will be required by all the railways in the close future. Therefore, the hypothesis is that only the current functionality in the CCS TSI needs to be migrated to the new systems.

Other organizations are investigating the evolution of the functionalities requested by railways. In particular, UIC, in its project “Future Railway Mobile Communication System” (FRMCS), will carry out a study on future functionality. The results of this study are not available at the moment of writing the current report. This study cannot yet benefit from the deliverables of the FRMCS project or of other projects.

If the hypothesis is changed, the analysis in this study may have to be reviewed.

### 4.4. Network Options

Broadly speaking, the Options available at Member State level can be distinguished based on the degree to which they depend on (1) networks dedicated to rail operations, (2) commercial mobile networks with few if any modifications to accommodate rail operations, or (3) networks based on commercial mobile technology (e.g. some form of LTE), but enhanced to support rail operations (and PPDR), as depicted in Figure 4.

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51 In this document, for clarity, the term *mandatory* is used for items related to the CCS TSI, and the term *additional* is used for items not related to the CCS TSI. The term *optional* can be confusing, because in this document Options are used for other purposes.

52 Rail stakeholders are generally of the view that it is impractical to support passenger entertainment or general communications with the same networks and technologies as train operations. Doing so would entail numerous regulatory and policy complexities, and would also require orders of magnitude more bandwidth (and thus a substantially different design) than is required for train operations.


54 NGTC and Shift2Rail projects are to be considered.
The “rail-specific network” might represent a GSM-R network as it might exist today, or might represent a future “GSM-R successors” network. In either case, we are talking about a solution at Member State level that is utilised solely for rail operations (and possibly some other rail functions).

The “standard commercial mobile network” is a public mobile network that does not contain special enhancements, capabilities, or “hardening” to make it particularly suitable for rail operations, e.g. an LTE network operated by a normal MNO.

The “network with rail and PPDR enhancements” might be based on the same basic technology and standards as a commercial mobile network, but includes special functionality to support functions such as rail emergency call and group calls (as might be available for instance in LTE Release 13), together with guaranteed capacity, quality of service and availability and enhanced robustness.

Somewhat in contrast to normal Impact Assessment practice, these Options cannot be viewed as being mutually exclusive.

- First, there is a relationship on the time axis. In all conceivable scenarios, for instance, existing GSM-R solutions will co-exist with other solutions for many years, probably until 2028 or 2030.
- Second, there will often to be an overlapping relationship in terms of space or geography. It is quite likely that solutions based on standard commercial mobile networks will co-exist with solutions based on, for instance, networks with enhancements to support rail and/or PPDR operations in the same Member State at the same time (with the commercial solutions used, for example, for slower speed or lower frequency lines).

These Options differ from one another chiefly in that rail operations functionality cannot depend on more network functionality than the network is capable of providing. Commercial mobile networks routinely provide only a subset of the functionality and robustness that rail operations ideally seeks (see Figure 5). To use a commercial mobile network with no special enhancements, either the rail-specific functionality must be re-architected so as to eliminate dependencies on rail-specific network enhancements, or rail must do without the respective capabilities.\textsuperscript{55}

\textsuperscript{55} “Doing without” may be feasible depending on the traffic characteristics, but is presumably out of the question for high speed lines operating under ETCS Level 2 or later.
In none of these cases do we distinguish as to who owns or controls the respective network or networks. That is unimportant, as long as the Member State ensures that there are reliable assurances that committed service levels will be met. Multiple solutions already exist within Europe today.

With that said, the Options of interest are as described in the following sub-sections.

**Finding 17.** At Member State level, Options differ largely on the degree to which private networks, unmodified commercial networks, or commercial networks with modifications for mission critical services are use. Many hybrids are possible.

### 4.4.1. Rail-specific networks

In these Options, rail continues to operate single-purpose specialised networks.

**GSM-R**

Rail continues to use GSM-R technology. Where required, implementation of GSM-R successors can take place, providing enhancements for voice and data capacity, robustness (geo-redundant cores), resilience against interference, etc. It should be noted that GPRS / EDGE will only increase (radio channel) capacity for data traffic but not for Voice. In addition the maintainability and ability for evolution of GSM-R will decrease due to increased obsolescence of the corresponding know-how.

**GSM-R successors**

There is no official published standard as of now, but we assume that GSM-R successors will imply that rail evolves to use an enhanced form of transmission, that remains compatible with GSM-R or moves to a newer, already existing network technology such as LTE. It would represent an all-IP evolution of the GSM-R core and radio network, together with the
coexistence with other technologies. Applications providing railway functionality would be de-coupled as much as possible from the characteristics of the radio bearer. Applications would be de-coupled as much as possible from the characteristics of the radio bearer. In any case, GSM-R successors will have to remain interoperable with GSM-R due to the expected length of the migration time.

As far as spectrum is concerned, there will be a need to control the network and spectrum (in case specific bands are to be used and licenses owned by railways). In case spectrum is used under a LSA-type scheme, this will require strict geographical separation and coordination will be required (not excluded possibility of PPP).

The GSM-R successor operator could also be a MVNO using a combination of unmodified and/or modified commercial mobile networks and even PPDR networks. Various options could be considered depending on the equipment operated by the MVNO (core network operated by the MVNO, virtual core network provided to the GSM-R successor operator…).

The MVNO could also operate over all commercial MNOs (and this should be an obligation in their license) but it should be noted that no opportunity is foreseen for this scenario by most mobile operators.

4.4.2. Unmodified commercial mobile networks

In this Option, rail uses commercial mobile and/or satellite networks with little or no special adaptation to rail-specific needs other than commitments to cover the relevant lines.

In the most likely near term configuration, rail applications would become independent from the radio bearer level. They would operate using IMS platforms on LTE networks. Traffic management would appear to represent a serious concern. At times of stress (for instance, a natural disaster), networks would tend to be overloaded with normal commercial traffic. In the absence of prioritisation mechanisms, mission critical traffic might not get through. Prioritisation between or among multiple mission critical services must also be addressed. In this Option, it is crucial not only that deployed networks have the right technical capabilities, but that network operators configure their networks to properly favour mission critical applications.

4.4.3. Networks with rail (and PPDR) enhancements

In this Option, rail would use a network based on technology beyond current GSM-R and its immediate successors, such as LTE. The network could either be a commercial mobile network, or a network dedicated to train operations and possibly including support for other mission-critical applications such as PPDR. In either case, the network would reflect extensive special adaptations to meet rail-specific (and possibly PPDR) needs, and substantial hardening of facilities, together with commitments to cover the relevant lines. Among the special adaptations needed would be traffic prioritisation and pre-emption mechanisms to favour mission critical traffic over any normal commercial traffic (see also Section 4.4.2).

In the most likely near term configurations, rail applications would become independent from the radio bearer level. They would operate using IMS platforms on LTE networks that actively support (for instance) LTE Release 12 and 13 capabilities, and that have been enhanced for reliability and robustness.

In a number of plausible scenarios, it might be useful to employ some form of LTE in the existing GSM-R bands (876-880 MHz (uplink) and 921-925 MHz (downlink)), either alone or else co-existing with GSM-R (see Section 5.4.3). The feasibility of doing so has not been studied.

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56 The decision to make rail applications bearer independent is in principle a European rail decision, not a Member State decision (see Section 5.4.1); however, the viability of this Member State decision depends to a significant degree on the success of that European rail sector decision.

57 Again, the decision to make rail applications bearer independent is in principle a European rail decision, not a Member State decision; however, the viability of this Member State decision depends to a significant degree on the success of that European rail sector decision.
Satellite networks would most likely serve a complementary role for low speed and/or low frequency lines (e.g. regional lines).

**Enhanced commercial mobile networks**

In this Option, rail uses commercial mobile networks with extensive special adaptations to meet rail-specific (and possibly PPDR) needs, together with commitments to cover the relevant lines.

**Mission-critical networks**

In this Option, rail uses dedicated non-commercial mobile networks (possibly together with other mission-critical sectors) with extensive special adaptations to meet rail-specific (and possibly PPDR) needs, together with commitments to cover the relevant lines.

**4.4.4. Hybrid networks**

In principle, many hybrid solutions are possible. The one that we have identified as being of particular interest for purposes of this study is a solution where either a rail-specific network or a network that includes rail-specific enhancements is used to cover part of the national territory, but one or more commercial mobile or satellite networks (with few or no rail-specific enhancements) are used as radio access bearer to cover portions of the national territory where railway traffic conditions permit. “Hybrid” could potentially have many different meanings. What is meant here is a solution where different parts of the national territory are covered by physically distinct networks using distinct equipment. A solution based solely on different generations of mobile switching equipment would not necessarily be hybrid in this sense, since the mobile services could probably be provided by a single network offering multiple mobile capabilities.

**4.5. Assessment of impacts**

**4.5.1. Definition of criteria**

These criteria were collected during the first workshop and are grouped to align them with EU impact assessment methodology.

**Effectiveness**

Effectiveness must consider both normal operation and operation under stress (e.g. at times of bad weather, natural or man-made disasters …).

In hybrid networks, and in multi-technology networks, these criteria need to be understood in relation to each of the networks or technologies involved. The qualitative assessment that follows in Section Error! Reference source not found. is, to that extent, an oversimplification.

In our assessment, we take into account the following effectiveness criteria:

- Coverage: geographical coverage of rail tracks, railway stations and tunnels
- Reliability. It should be noted that on many railway lines “commercial network’s reliability” is considered as sufficient.
- Robustness (i.e. reliability in the face of stress)
- Resilience to Interference. It is expected that today’s situation with GSM-R (interferences from public GSM to GSM-R) is not repeated, and that obligation to be protected against interferences is imposed both at the network side (license obligation) and at the terminal side (hardened terminals).
- Latency (i.e. end to end delay across the network)
- Security: embraces both jamming of radio networks and hacking of IP-based networks. Originally the terms jamming and interferences were used interchangeably but nowadays most radio users use the term “jamming” to describe the deliberate use of
radio noise or signals in an attempt to disrupt communications (or prevent listening to broadcasts). Hacking is "Break into computer systems or software" and is increasingly being performed for intrusion in IP networks. Hacking though the increasing deployment of IP-based solutions has to be taken into account and specific measures are mandatory in order to ensure security at IP-level. The fact that railway networks are not in a closed circuit mode and are connected to the Open Internet increases risks of intrusion. It is a matter of both IP and SIP and Diameter.

- Traffic prioritisation: the selected system needs to be able to control traffic overload and manage communication priorities.
- Functionality: This criterion includes capabilities embedded in the GSM-R standard, such as functional addressing, location dependent addressing, and group call. Requirements might differ by railway line category.
- Capacity: capacity to support traffic both at the radio interface and in the network sub-system.
- Ease of use: the future communications system should be as seamless as possible ("plug and play" onboard modules).
- Ease of migration: the future solution will require both backward compatibility with existing solutions and a step-by-step migration seems to be preferable. The costs of transition are not integrated in this criterion but in the efficiency category.
- Ability to incorporate satellite and/or Wi-Fi on suitable lines

Interoperability and support for roaming are not listed as criteria because they are firm requirements for all Options. Their importance and societal value for Europe are clear.

### Efficiency

The cost of network deployment and operation include migration costs as well as new network costs or renting costs. This would include both CAPEX (Capital Expenditures) and OPEX (Operational Expenditures). Various ownership and control models are possible, but these costs are typically carried by the Member State and are thus relevant here. Many of these costs are typically borne by the Member State infrastructure managers (IMs), but are effectively passed through to the railway undertakings (RUs, i.e. train operating companies) through track access charges.

In our assessment, we take into account the following efficiency criteria:

- Network CAPEX
- Network OPEX
- Terminal CAPEX
- Spectrum opportunity costs
- Opportunity to support other services: i.e. the ability to support commercial communications (for railways staff) and/or entertainment communications (for passengers)
- Time sequencing/lifetime: there needs to assess the time development/deployment of the new system when assessing the different solutions likely to be chosen and expected lifetime of these solutions. This criteria becomes particularly relevant when assessing new technologies in new frequency bands for instance (need to assess likely spectrum allocation timelines).

### Coherence

- Legal restriction: e.g. equipment has to be owned by the IM, e.g. Railways considered as critical infrastructure with specific requirements

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58 no detailed cost analysis was requested in the ToR but cost indications are given in annex
• Manageability: This criterion reflects the ability to verify operator compliance with pre-defined obligations. How to measure that operators do comply with their obligations (QoS) is a strong requirement from the railways community. The services needed by the GSM-R community have to be traceable, contractable. If not, the services fail in compliancy requirements.

• Social impacts: this criteria takes into account possible resistance from railways telecom engineers to change to a new radio network and staff competency requirements (it becomes difficult hiring experienced people in radio/IP networks and this has a direct impact of overall costs: costs of training and salary costs). However, this issue can be undermined by alternative solutions such as network sharing/outsourcing. It is likely that it will be impossible to hire staff with required GSM-R know how on the long term perspective because the technology is obsolete.

• Certification is not included in the table. Both terminal and network certification are critical; however, this is a general European rail issue, and is addressed in Chapter 4.5.

4.5.2. Qualitative assessment

Qualitative assessment is presented in this section for ETCS data applications and for voice applications.

Benefits and costs are to the rail sector in the Member State, as might be seen from the perspective of the Member State government. There are costs and benefits to other sectors that will surely be of interest to the Member State government, but they are not directly addressed here since they are somewhat outside the scope of this study.

ETCS data applications

For each option, we provide in the table below our evaluation of the criteria for ETCS data applications:

59 But a stakeholder mentioned the opposite problem of people not wishing to be seen as old fashioned and out of touch with modern technology
Table 4. Qualitative assessment of various approaches at Member State level – ETCS data

<table>
<thead>
<tr>
<th></th>
<th>Rail-specific networks</th>
<th>Unmodified commercial mobile networks</th>
<th>Networks with rail and possibly PPDR enhancements</th>
<th>Hybrid networks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GSM-R</td>
<td>GSM-R successors</td>
<td>Enhanced commercial mobile networks</td>
<td>Mission-critical networks</td>
</tr>
<tr>
<td><strong>Effectiveness overall</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Coverage</td>
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<tr>
<td>Reliability</td>
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<td>0</td>
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<tr>
<td>Robustness</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>Resilience to interference</td>
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<tr>
<td>Latency</td>
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<td>Security</td>
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<td>-</td>
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</tr>
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<td>Functionality</td>
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<td>0(^{61})</td>
<td>0</td>
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<tr>
<td>Capacity</td>
<td>0</td>
<td>+</td>
<td>++</td>
<td>++</td>
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<tr>
<td>Ease of use</td>
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<tr>
<td>Ease of migration</td>
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<td>0</td>
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<td>-</td>
</tr>
<tr>
<td>Ability to incorporate satellite and/or Wi-Fi on suitable lines</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
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<tr>
<td><strong>Efficiency overall</strong></td>
<td>0</td>
<td>0</td>
<td>+</td>
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<tr>
<td>Network CAPEX</td>
<td>0</td>
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<td>Network OPEX</td>
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<tr>
<td>Terminal CAPEX</td>
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<tr>
<td>Spectrum opportunity costs</td>
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<tr>
<td>Ability to support rail business services(^{63})</td>
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<td>++</td>
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<tr>
<td>Ability to support railway operations/services</td>
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<td>Time sequencing/lifetime</td>
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<td>Coherence</td>
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<tr>
<td>Legal restriction</td>
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<tr>
<td>Manageability</td>
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<td>-</td>
<td>-</td>
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<tr>
<td>Social impacts</td>
<td>0</td>
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<td>-</td>
<td>-</td>
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</tbody>
</table>

Note: the ratings that are used are 0 (to denote impacts the same as those of the baseline), + (better than the baseline), ++ (much better than the baseline), - (worse than the baseline), and -- (much worse than the baseline).

For each of the criteria noted above, we explain our evaluation.

For a hybrid network using a private network on for instance high speed lines, and commercial mobile services and/or satellite on lines where traffic permits, the limitations of

\(^{60}\) In hybrid networks, the portion of the territory covered by other means (for instance, GEO satellite) is likely to experience greater latency than portions covered by any form of mobile services.

\(^{61}\) Linked to current and forthcoming network neutrality laws, which may need revision.

\(^{62}\) LTE does not support high speeds today but could support up to 500 km/h if standardisation is adapted. Various capabilities in the GSM-R standards will not necessarily be supported by commercial mobile networks, nor by satellite or Wi-Fi networks in hybrid configurations.

\(^{63}\) Support of consumer services such as entertainment is typically not allowed today.
the networks that lack special accommodations for rail or other mission critical services are relevant only to the lines where they are deployed.

**Effectiveness**

- **Interoperability** (not part of the table but added here for clarity): the flexibility of on-board equipment and the related certification process will be a key item for further investigation.
  - GSM-R successors, enhanced commercial mobile networks and mission-critical networks will
  - Commercial unmodified networks & Hybrid networks will probably present interoperability hurdles

- **Coverage:**
  Main sources: interviews (Astrid, EIM, CER, KPN...), desk research
  - GSM-R successors: same radio network provides the same coverage as GSM-R today
  - Commercial unmodified networks are not likely to provide the same coverage as GSM-R networks unless they are paid to do so (see Chapter 3)
  - Enhanced commercial mobile networks will be adapted so that coverage is at least as good as GSM-R networks
  - Mission-critical networks (e.g. PPDR networks) will be adapted so that coverage is at least as good as GSM-R networks
  - Hybrid networks: A hybrid network using satellite networks for remote areas could provide better coverage than GSM-R

- **Reliability**
  Main sources: interviews with requesting stakeholders and with manufacturers, desk research
  - GSM-R successors: same radio network provides the same reliability as GSM-R today
  - Commercial unmodified networks are not able to provide the same reliability as GSM-R networks unless they are paid to do so (see Chapter 3)
  - Enhanced commercial mobile networks will be designed so that reliability matches GSM-R networks reliability
  - Mission-critical networks. No indication so far that PPDR networks plan to have a similar reliability as GSM-R. Till now, PPDR representatives claim that their target is similar to commercial networks.
  - Hybrid networks: the combination of various networks with multiple providers could negatively affect reliability, and the use of commercial mobile networks raises possible concerns unless explicitly addressed

- **Robustness**
  Main sources: interviews and SCF report, desk research
  - GSM-R successors: same radio network provides the same robustness as GSM-R today
  - Commercial unmodified networks are not able to provide the same robustness as GSM-R networks unless they are paid to do so (see Chapter 3)
  - Enhanced commercial mobile networks will be designed so that robustness matches GSM-R networks robustness
  - Mission-critical networks: no indication so far that PPDR networks plan to have a similar reliability as GSM-R. Till now, PPDR representatives claim that their target is similar to commercial networks.

---

64 This is the date of start of transition.
- Hybrid networks: the combination of various networks with multiple providers could negatively affect robustness, and the use of commercial mobile networks raises possible concerns unless explicitly addressed

- Resilience to Interference:
  Main sources: interviews (CER, BnetzA, ECO, TrioRail...), desk research
  - We consider that the GSM-R band is subject to interference today from GSM in the adjacent band, and that other frequency bands for LTE or PPDR networks will not be affected by the same adjacent band interference. Given the experiences with GSM-R interference, future decisions on spectrum, receiver quality and coordination will take into account interferences in a better way.
  - GSM-R successors: ensuring protection against interferences is considered as a basic need, so it should be better than GSM-R. Better coordination and mandatory prevention of interferences will be included as a basis for any GSM-R successor.
  - Mission-critical networks: Given the experiences with GSM-R interference, future decisions on spectrum, receiver quality and coordination will take into account interferences in a better way. Mission-critical terminals must be hardened. It is not a matter of technology but of availability requirements and of network density.
  - Hybrid networks: might be affected by interferences in unlicensed bands (eg. WiFi)

- Latency
  Main sources: interviews, desk research
  - GSM-R successors: same radio network provides the same latency as GSM-R today
  - Commercial unmodified networks may provide good latency (and possibly better with LTE technology than with GSM technology), but will not necessarily provide the same latency as GSM-R networks unless they are paid to do so
  - Enhanced commercial mobile networks will be designed so that latency matches GSM-R networks latency
  - Mission-critical networks can provide the same latency as GSM-R networks
  - Hybrid networks: the combination of various networks with multiple providers could negatively affect latency, especially if geosynchronous satellites are used for portions of the national territory, and the use of commercial mobile networks raises possible concerns unless explicitly addressed

- Security
  Main sources: interviews (Astrid, Bouygues Telecom, CER, ERTMS UG, Network Rail...), desk research
  - GSM-R successors: the IP network sub-system, SIP and Diameter will have to be specifically designed in order to provide the same security level as GSM-R today
  - Commercial unmodified networks do not provide the same security as far as the IP/SIP/Diameter part is concerned
  - Enhanced commercial mobile networks will be designed so that security matches GSM-R networks security
  - Mission-critical networks will provide the same security level as GSM-R networks
  - Hybrid networks: the combination of various networks with multiple providers could negatively affect security, and the use of commercial mobile networks raises possible concerns unless explicitly addressed. Wi-Fi access points are easier to hack than cellular networks.
- Traffic prioritisation
  Main sources: interviews (ASTRID…) and SCF report, desk research
  - GSM-R successors networks presumably offer traffic prioritisation
  - Commercial unmodified networks will most probably not offer traffic prioritisation even though this will be technically possible; it might not be allowed due to political decisions (such as today’s situation, where public networks are not allowed to treat different users in a different way).
  - Enhanced commercial mobile networks will probably offer traffic prioritisation
  - Mission-critical networks shall provide traffic prioritization
  - Hybrid networks: the use of commercial mobile networks raises concerns unless explicitly addressed

- Functionality
  Main sources: interviews with manufacturers, desk research
  - GSM-R successors networks could offer the same functionalities as GSM-R networks plus higher data rates services
  - Commercial unmodified networks are not likely to support GSM-R-like specific services
  - Enhanced commercial mobile networks could support GSM-R-like specific services
  - Mission-critical networks could provide GSM-R-like specific services
  - Hybrid networks: the use of commercial mobile networks raises concerns unless explicitly addressed

- Capacity
  Main sources: interviews with manufacturers, desk research
  - GSM-R successors : Enhanced capacity, thanks to move to packet mode and full-IP
  - Commercial unmodified networks will offer higher capacity than GSM-R networks
  - Enhanced commercial mobile networks will offer higher capacity than GSM-R networks
  - Mission-critical networks will offer higher capacity than GSM-R networks but are likely to operate a limited amount of spectrum compared to commercial networks
  - Hybrid networks: depending on implementation, might offer higher capacity than GSM-R networks

- Ease of use
  Main sources: interviews (manufacturers), desk research
  - GSM-R successors : as easy to use as GSM-R networks
  - Commercial unmodified networks will not support some specific railways services except if the separation of application and transport is really achieved
  - Enhanced commercial mobile networks will be easy to use but not as easy to use as GSM-R because they will not be dedicated to railways
  - Mission-critical networks will be easy to use but not as easy to use as GSM-R because they will not be dedicated to railways
  - Hybrid networks: probably more complicated than on a single network

- Ease of migration
  Main sources: interviews, SCF report, desk research
  - GSM-R successors : quite easy as there will be limited modification to the radio networks

65 Depends on interpretation of forthcoming EU legislation related to network neutrality (will operators be authorised to prioritize certain traffic flows for commercial operation?)
- Commercial unmodified networks will be easy to adapt
- Enhanced commercial mobile networks will be fully “plug and play”
- Mission-critical networks will need specific adaptations to railway needs (e.g. terminals)
- Hybrid networks: probably more complicated than on a single network

Ability to incorporate satellite and/or Wi-Fi on suitable lines

Main sources: interviews, SCF report, desk research
- GSM-R successors will enable easy integration of satellite and/or Wi-Fi
- Commercial unmodified networks will enable easy integration of Wi-Fi but satellite integration probably more complex
- Enhanced commercial mobile networks will enable easy integration of Wi-Fi but satellite integration probably more complex
- Mission-critical networks will enable easy integration of satellite and/or Wi-Fi
- Hybrid networks will enable easier integration of satellite and/or Wi-Fi since their basic characteristic is the combination of different networks, including non 3GPP.

Efficiency

- Network CAPEX

Main sources: SCF study, interviews (Agurre…), desk research (see detailed cost figures in annex)
- GSM-R successors: limited CAPEX for implementation of an IP network sub-system. This equipment is likely to be the same as commercial GSM networks.
- Commercial unmodified networks do not require any CAPEX from the railways
- Enhanced commercial mobile networks are the best option in terms of CAPEX vs the basic features (coverage, robustness, reliability…)
- Mission-critical networks: the cost of deploying such networks depends on the frequency band used but will be supported by a third party. Areas to be covered by PPDR and railways are not the same. Who would pay for what has to be defined.
- Hybrid networks: because the solution could be tailored to line requirements, would tend to be less expensive than other solutions

- Network OPEX

Main sources: SCF study, interviews, desk research (see detailed cost figures in annex)
- GSM-R successors: are expected to bring lower OPEX than GSM-R
- Commercial unmodified networks: leasing capacity to commercial mobile operators is likely to be more expensive than GSM-R OPEX
- Enhanced commercial mobile networks: leasing capacity to commercial mobile operators is likely to be more expensive than GSM-R OPEX but broadband data services and more capacity will be available
- Mission-critical networks: leasing capacity to a PPDR operator is likely to be more expensive than GSM-R
- Hybrid networks: because the solution could be tailored to line requirements, would tend to be less expensive than other solutions

- Terminal CAPEX

Main sources: SCF study, interviews, desk research (see detailed cost figures in annex)
- GSM-R successors: cost should be close to GSM-R terminals
- Commercial unmodified networks & Enhanced commercial mobile networks: cheap terminals are available. Onboard terminals should include protection against interferences additional filtering. The cost of such a modification is negligible compared to the overall cost of the GSM-R terminal.
- Mission-critical networks: cost should be similar to GSM-R terminals
- Hybrid networks: the cost of supporting multiple technologies will raise the terminal cost

- Spectrum opportunity costs
  Main sources: interviews with regulator stakeholders, desk research
  - GSM-R successors: the same spectrum is used
  - Commercial unmodified networks: no specific spectrum used
  - Enhanced commercial mobile networks: no specific spectrum used
  - Mission-critical networks: spectrum probably paid by the PPDR user but could also be paid by the railways or both.
  - Hybrid networks: no specific spectrum used

- Ability to support other services
  Main sources: interviews, desk research
  - GSM-R successors: very limited ability to support commercial communications and restrictions in the terms of licence
  - Commercial unmodified networks: already support commercial services
  - Enhanced commercial mobile networks: already support commercial services
  - Mission-critical networks: not designed to support commercial applications
  - Hybrid networks already offer commercial services but will be a mix from different services (and service qualities)

- Ability to support railway operations/services
  Main source: comment from SBB. Services like e.g. ready-for-departure, real-time, information about rail operation for train staff, staff disposition tools, etc. are usually built upon data bearers and require moderate to medium data-rates. Due to the lack of bandwidth of GSM-R (GPRS), today public mobile networks are often used by railway undertakers for those services.
  - GSM-R successors, Commercial unmodified networks, Enhanced commercial mobile networks, Hybrid networks will have much more capacity than GSM-R
  - Mission-critical networks will be a mix from different services (and service qualities)

- Time sequencing/lifetime
  Main sources: interviews, desk research
  - GSM-R successors: same as GSM-R
  - Commercial unmodified networks: LTE/LTE-A networks already available and coverage is improving all over Europe
  - Enhanced commercial mobile networks: LTE/LTE-A networks already available and coverage is improving all over Europe
  - Mission-critical networks: broadband PPDR networks are being planned in Europe and are expected to become operational in 2020-2030 with an expected lifetime of 20+ years
  - Hybrid networks are already in use by railways

Coherence

- Legal restriction
  Main sources: interviews (regulatory and manufacturing stakeholders), desk research
  - GSM-R successors: no difference with GSM-R, the network is owned by the infrastructure manager
  - Commercial unmodified networks: the network is not owned by the railways infrastructure manager
  - Enhanced commercial mobile networks: the network is not owned by the railways infrastructure manager
- Mission-critical networks: the network is not owned by the railways infrastructure manager
- Hybrid networks: portions of the network are not owned by the railways infrastructure manager

### Manageability
Main sources: interview, desk research
- GSM-R successors: no difference in network ownership as for GSM-R
- Commercial unmodified networks: IM cannot manage compliance with pre-defined obligations. Railways buy commercial capacity with no specific agreement with the network operator
- Enhanced commercial mobile networks: IM manage compliance with pre-defined obligations through a contract with the network operator
- Mission-critical networks: IM manage compliance with pre-defined obligations through a contract with the PPDR network manager
- Hybrid networks: probably more difficult than with a single, integrated network

### Social impacts
Main sources: interview, desk research
- GSM-R successors: limited change compared to GSM-R network
- Commercial unmodified networks: railways staff do not manage the radio network
- Enhanced commercial mobile networks: railway staff do not manage the radio network
- Mission-critical networks: railways staff do not manage the radio network
- Hybrid networks: railways staff do not manage portions of the radio network

### Voice applications
For each option, we provide in the table below our evaluation of the criteria for voice applications:
Table 5. Qualitative assessment of various approaches at Member State level – Voice

<table>
<thead>
<tr>
<th></th>
<th>Rail-specific networks</th>
<th>Unmodified commercial mobile networks</th>
<th>Networks with rail and possibly PPDR enhancements</th>
<th>Mission-critical networks</th>
<th>Hybrid networks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GSM-R</td>
<td>GSM-R successors</td>
<td>Unmodified commercial mobile networks</td>
<td>Enhanced commercial mobile networks</td>
<td>Mission-critical networks</td>
</tr>
<tr>
<td>Effectiveness overall</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Coverage</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Reliability</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Robustness</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Resilience to Interference</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Latency</td>
<td>0</td>
<td>0</td>
<td>?</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Security</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Traffic prioritisation</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Functionality⁶⁶</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Capacity</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Ease of use</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ease of migration</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Efficiency overall</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Network CAPEX</td>
<td>0</td>
<td>-</td>
<td>++</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Network OPEX</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Terminal CAPEX</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Spectrum opportunity costs</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ability to support rail business services⁶⁷</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Ability to support fixed/mobile services</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Time sequencing/lifetime</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Coherence</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Legal restriction</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Manageability</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Social impacts</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

For most of the criteria noted above, our evaluation is often (but not always) the same as for ETCS data. We explain the differences in the following text:

**Effectiveness**

- **Interoperability** (not part of the table but added here for clarity): the flexibility of on-board equipment and the related certification process will be a key item for further investigation.

- **Coverage**:
  - Hybrid networks: satellite networks could provide better coverage than GSM-R outdoors but not indoors and WiFi networks mainly provide data services, not

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⁶⁶ In hybrid networks, the portion of the territory covered by other means (for instance, GEO satellite) is likely to experience greater latency than portions covered by any form of mobile services.

⁶⁷ Linked to current and forthcoming network neutrality laws, which may need revision.

⁶⁸ Related to line categories.

⁶⁹ LTE does not support high speeds today but could support up to 500 km/h if standardisation is adapted. Various capabilities in the GSM-R standards will not necessarily be supported by commercial mobile networks, nor by satellite or Wi-Fi networks in hybrid configurations.

⁷⁰ Support for consumer services such as entertainment is typically not allowed today.
circuit-switched voice. Voice over Wifi is now becoming available and should become mainstream in the coming years.

- Reliability: same as ETCS data
- Robustness: same as ETCS data
- Resilience to Interference: same as ETCS data
- Latency: same as ETCS data but jitter is an important QoS parameter impacting the audible voice quality
  - Hybrid networks: the combination of various networks (especially satellite if GEO satellites are used) could significantly increase latency.
- Security: same as ETCS data (with the assumption that voice will be 100% IP-based)
- Traffic prioritization: there might be more “priority levels” than for ETCS data
- Functionality: same as ETCS data (with the hypothesis of all specific functionalities being in the application layer). We can expect the successor to correct the limitations of GSM-R (more efficient REC and location-dependent addressing capabilities) and to be specifically tailored to railway needs.
- Capacity: same as ETCS data (Enhanced capacity, thanks to move to packet mode and full-IP)
- Ease of use: same as ETCS data
- Ease of migration: same as ETCS data

Efficiency
- Network CAPEX: same as ETCS data
- Network OPEX: same as ETCS data
- Terminal CAPEX: same as ETCS data (cost should be close to GSM-R terminals apart for hybrid networks)
- Spectrum opportunity costs: same as ETCS data
- Ability to support other services: additional voice services are not likely to be offered to passengers
- Ability to support fixed/mobile services: With new bearer independent services, the successor of GSM-R should support a common layered architecture (transport, connectivity and application) to be used by fixed/dispatcher and mobile terminals. This will decrease costs, network complexity and increase service interoperability
  - GSM-R successors: SIP/VoIP as base enables common applications @ dispatcher and mobile terminal
  - Commercial unmodified networks and Enhanced commercial mobile networks: possible as core network should remain at railways
  - Mission-critical networks: depends on technology used
- Hybrid networks: probably not easy to implement Time sequencing/lifetime: same as ETCS data

Coherence
- Legal restriction: same as ETCS data
- Manageability: same as ETCS data
- Social impacts: same as ETCS data

Finding 18. At this level of analysis, it is necessary to distinguish between voice requirements and (ETCS) data requirements.
5. The European rail level

<table>
<thead>
<tr>
<th>Key Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Key elements of the Preferred Option for European rail authorities would appear to be to add specific capabilities to the relevant specifications to enable bearer independent applications in support of a small, carefully chosen range of bearer technologies, potentially including current and future LTE; possibly Wi-Fi or successor technologies; and possibly satellite networks (for lines where conditions are suitable). When specifications are sufficiently mature, 5G will be a strong candidate for inclusion.</td>
</tr>
<tr>
<td>- The use of GPRS or EDGE to carry ETCS traffic is a positive development that is already ongoing.</td>
</tr>
<tr>
<td>- Even if Member State decisions are far in the future, a coordinated standards-based approach at European level can generate substantial benefits.</td>
</tr>
</tbody>
</table>

Decisions at the European rail level are the decisions that are core to the current study. The decision-makers include European rail authorities: the European Commission (DG MOVE), with support from the European Railway Agency (ERA), the Union Internationale des Chemins de Fer (UIC), a global organisation, and other sector organisations and stakeholders. Complementary decisions may be required on the part of other European institutions (such as telecommunications decisions by DG Connect) in order to support decisions in the rail area, but they are not discussed further in this study because they depend on the selected way forward and are consequently difficult to predict.

We have structured the analysis in terms of an Impact Assessment, as with the cross-sectoral European initiatives and the Member State initiatives; in practice, however, what ought to be done seems to be fairly clear based on the results of the previous chapters. The Impact Assessment is therefore much abbreviated.

Section 5.1 provides a definition of the Problem from the perspective of European rail authorities; Section 5.2 discusses the Objectives; Section 5.3 reviews the control instruments (TSI, EIRENE, and ETCS specifications) available to European rail authorities together with the UIC; Section 5.4 discusses the elements of the Preferred Option (which is the only Option that seems to be of interest in comparison with a business as usual Option); and Section 5.5 assesses Impacts of the Preferred Option against a business as usual Option (under which no new actions to achieve a standardised approach to the evolution of GSM-R would be undertaken by European rail authorities).

5.1. The Problem at European rail level

Relative to the rail-specific decisions to be taken at European level, we suggest the following definition of the Problem:

- Identify technical, spectrum management, and policy measures to be undertaken to enable continued provision of critical operational communications functionality to the European rail sector as technology and markets evolve going forward.

For the rail-specific problem at European level, we have identified one Specific Objective to date (see also Section 5.4.1):
• Promote a clean partition of function between the applications that run over GSM-R (including ETCS) and the underlying transport mechanism in order to simplify not only the forthcoming migration, but also future migrations.

Implicit in this Problem definition is our belief that it is mandatory to solve these issues for mission critical train functionality, primarily for train operation. The possible ability however of the same solution to meet additional rail business requirements, or perhaps even passenger entertainment needs, is not a mandatory requirement; however, meeting these additional needs can be factored in as a possible price/performance optimisation.

In stating the Problem in this way, we are following the general line put forward in a previous study by Analysys Mason (2014), which observed: “Rail-sector communications fall into three categories: critical operational communications, business-supporting communications, and passenger entertainment/general communications. GSM-R is used for the first category, and, in some cases, the second category, but does not have the bandwidth to support the third.” We believe that this is not just a function of available bandwidth, but rather a result of the underlying structure of the functional requirements themselves. It is possible, but not necessary, to satisfy business support, general communication and passenger entertainment needs with the same technology that is used for train operations.

We note that the definition of mission criticality proved to be challenging in the previous study SCF (2014). In their report, “Is Commercial Cellular Suitable for Mission Critical Broadband?”, they observe: “The ‘mission critical/non-mission critical’ dichotomy is … an oversimplification. There are many degrees of criticality.”

As in any analysis of European policy, implicit in these definitions of the respective Problems is the desire that the solution be as effective, efficient, and coherent (with other aspects European policy) as possible.

5.2. Rail-specific Objectives

Consistent with our approach in Section 4.3, we put forward the following General Objectives for the rail-specific Problem at European level:

• Support all current and anticipated future mandatory rail operational functionality (including communications to and from the dispatcher, ETCS support, and Railway Emergency Call) at reasonable cost using modern, supportable technology.

• Support additional, rail functionality (possibly including business-supporting communications and passenger entertainment/general communications) to the extent that the same mechanisms can do so at reasonable cost.

5.3. Control instruments available to European rail authorities

It is helpful to begin by noting that European rail authorities have a number of well-defined control instruments available to them.

• The CCS TSI;

• Annex A, containing both EIRENE specifications and ETCS specifications.

These specifications (CCS TSI Annex A: EIRENE specifications and ETCS specifications) represent a good basis for the definition of future solutions, accommodating those configurations that, based on the analysis in Chapters 3 and 4, make sense and are likely to be desired by multiple Member States. Further revision and expansion will be needed, according the applicable change management processes.

This represents something of a shift from the current structure of these documents. In practice, significant variation exists within the Member States, especially between high

71 In this document, for clarity, the term mandatory is used for items related to the CCS TSI, and the term additional is used for items not related to the CCS TSI. The term optional can be confusing, because in this document Options are used for other purposes.
speed lines versus lower speed lower frequency lines; however, in principle, there is only a single set of standards today, based on GSM-R.

Going forward, the same rail operations applications must be able to operate not only over current GSM-R, but over other technologies as well (implying replacement not only of software, but in many cases of hardware as well). On the one hand, this implies changes to the applications themselves to reduce or alter their dependence on the underlying network; on the other hand, it means that a (presumably small) number of network configurations must be documented as supported configurations in order to ensure interoperability, to enable rolling stock to roam, and to achieve economies of scale.

In this chapter, we identify the nature of changes that are required to the specifications; however, we refrain from indicating how this is best achieved within the existing specifications (for example, by means of separate documents per configuration versus separate chapters within existing documents). Those decisions are best taken by the subject matter experts who routinely maintain the relevant specifications.

5.4. Elements of the Preferred Option

In an Impact Assessment, one would generally define multiple Options. In this case, however, it is fairly clear based on the results of the previous chapters what ought to be done. In the interest of readability and brevity, we will leap ahead to the fairly obvious conclusions.

Under the Preferred Option, European specifications (in CCS TSI) would be revised to permit or require, in suitable configurations:

- Bearer independent applications capable of operating over a range of bearer technologies, potentially including:
  - current mobile data technology based on GPRS or EDGE;
  - current and future LTE;
  - possibly Wi-Fi or successor technologies; and
  - possibly satellite networks (for lines where conditions are suitable).

A number of additional technologies, especially 5G mobile technology, are identified as future candidates for inclusion, and a number of areas are identified as candidates for further study.

In Section 5.5, we compare the Impacts of taking this Option to those of the “business as usual” Option where European rail authorities take no new actions to promote the future evolution of GSM-R.

Finding 19. Key elements of the Preferred Option for European rail authorities would appear to be to add specific capabilities to the relevant specifications to enable bearer independent applications in support of a small, carefully chosen range of bearer technologies, potentially including current and future LTE; possibly Wi-Fi or successor technologies; and possibly satellite networks (for lines where conditions are suitable). When specifications are sufficiently mature, 5G will be a strong candidate for inclusion.

5.4.1. Bearer independent applications in support of a range of bearer technologies

The GSM-R user community is strongly of the view that the specifications need a serious overhaul in order to ensure that the rail operations applications that operate above GSM-R are fully de-coupled from its underlying transport. This is not the case today. The perceived
need was clearly visible in both of the workshops that we have conducted to date, and also in the Analysys Mason (2014) study.

We believe that this perception on the part of the GSM-R user community is sound. Decoupling the rail applications from the corresponding radio transmission bearer is necessary, not only to enable the evolution of the system to a GSM-R successor circa 2030, but also to facilitate any subsequent technological evolution that might prove to be required. It is also facilitates cross-sectoral sharing of the network.\(^{72}\)

Bearer independence cannot mean that every Member State or IM freely chooses its bearer, since that would impact interoperability; rather, it means that the CCS TSI would specify a small number of permissible bearers, and the Member State would be free to choose among them.

Stakeholders note that, while this change is necessary, it is by no means simple. The change requires a new architecture of the communications stack on-board and trackside, and a re-assignment of functions between ETCS application and the communications portion at the specification level, to allow the use of different radio transmission bearers while keeping the end application stable.

Our focus in this section is on data applications, but similar considerations apply to voice services used for rail operations. As the transmission becomes a pure IP-based substrate, bearer independence for rail operational voice communications becomes equally important. We return to this point in Section 5.4.4.

Ease of use considerations, especially during a transitional period, suggest that the user interface (e.g. to the user in the cab) should change as little as possible – ideally, not at all – as a function of the radio bearer system that is used, and also should not diverge more than is strictly necessary from the user interface that is already in place today (or failing this should provide a compatibility mode).

Feedback from the user community made clear that a migration of rail applications to the Internet Protocol (IP) is viewed as the most promising direction by far; however, this also implies potentially opening new security exposure, and support for multiple configurations may also complicate the certification of future rail operational systems. Once again, we believe that the user community has reached sound conclusions – the migration to IP is clearly appropriate, even though it introduces technical challenges that will have to be addressed.

Work along these lines has already begun as part of the GSM-R successors initiative. GSM-R successors would be an all-IP evolution of the GSM-R standard. Applications would be decoupled from the characteristics of radio bearer.

This decoupling clearly needs to progress.

Recommendation 1. The relevant specifications need a serious overhaul in order to ensure that the rail operational functionality that operates above GSM-R is properly de-coupled from its underlying transport and is future proof.

Closely linked to this assessment is our belief that this de-coupling must be effective, not only for ETCS and other data applications, but also for voice applications. Will the work that has already been initiated fully address whatever would be needed to fully de-couple voice applications such as Rail Emergency Call and Group Calls? In particular, to what degree is it feasible to duplicate GSM-R functionality in a commercial mobile (or satellite or Wi-Fi) network that does not include support for capabilities such as ProSe or GCSE? (We would also note that the fact that the capabilities show up in LTE standards does not necessarily

\(^{72}\) Even where different sectors share the bearer services, they might still each require distinct services or applications, and might each have distinct requirements for availability and/or Quality of Service (QoS).
mean that they will show up in *infrastructure equipment* or in *deployed commercial mobile networks.*

GCSE itself does not represent a group call facility; rather, it represents network support, based on which network application servers and clients could implement the requisite functionality.

The question that we would raise here is, once the applications have been de-coupled from the underlying bearer service, to what degree is it possible to replicate functions such as Rail Emergency Call and Group Call with a "lowest common denominator" network that contains no special support for these features? Some functions that are performed in the GSM-R network today would presumably have to be managed by the application (or done without) if voice communications are operating over Wi-Fi or satellite.

A detailed technical study is well beyond the scope of the current project, but we consider it an appropriate action to be undertaken by ERA and standardisation bodies like UIC, ETSI, 3GPP and IEEE.

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**Recommendation 2.** ERA and the European rail sector should study the degree to which necessary rail voice communications functionality could be provided by a “lowest common denominator” network (such as a purely IP-based radio network) that contains no special support at all for rail-specific voice communications functionality such as Rail Emergency Call and Group Call. (Application and end-to-end performance and reliability requirements might still be relevant.)

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### 5.4.2. Cost, certification, and the number of supported configurations

Over the course of the study, differing views were expressed as to the number of technical configurations that could and should be supported. Some Infrastructure Managers expressed a preference for maximum flexibility, and for a large number of supported configurations; some equipment suppliers expressed concerns over implementation and support costs if more than a very few configurations are supported.

We believe that there is merit in both views.

Technology has evolved in ways that make a more diverse use of technology possible. The cost today of supporting more than one technology is far less than was the case ten or more years ago. With current technology, it is no longer necessary to implement a one size fits all, monolithic standard as a successor to GSM-R.

At the same time, there are clear limits to the number of configurations that should be supported and supportable. As the number of supported configurations grows, the mix and match combinatorial problem between trackside infrastructure and cab equipment grows more rapidly, which implies that the complexity of ensuring that all equipment can interoperate and roam on all relevant tracks grows exponentially.

Throughout the study, stakeholders reminded us of the need to take the cost and complexity of certification into account, both for equipment and at network level. Our belief is that certification costs are likely to increase at a more-than-linear rate as the number of supported configurations grows. This also suggests that there are practical upper limits on the number of configurations that should be supported by a successor to GSM-R.

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73 Roughly speaking, the number of combinations of trackside and cab equipment grows as the square of the number of supported configurations, i.e. it grows much more rapidly.
Recommendation 3. A successor to GSM-R could support more permissible configurations than are possible today, but care must be taken to ensure that the number of supported configurations is no greater than is truly necessary, sustainable, and regularly reviewed.

It goes without saying that continued interoperability with GSM-R, however defined, will continue to be a requirement for many years, presumably until at least 2030.

Recommendation 4. As new bearers are introduced, continued interoperability with GSM-R as deployed must be maintained.

It is clear that certification costs will be higher under a new, more flexible standard than they are under GSM-R. Moreover, given the importance of interoperability and roaming, there should be a strong European interest in ensuring that certification is done consistently across the Member States.

Stakeholders told us that a change in the communications configuration often required re-certification of the entire train. This might be appropriate for large changes, however defined, but there would seem to be an argument for a more flexible and granular certification system going forward.

In theory, certification of equipment takes place at European level; in practice, however, there are often national specificities, and it is often necessary for a change to be certified in multiple Member States for those trains that roam. This is a cost today, and can be expected to represent a greater cost going forward as the number of configurations increases.

With these considerations in mind, there is a clear need in our view to take a fresh look at the certification of operational rail communications equipment at European level. A more granular and flexible certification of rail communications equipment would appear to be in order, and there should be as few national specificities as possible, ideally none at all.

The details are well beyond the scope of the current study, but the need seems to be clear.

Recommendation 5. ERA and the European rail sector should consider carefully European certification requirements for operational rail communications. A more granular and flexible certification of operational rail communications equipment would appear to be in order. There should be as few national specificities in the systems as possible (ideally none at all) with the goals of achieving a single certificate in Europe and thereby optimising costs.

5.4.3. 3GPP Release 12, Release 13, and subsequent releases

Rail operational standards will need to track the continuing evolution of mobile technology. The following provides a rough indication of the path that we anticipate in Europe.

It seems too early to already define commercial lifetime for each 3GPP releases. The real question is which 3GPP release of LTE will be the last one broadly implemented and how long it will be supported. The following table gives precise figures for 3GPP work and our expectation for commercial availability.

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74 Comparison with other transportation sectors might well be fruitful. Our sense is that the process of European level harmonisation of certification of airplanes is more advanced than that of trains. See for instance EASA, “Aircraft Certification”, at https://www.easa.europa.eu/easa-and-you/key-topics/aircraft-certification.

75 This possibility was raised at the stakeholder meeting in Lille on 11 February 2015. Our sense is that the idea was strongly supported by stakeholders.
Planning for fifth generation (5G) mobile is significantly intertwined with that of LTE. It is possible that 5G will be based on LTE technology, at least for frequencies below 6 GHz.

A number of capabilities (notably Proximity Service (ProSe) and Group Communications Service Enablers (GCSE)) are reflected in Release 12 in support of the PPDR community. A number of these enhancements could potentially be directly relevant to rail operations; however, there are gaps in what has been developed to date, which are not expected to be closed until Release 13. These capabilities could provide a basis for capabilities such as Rail Emergency Calls and Group Calls that are routine within GSM-R today.76

Our understanding is that operational rail communications experts have to date had little or no involvement in the relevant 3GPP SA6 standards activities. This runs the risk that 3GPP standards might emerge that do not fully address operational rail communications needs, both in terms of bearer-independence and in terms of the needs of specific applications.

Recommendation 6. The rail sector would be well advised to ensure that rail communications experts participate in 3GPP SA6 standards activities in order to ensure that these potentially crucial standards fully and appropriately address rail communications needs.

Based on what is known today, we believe that work should begin soon on developing specifications to enable migration of GSM-R capabilities to LTE networks that support these capabilities.

So far as we can see, the technical specifications need not distinguish as to whether the capabilities are provided by an enhanced commercial network, versus a network dedicated to rail applications, versus a network shared with PPDR. Instead, the specifications could be drafted in terms of the technical capabilities that the network must be able to support.

Reliability / robustness should also be specified.

The specification would presumably include a small number of supported spectrum bands, possibly including not only licensed bands but also unlicensed. For reasons indicated in Chapter 4, there are good reasons for these bands to include any LTE-relevant bands that are slightly lower than the current GSM-R band in frequency (e.g. 800 MHz, eventually 700 MHz, and 450 – 470 MHz in the event that it becomes realistically available), so as to facilitate the use of existing GSM-R sites.

Stakeholder feedback has strongly favoured a release-independent approach to standardisation of LTE as one of several successors to current GSM-R. Stakeholders note that Releases 12 and 13 are both likely to be obsolescent by 2030, the date at which we assume that GSM-based solutions are no longer supportable. The same may well be true for

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76 In comments on this study, representatives of the PPDR community expressed willingness to “collaborate with ERA/UIC to ensure that any future rail-specific functionality is considered” in this standards work.

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Table 6. Anticipated evolution and deployment of mobile standards in Europe.

<table>
<thead>
<tr>
<th>Commercial name</th>
<th>3GPP Release</th>
<th>3GPP start date</th>
<th>3GPP freeze date</th>
<th>Commercial availability from</th>
<th>Expected commercial lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTE release 12</td>
<td>2012</td>
<td>March 2015</td>
<td>2016-2018</td>
<td>2016-2031</td>
<td></td>
</tr>
<tr>
<td>LTE release 13</td>
<td>2013</td>
<td>March 2016</td>
<td>2017-2019</td>
<td>2017-2032</td>
<td></td>
</tr>
</tbody>
</table>

Source: IDATE
Release 14. We agree with these views; at the same time, we consider it likely that the standards will have to deal with the degree to which an LTE network contains special support for capabilities such as Rail Emergency Calls and Group Calls.

**Recommendation 7.** Planning should begin incorporating 3GPP LTE-based standardised solutions into a successor to GSM-R. This should be done, as much as possible, in a manner that is independent of specific LTE releases.

Some stakeholders expressed interest in using the existing GSM-R bands as a transition mechanism, and specifically in the use of LTE in these bands. This is an interesting idea, but may have implications in terms of interference and interoperability. The extended GSM-R bands might conceivably also be of interest.

**Recommendation 8.** ERA should consider initiating a study on the use of 3GPP LTE in the existing 4 MHz GSM-R uplink and downlink bands, and possible coexistence with GSM-R in the band. The possible role and relevance (if any) of the E-GSM-R extension bands (873-876 MHz (Uplink) and 918-921 MHz (Downlink)) should also be reviewed at that time.

### 5.4.4. Current mobile technology: EDGE, UMTS/3G, and LTE

Work is already ongoing to adapt ETCS to operate over EDGE. This allows the use of the existing GSM-R infrastructure, providing a backwards compatible option for IP applications with a data rate greater than that available when transmitting data over circuit switched GSM-R.

Current mobile networks are already used in support of rail operations, especially for lower speed and/or low frequency lines (e.g. in France and Switzerland).

ETCS over EDGE is already important in light of capacity limitations in GSM-R. Since work on ETCS over EDGE is already ongoing, we assume that no additional actions are needed, and therefore make no explicit recommendations.

**Finding 20.** The use of GPRS or EDGE to carry ETCS traffic is a positive development that is already ongoing.

Stakeholders have made clear that 3G / UMTS is of little or no interest. It is already on the way to obsolescence, and offers less data capability than LTE. Most experts anticipate that 3G / UMTS will be switched off sooner than 2G / GSM.

### 5.4.5. Evolution to 5G mobile services

The evolution of new 5G mobile services is felt to be an important development for Europe. At the moment, however, there is enormous uncertainty as to what will constitute 5G. Real specifications work has not even begun yet (see Table 6).

As of today, we do not advocate an active effort to specify how GSM-R services might operate over 5G. First, it is much too early – the uncertainty as to what might constitute 5G is too great. As a related matter, it is not yet clear whether 5G will offer meaningful advantages over LTE in the medium term, given that rail operational bandwidth demands are modest and not yet demonstrably growing much over time.
If 5G were to develop as many expect, providing seamless “HetNet” integration between licensed and unlicensed spectrum, mobile and Wi-Fi, then incorporating 5G into the mix is likely to be appropriate. Even though it is too early for standards work to explicitly accommodate 5G, it is important to monitor its evolution, and rail standards work should not needlessly preclude its eventual use.

The regulation / specification work should enable a late choice of the radio technology by ensuring the independence of the railway application layer.

| Recommendation 9. | ERA and the European rail sector should monitor the evolution of radio technologies, such as 5G mobile services, and should consider incorporating support into a successor to GSM-R once the standards are sufficiently mature. |

### 5.4.6. Satellite networks

As noted in Section 4.1.4, satellite could provide an effective means of coverage (for lines where traffic conditions are suitable) for remote parts of the national territory. Doing so would require extending existing specifications to permit suitable configurations. This appears in our view to be warranted.

Full de-coupling of applications from the underlying bearer would need to be required (see Section 5.4.1), and the implications for voice should be considered carefully. If geosynchronous (GEO) satellites were used, the long inherent round trip delay would be obvious, both for data and for voice.

The railway application layer should remain independent from the RAN used and from how the core network is implemented. All this doesn’t exclude the use of a commercial mobile network or a satellite link along rural lines where a best-effort solution is acceptable for the railway voice communications.

| Recommendation 10. | The ERA, the European Space Agency (ESA), and the European rail sector should continue to study the degree to which the use of satellite is feasible and practical for operational rail communications. Current GEO (and possibly LEO) satellites might possibly be acceptable for lines in remote areas with suitable traffic characteristics. Future MEO satellites are likely to have still greater applicability. |

### 5.4.7. Wi-Fi networks

Rail stakeholders have expressed a strong interest in being able to operate a successor to GSM-R over Wi-Fi (or a successor to Wi-Fi).

Assuming that GSM-R applications evolve to a pure or nearly pure IP service (see Section 5.4.1), technical issues should be straightforward. Further, the incremental cost of adding Wi-Fi support to cab equipment is likely to be quite low.

We note, however, that expected coverage of Wi-Fi systems would probably be limited to train stations and shunting yards in light of the limited range of Wi-Fi systems (due to the use of unlicensed frequency bands and low power). With that in mind, whether the effort of incorporating Wi-Fi or successors into future revisions of the specifications for a successor to GSM-R is warranted requires thought and study. As noted in Section 5.4.2, we consider it

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77 In a sense, 5G would be part of the planning in any case, due to its close relationship to LTE. It is expected that 5G may initially rely on LTE coverage for frequency bands below 6 GHz.
important that new configurations are not introduced into successor standards to GSM-R unless their inclusion is clearly warranted.\textsuperscript{78}

Our belief is that the real benefits of Wi-Fi support flow, not from coverage requirements, but rather from capacity requirements in stations and especially in shunting yards. Communications traffic can be high in stations and shunting yards – in the Workshops, stakeholders from Switzerland and Germany indicated that GSM-R capacity constraints in shunting yards are already severe. A limited distance bearer technology such as Wi-Fi would appear to offer considerable promise as a means of alleviating congestion.

In order to obtain economies of scale in regard to the chipsets used by suppliers of rail communications equipment to implement Wi-Fi, it would presumably need to operate in the same licence-exempt bands that are used today. This means that the risk of interference with consumer Wi-Fi would need to be assessed. This is probably not a major concern for shunting yards, but could be a concern if Wi-Fi is used in train stations.

A range of technical considerations would need to be taken into account, including (1) lack of network traffic management capabilities in Wi-Fi, (2) lack of standardised hand-off from one Wi-Fi hotspot to the next, and (3) absence of new 3GPP capabilities that might possibly be used to support Rail Emergency Call and Group Call.

The time frame of the overall migration would also need to be considered once a migration plan is further along. Once other high capacity solutions are introduced (e.g. based on LTE), the capacity constraint in shunting yards will presumably be mitigated in a different way. The migration plan is beyond the scope of the current study.

\begin{svgraybox}
Recommendation 11. ERA and the European rail sector should consider whether the inclusion of Wi-Fi (and/or some other low bandwidth optimised radio bearer) into standards for a successor to GSM-R is warranted. The prime motivations to do so would be to increase capacity in train stations and shunting yards, and also to reduce the cost of communication infrastructures. Coexistence with consumer Wi-Fi would need to be assessed, as well as the planned migration schedule to successors to today’s GSM-R.
\end{svgraybox}

\section*{5.5. Assessment of Impacts}

The detailed impacts will depend on myriad decisions; however, it is fairly clear that a failure on the part of European rail authorities to expand specifications so as to accommodate a practical evolution of the GSM-R system will result in a proliferation of inconsistent and possibly non-interoperable solutions at Member State level, thus reducing interoperability, ability to roam, and economies of scale at European level.

\subsection*{5.5.1. Definition of criteria}

These criteria are specific to the activities of rail authorities at European level.

\textbf{Effectiveness}

Effectiveness at this level is largely a function of the degree to interoperability and roaming of trains among the Member States, where required, is enabled; and of the ease of migration to accommodate new functional requirements and/or new technology, both during the transition period to a successor to GSM-R, and during future transitions.

\textsuperscript{78} Ultra-narrow band (UNB) is an emerging technology that might conceivably represent an interesting alternative to Wi-Fi. It is said to be suitable for low data volumes at longer distances than Wi-Fi. Any technology with such properties could be of interest.
Efficiency

Efficiency reflects the likely cost of migration, and the likely unit costs of future infrastructure and equipment.

5.5.2. Qualitative assessment

Qualitative assessment is straightforward. Benefits and costs are to the European rail sector, as seen from the perspective of European rail authorities.

<table>
<thead>
<tr>
<th></th>
<th>Business as usual</th>
<th>Preferred Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness overall</td>
<td>0</td>
<td>++</td>
</tr>
<tr>
<td>Future interoperability</td>
<td>0</td>
<td>++</td>
</tr>
<tr>
<td>Ease of migration</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Efficiency overall</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Cost of migration</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Future equipment costs</td>
<td>0</td>
<td>+</td>
</tr>
</tbody>
</table>

The ratings that are used are 0 (to denote impacts the same as those of the baseline), + (better than the baseline), ++ (much better than the baseline), - (worse than the baseline), and -- (much worse than the baseline).

Effectiveness

- Future interoperability:
  - Business as usual: Interoperability today is excellent, but GSM-R is unlikely to be fully sustainable after roughly 2030. In the absence of concrete European-level initiatives and coordination, Member States would effectively be forced to find their own solutions to the long term challenge of finding GSM-R successors. This would with high likelihood lead to a proliferation of different solutions at Member State level. The likelihood that these different solutions would all be fully interoperable with one another, in the absence of active efforts at European level, to ensure that it is so, is very low. For this reason, it is highly likely that a pure “business as usual” approach with no significant extensions to existing standards for operational rail communications would lead to a significant deterioration in interoperability (for instance, would limit the ability of trains to roam, and would increase the need for bilateral negotiations [a form of economic transaction costs] between IMs in nearby Member States) in the future.
  - The preferred Option establishes specifications to ensure interoperability. These could be backed up with enforcement capabilities at European level at least as good as those that exist today. This is greatly preferable, in our view, to the likely evolution under the “business as usual” scenario. We consider this to represent a major argument for continued efforts at European level to ensure an orderly and fully interoperable transition to a successor (or small number of successors) to GSM-R.

- Ease of migration
  - If GSM-R were maintainable forever, there would be no migration costs or complexity in the Business as Usual case; this, however, is not the case.
  - In the absence of coordinated European standards, Member State decisions on the approach, even where decisions are common, could lead to lack of coordination as to the time frames in which migration is undertaken, or the intermediate steps taken to ensure interoperability during a transition.
  - A standards-based approach at European level enables systematic migration of roadside equipment and cabin equipment.

Efficiency

- Cost of migration
- The cost of migration is likely to be substantially higher in the absence of coordination of standards at Europeans level due to transaction costs among the Member States (i.e. the need for bilateral coordination among each pair of interconnected Member States).

- Under a fully standards-based migration, transaction costs are reduced. Coordination among the Member States is simplified. Equipment supporting several of the supported configurations is likely to emerge, thus facilitating an orderly and seamless transition.

- **Future equipment costs**
  - Under a business as usual scenario, approaches are likely to proliferate, which would work at cross purposes with achieving manufacturing economies of scale in both trackside and cabin equipment.
  - Under the Preferred Option, a number of well-defined configurations can emerge, enabling economies of scale and thus lowering unit costs both for trackside and for cabin equipment.

**Finding 21.** Even if Member State decisions are far in the future, a coordinated standards-based approach at European level can generate substantial benefits.
6. Findings and recommendations

Here we provide a list and index of our findings (Section 6.1) and recommendations (Section 6.2).

6.1. Findings

Our Findings are as follows. The page on which the finding is explained appears to the right.

Finding 1. The need for a successor to GSM-R is motivated by anticipated eventual obsolescence of GSM, capacity limitations in GSM-R, and a desire to reduce costs. Previous studies have found that functional requirements and bandwidth demand are evolving only slowly; however, not all stakeholders agree. ................................................................. 14

Finding 2. Multiple studies have assessed possible ways forward for operational rail communications (and for other mission critical networks). ................................................................. 15

Finding 3. It is exceedingly difficult to express clear, non-overlapping Options with which to address this Problem. ................................................................. 20

Finding 4. We find it useful to distinguish among three interrelated sets of decisions: (1) A cross-sectoral decision at European level as to how to handle PPDR, energy, intelligent highway transport, and rail communications overall; (2) a rail-specific decision; and (3) Member State (national) decisions. ................................................................. 21

Finding 5. Public Protection and Disaster Relief (PPDR) forces hope to upgrade their communications capabilities using broadband technology. ................................................................. 22

Finding 6. Needs for the energy sector are driven primarily by smart metering and smart grid applications; these have, however, different network implications. ................................................................. 22

Finding 7. Railway functional requirements for train operational communications have been found in previous studies to be evolving only slowly; however, needs may increase in the medium-far future. ................................................................. 23

Finding 8. There are commonalities between rail and other mission-critical applications for voice and data radio services, but also important differences such as speed. ................................................................. 23

Finding 9. Technology is evolving in ways that provide many new opportunities going forward. ................. 24

Finding 10. We are analysing European cross-sectoral Options and Sub-Options from least active intervention to most active intervention. A range of solutions are possible, with different implications in terms of cost and ease of implementation. ................................................................. 28

Finding 11. For reasons outlined in SCF (2014), the cost of a cross-sectoral network based on MNO services for PPDR and rail might well be somewhat less than that of the private networks used today, even after allowing for the costs of hardening the network to provide reliability and expanding its coverage. At the same time, it is necessary to bear in mind that their analysis was primarily relative to existing PPDR networks, and only tangentially relevant to operational rail network requirements; moreover, their analysis rests on the assumption that a various reliability, coverage, management and practical requirements can be met that, in practice, quite possibly cannot be met. Further study is needed. ................. 35

Finding 12. Taking migration costs into account (which is not fully possible until far more is known about the migration) an Enhanced Business as Usual approach (with private rail networks using modernised technology) might well be comparable in efficiency to the various network sharing sub-Options that we have considered. ................................................................. 35

Finding 13. If the GSM-R bands can eventually be released, the opportunity cost for the European Union as a whole of up to roughly €2.5 billion could be freed. This number rests however on many assumptions, and must be interpreted with caution. ......................... 36

Finding 14. Coverage requirements can differ greatly among different wireless applications. For rail operational networks, they differ as well as a function of speed and traffic of the lines.
Finding 15. There could be enormous value in re-use of the existing trackside GSM-R locations by a future replacement system. This does not necessarily imply that the same ownership and control model be carried forward. As long as a future successor to GSM-R were to operate in frequency bands similar to or slightly lower than the frequency band of GSM-R, and assuming no radical growth in bandwidth demands, the same route kilometres could be covered using the same sites. ................................. 39

Finding 16. Multi-technology support has potential value. Current geosynchronous satellites are subject to substantial latency, but could nonetheless be better than lack of coverage in remote areas, and are in use for operational rail communications in other parts of the world. In the future (post 2030), use of MEO satellites to cover remote areas might bring considerable additional benefits. .................................................. 40

Finding 17. At Member State level, Options differ largely on the degree to which private networks, unmodified commercial networks, or commercial networks with modifications for mission critical services are use. Many hybrids are possible. .................................................. 42

Finding 18. At this level of analysis, it is necessary to distinguish between voice requirements and (ETCS) data requirements. ............................................................. 58

Finding 19. Key elements of the Preferred Option for European rail authorities would appear to be to add specific capabilities to the relevant specifications to enable bearer independent applications in support of a small, carefully chosen range of bearer technologies, potentially including current and future LTE; possibly Wi-Fi or successor technologies; and possibly satellite networks (for lines where conditions are suitable). When specifications are sufficiently mature, 5G will be a strong candidate for inclusion. ....... 61

Finding 20. The use of GPRS or EDGE to carry ETCS traffic is a positive development that is already ongoing. ........................................ 66

Finding 21. Even if Member State decisions are far in the future, a coordinated standards-based approach at European level can generate substantial benefits. ........................................ 70

6.2. Recommendations to the ERA and the European rail sector

Based on our analysis, our recommendations to the ERA and to the European rail sector are as follows. The page on which the recommendation is explained appears to the right.

Recommendation 1. The relevant specifications need a serious overhaul in order to ensure that the rail operational functionality that operates above GSM-R is properly de-coupled from its underlying transport and is future proof. ............................................................. 62

Recommendation 2. ERA and the European rail sector should study the degree to which necessary rail voice communications functionality could be provided by a "lowest common denominator" network (such as a purely IP-based radio network) that contains no special support at all for rail-specific voice communications functionality such as Rail Emergency Call and Group Call. (Application and end-to-end performance and reliability requirements might still be relevant.) ............................................................. 63

Recommendation 3. A successor to GSM-R could support more permissible configurations than are possible today, but care must be taken to ensure that the number of supported configurations is no greater than is truly necessary, sustainable, and regularly reviewed.64

Recommendation 4. As new bearers are introduced, continued interoperability with GSM-R as deployed must be maintained. ............................................................. 64

Recommendation 5. ERA and the European rail sector should consider carefully European certification requirements for operational rail communications. A more granular and flexible certification of operational rail communications equipment would appear to be in order. There should be as few national specificities in the systems as possible (ideally none at all) with the goals of achieving a single certificate in Europe and thereby optimising costs. ............................................................. 64

Recommendation 6. The rail sector would be well advised to ensure that rail communications experts participate in 3GPP SA6 standards activities in order to ensure that these potentially crucial standards fully and appropriately address rail communications needs. ............ 65
Recommendation 7. Planning should begin incorporating 3GPP LTE-based standardised solutions into a successor to GSM-R. This should be done, as much as possible, in a manner that is independent of specific LTE releases.

Recommendation 8. ERA should consider initiating a study on the use of 3GPP LTE in the existing 4 MHz GSM-R uplink and downlink bands, and possible coexistence with GSM-R in the band. The possible role and relevance (if any) of the E-GSM-R extension bands (873-876 MHz (Uplink) and 918-921 MHz (Downlink)) should also be reviewed at that time.

Recommendation 9. ERA and the European rail sector should monitor the evolution of radio technologies, such as 5G mobile services, and should consider incorporating support into a successor to GSM-R once the standards are sufficiently mature.

Recommendation 10. The ERA, the European Space Agency (ESA), and the European rail sector should continue to study the degree to which the use of satellite is feasible and practical for operational rail communications. Current GEO (and possibly LEO) satellites might possibly be acceptable for lines in remote areas with suitable traffic characteristics. Future MEO satellites are likely to have still greater applicability.

Recommendation 11. ERA and the European rail sector should consider whether the inclusion of Wi-Fi (and/or some other low bandwidth optimised radio bearer) into standards for a successor to GSM-R is warranted. The prime motivations to do so would be to increase capacity in train stations and shunting yards, and also to reduce the cost of communication infrastructures. Coexistence with consumer Wi-Fi would need to be assessed, as well as the planned migration schedule to successors to today's GSM-R.
# 7. Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full term</th>
</tr>
</thead>
<tbody>
<tr>
<td>3G/4G/5G</td>
<td>Third/fourth/fifth generation (of mobile telecoms technology)</td>
</tr>
<tr>
<td>3GPP</td>
<td>Third Generation Partnership Project</td>
</tr>
<tr>
<td>ADL</td>
<td>Asymmetric Downlink</td>
</tr>
<tr>
<td>ASA</td>
<td>Authorised Spectrum Access</td>
</tr>
<tr>
<td>ASCI</td>
<td>Advanced Speech Call Items</td>
</tr>
<tr>
<td>ATO</td>
<td>Automatic Train Operation</td>
</tr>
<tr>
<td>ATP</td>
<td>Automatic Train Protection</td>
</tr>
<tr>
<td>CAGR</td>
<td>Compound annual growth rate</td>
</tr>
<tr>
<td>CBTC</td>
<td>Communications-Based Train Control</td>
</tr>
<tr>
<td>CCS-TSI</td>
<td>Control-Command and Signalling Technical Specification for Interoperability</td>
</tr>
<tr>
<td>CDMA</td>
<td>Code division multiple access</td>
</tr>
<tr>
<td>CEPT</td>
<td>European Conference of Postal and Telecommunications</td>
</tr>
<tr>
<td>CSFB</td>
<td>Circuit-switched fall back</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>ECC</td>
<td>European Communications Committee (of CEPT)</td>
</tr>
<tr>
<td>ECC-DEC/(02)/05</td>
<td>CEPT Report on 169.4-169.8125MHz</td>
</tr>
<tr>
<td>EDGE</td>
<td>Enhanced Data Rates for GSM Evolution</td>
</tr>
<tr>
<td>EDOR</td>
<td>European Train Control System Data Only Radio</td>
</tr>
<tr>
<td>EIRENE</td>
<td>European Integrated Railway Radio Enhanced Network</td>
</tr>
<tr>
<td>EPC</td>
<td>Evolved Packet Core</td>
</tr>
<tr>
<td>ERA</td>
<td>European Railway Agency</td>
</tr>
<tr>
<td>ERTMS</td>
<td>European Rail Traffic Management System</td>
</tr>
<tr>
<td>ESA</td>
<td>European Space Agency</td>
</tr>
<tr>
<td>ETCS</td>
<td>European train control system</td>
</tr>
<tr>
<td>ETSI</td>
<td>European Telecommunications Standards Institute</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EUTC</td>
<td>European Utilities Telecom Council</td>
</tr>
<tr>
<td>FDD</td>
<td>Frequency division duplex</td>
</tr>
<tr>
<td>FRMCS</td>
<td>Future Railway Mobile Communication Systems</td>
</tr>
<tr>
<td>GBNR</td>
<td>Ground Based Network (Resilient)</td>
</tr>
<tr>
<td>GCSE-LTE</td>
<td>Group Call System Enabler – LTE</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross domestic product</td>
</tr>
<tr>
<td>GEO</td>
<td>Geostationary Orbit</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic information system</td>
</tr>
<tr>
<td>GPRS</td>
<td>General Pac</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile Communications</td>
</tr>
<tr>
<td>GSM-R</td>
<td>Global System for Mobile Communications, adapted for Railway</td>
</tr>
<tr>
<td>HetNets</td>
<td>Heterogeneous Networks</td>
</tr>
<tr>
<td>HSPA</td>
<td>High Speed Packet Access</td>
</tr>
<tr>
<td>HS Rail</td>
<td>High Speed Rail</td>
</tr>
<tr>
<td>IM</td>
<td>Infrastructure manager</td>
</tr>
<tr>
<td>IMT</td>
<td>International Mobile Telecommunications</td>
</tr>
<tr>
<td>IP</td>
<td>Internet Protocol</td>
</tr>
<tr>
<td>IPR</td>
<td>Intellectual property rights</td>
</tr>
<tr>
<td>ISI</td>
<td>Inter System Interface</td>
</tr>
<tr>
<td>ITU</td>
<td>International Telecommunications Union</td>
</tr>
<tr>
<td>ITU-R</td>
<td>International Telecommunications Union Radiocommunication Sector</td>
</tr>
<tr>
<td>LEO</td>
<td>Low Earth Orbit communication satellites</td>
</tr>
<tr>
<td>LSA</td>
<td>Licensed Shared Access</td>
</tr>
<tr>
<td>LTE</td>
<td>Long Term Evolution</td>
</tr>
<tr>
<td>M2M</td>
<td>Machine to machine</td>
</tr>
<tr>
<td>MCPTToLTE</td>
<td>Mission Critical PTT over LTE</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
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</tr>
<tr>
<td>MEO</td>
<td>Medium Earth Orbit satellite</td>
</tr>
<tr>
<td>METIS</td>
<td>Mobile and wireless communications Enablers for the 2020 Information Society</td>
</tr>
<tr>
<td>MNO</td>
<td>Mobile network operator</td>
</tr>
<tr>
<td>MORANE</td>
<td>Mobile Radio For Railways Networks in Europe</td>
</tr>
<tr>
<td>MTBF</td>
<td>Mean time between failure</td>
</tr>
<tr>
<td>MVNO</td>
<td>Mobile virtual network operator</td>
</tr>
<tr>
<td>NextG</td>
<td>Next Generation</td>
</tr>
<tr>
<td>OFDMA</td>
<td>Orthogonal frequency-division multiple access</td>
</tr>
<tr>
<td>OTT</td>
<td>Over-the-top</td>
</tr>
<tr>
<td>PA</td>
<td>Public address</td>
</tr>
<tr>
<td>PAS</td>
<td>Publicly Available Specification</td>
</tr>
<tr>
<td>PLC</td>
<td>Power-line communications</td>
</tr>
<tr>
<td>PMR</td>
<td>Private mobile radio</td>
</tr>
<tr>
<td>PPDR</td>
<td>Public protection and disaster relief</td>
</tr>
<tr>
<td>PPP</td>
<td>Public-private partnership</td>
</tr>
<tr>
<td>PTT</td>
<td>Push to talk</td>
</tr>
<tr>
<td>RAN</td>
<td>Radio access network</td>
</tr>
<tr>
<td>REC</td>
<td>Railway Emergency Call</td>
</tr>
<tr>
<td>RF</td>
<td>Radio frequency</td>
</tr>
<tr>
<td>RTPI</td>
<td>Real-time passenger information</td>
</tr>
<tr>
<td>RU</td>
<td>Railway undertaking (same as TOC)</td>
</tr>
<tr>
<td>SAT</td>
<td>System acceptance test</td>
</tr>
<tr>
<td>SDL</td>
<td>Supplementary Downlink</td>
</tr>
<tr>
<td>SDR</td>
<td>Software-defined radio</td>
</tr>
<tr>
<td>SIM (card)</td>
<td>Subscriber identity module</td>
</tr>
<tr>
<td>SLA</td>
<td>Service level agreement</td>
</tr>
<tr>
<td>SMS</td>
<td>Short message service</td>
</tr>
<tr>
<td>TC</td>
<td>Technical Committee (of ETSI)</td>
</tr>
<tr>
<td>TCCA</td>
<td>TETRA + Critical Communications Association</td>
</tr>
<tr>
<td>TCCE</td>
<td>TETRA and Critical Communications Evolution</td>
</tr>
<tr>
<td>TDD</td>
<td>Time division duplex</td>
</tr>
<tr>
<td>TEDS</td>
<td>TETRA Enhanced Data Service</td>
</tr>
<tr>
<td>TEN-T</td>
<td>Trans-European Transport Networks</td>
</tr>
<tr>
<td>TETRA</td>
<td>Terrestrial Trunked Radio</td>
</tr>
<tr>
<td>TETRAPOL</td>
<td>An alternative digital radio technology for public safety</td>
</tr>
<tr>
<td>TOC</td>
<td>Train operating company</td>
</tr>
<tr>
<td>UHF-FM</td>
<td>Ultra High Frequency – Frequency Modulation</td>
</tr>
<tr>
<td>UIC</td>
<td>International Union of Railways</td>
</tr>
<tr>
<td>UMTS</td>
<td>Universal Mobile Telephone Service (a 3G service)</td>
</tr>
<tr>
<td>VBS</td>
<td>Voice Broadcast Service</td>
</tr>
<tr>
<td>VGCS</td>
<td>Voice Group Call Service</td>
</tr>
<tr>
<td>VHF</td>
<td>Very high frequency</td>
</tr>
<tr>
<td>VoIP</td>
<td>Voice over Internet Protocol</td>
</tr>
<tr>
<td>W-CDMA</td>
<td>Wideband code division multiple access (a 3G technology)</td>
</tr>
<tr>
<td>Wifi</td>
<td>Wireless fidelity</td>
</tr>
<tr>
<td>WRC</td>
<td>World Radio Conference</td>
</tr>
</tbody>
</table>