



Ben@Rail

Deliverable D 2.1

Structured overview of R&I objectives and their underlying benefits

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1. Executive Summary

To improve the adherence of future R&I activities, Ben@Rail shall develop a framework based on a stakeholder analysis and technological inputs. To achieve the final goal of assessing the benefits of the stakeholders from future R&I activities, the technological inputs will in the final stage be compared and weighted against the stakeholder requirements. This will allow to verify the research priorities within the upcoming Europe's Rail Joint Undertaking (ERJU).

This document provides a structured overview of the *R&I objectives* given by the research plans published by the European Rail Research Advisory Council (ERRAC) and the ERJU, and with this delivers the technical inputs for the comparison with the stakeholder requirements defined in Deliverable D1.1 "Simplified stakeholder tree and weighting matrix of requirements". The objectives have been extracted from different documents, with a main focus on the "Europe's Rail Joint Undertaking Master Plan" (MP) and the "Europe's Rail Joint Undertaking Multi-Annual Work Programme" (MAWP). Additional documents, published by other Shift2Rail research projects, like TER4RAIL and Mobility4EU, or representatives of other transport sectors, have been examined as well.

To extract the objectives from the available documents a top-down method has been used. For the systematic analysis, a structure with five layers has been defined:

1. Envisioned benefits & impacts.
2. R&I objectives.
3. Specific concepts.
4. Individual innovations.
5. Technical examples.

The analysis of the MAWP is the main body of this document. It considers the System Pillar (SP), the Innovation Pillar (IP) with one Transversal Topic (TT): Digital enablers, and seven Flagship Areas (FA): Network and mobility management (FA1), Digital & automated up to autonomous train operations (FA2), Intelligent & integrated asset management (FA3), A sustainable and green rail system (FA4), Sustainable competitive digital green rail freight services (FA5), Regional rail services / Innovative rail services to revitalise capillary lines (FA6), and Innovation on new approaches for guided transport modes (FA7). For the other documents a short analysis of the main topics has been conducted.

From the extracted data a list of all objectives and concepts has been compiled. The extraction of the MAWP gives a total of 20 *R&I objectives* with 45 underlying *specific concepts*. These objectives and concepts show an overall good alignment with those mentioned in the other examined documents. A few differences are noted which are recommended to be considered in the full top-down assessment in WP3.

The ranking of structural units of the MAWP was assessed quantitatively based on the indicative distribution of financial resources. It should be interpreted with reservation, due to the fact that there in many cases are interactions between or direct benefits from one area to another. The ranking of the underlying *R&I objectives* was only possible based on a qualitative assessment. It is therefore of limited reliability and only valid within each structural unit. The prioritisation of *R&I objectives* is for example not comparable across different FAs. The ranked list of structural units and *R&I objectives* is given below:

1. FA2: Digital & automated up to autonomous train operations
 - a. Next generation of ATC
 - b. Automated Train Operations up to GoA4
2. FA3: Intelligent & integrated asset management
 - a. Cost-effective asset management
 - b. Environment-friendly production of resilient assets
 - c. Automated execution of construction and supported interventions
3. FA4: A sustainable and green rail system
 - a. Minimised energy consumption
 - b. Climate change action
 - c. Healthier rail system
 - d. Attractiveness
4. FA5: Sustainable competitive digital green rail freight services
 - a. Migration to digitised rail freight operations
 - b. Enabling a seamless rail freight environment
5. FA1: Network and mobility management
 - a. Customer-oriented dynamic planning approach
 - b. Maintaining the reliability of rail traffic
 - c. Increased flexibility for smarter and tailored door-to-door services
6. ER: Exploratory research
7. FA6: Regional rail services / innovative rail services to revitalise capillary lines
 - a. Low-cost framework for regional/low density lines
 - b. Customer Service
8. SP: System Pillar
 - a. CCS+
 - b. EU Rail system
9. TT: Transversal topic: Digital enablers
10. FA7: Innovation on new approaches for guided transport modes
 - a. Exploration of non-traditional emerging technologies

2. Abbreviations and acronyms

Abbreviation / Acronym	Description
ACARE	Advisory Council for Aeronautics Research in Europe
ASO	Automated Marshalling/Shunting Operations
ATC	Automatic Train Control
ATO	Automatic Train Operation
ATP	Automatic Train Protection
CBM	Condition-Based Maintenance
CCA	Cross-Cutting Activities
CCS	Control Command and Signalling
DAC	Digital Automatic Coupler
DATO	Digital Automated Train Operations
DT	Digital Twin
EC	European Commission
ER	Exploratory Research
ERA	European Union Agency for Railways
ERJU	Europe's Rail Joint Undertaking
ERRAC	European Rail Research Advisory Council
ERTMS	European Rail Traffic Management System
ERTRAC	European Road Transport Research Advisory Council
EU	European Union
EUR	Euro
EURNEX	European rail Research Network of Excellence
FA	Flagship Area
GHG	Greenhouse Gas
GoA	Grade of Automation
HVAC	Heating, Ventilation, And Air Conditioning
ID	Identification
IM	Infrastructure Manager
IP	Innovation Pillar
IT	Information Technology
JU	Joint Undertaking
KPI	Key Performance Indicators
MAWP	Multi-Annual Work Programme
MP	Master Plan
R&I	Research & Innovation
RU	Railway Undertaking



S2R	Shift2Rail
SERA	Single European Railway Area
SP	System Pillar
SRIA	Strategic Rail Research and Innovation Agenda
TCMS	Train Control Monitoring System
TCN	Train Communication Network
TIMS	Train Integrity Monitoring System
TMS	Traffic Management System
TP	Transforming Project
TRL	Technology Readiness Level
TT	Transversal Topic
WP	Work Package

3. Background

The present document constitutes the Deliverable D1.2 “STRUCTURED OVERVIEW OF R&I OBJECTIVES AND THEIR UNDERLYING BENEFITS” in the framework of the WP2, Task 2.1 to 2.3. Ben@Rail relates to the work programme S2R-CCA-01-2021, “R&I impact and benefits to make rail attractive for stakeholders” and is a component of the Cross-Cutting Activities (CCA) funded under the Shift2Rail programme.

4. Objective/Aim

This document has been prepared to provide a structured overview of the R&I objectives lined out in the strategic research plans published by the European Rail Research Advisory Council (ERRAC) and the Europe’s Rail Joint Undertaking (ERJU). A top-down approach is taken to link the intended impacts and benefits of each identified *R&I objective* to their underlying concepts, innovations, and technical examples. This top-down perspective is oriented at the structure established for Shift2Rail, which is shown in Figure 1. To this end, technical items/concepts related to the research objectives set within strategic documents have been extracted, summarised, and structured. The documents of focus have been the “Europe’s Rail Joint Undertaking Master Plan” (MP) and the “Europe’s Rail Joint Undertaking Multi-Annual Work Programme” (MAWP) as they are the most detailed and most recent document published by the ERJU, providing a thorough description of the envisioned scope and technical content.

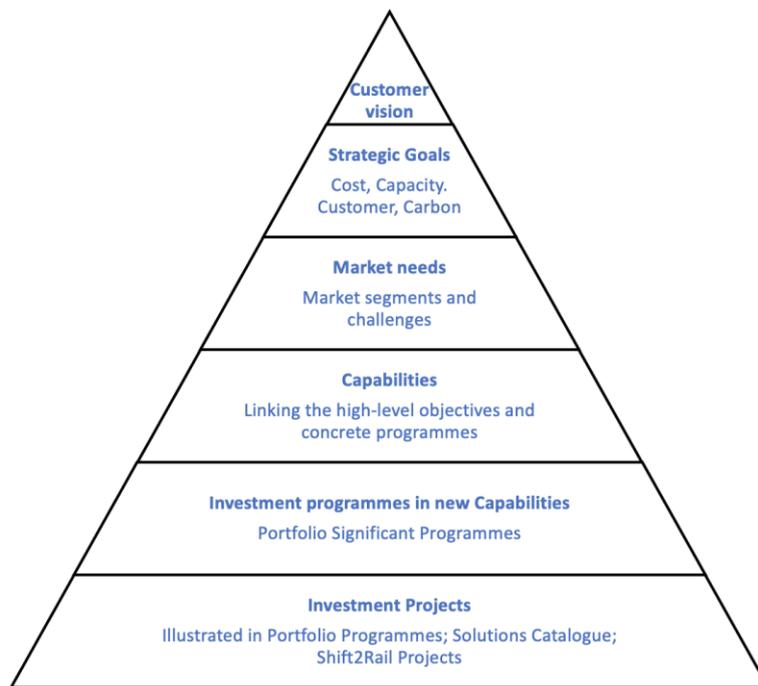


Figure 1: Top-down structure as a directional guideline for the extraction of benefits and related R&I objectives.

In addition to the MP, the MAWP and strategic documents by ERRAC, this document refers to material published by other research projects and representatives of other transport sectors. The summary of their identified key *R&I objectives* and technical areas of interest gives the possibility to confirm the consistency of the scope of objectives that is determined in the MP and the MAWP. Furthermore, this broader perspective on *R&I objectives* can also be considered for providing evidence-based recommendations in Task 3.3.



The structured overview constitutes the data set of technical items to be related to the stakeholder requirements from D1.1 "Simplified stakeholder tree and weighting matrix of requirements" in Task 3.1. In this way it is one of the two foundation pillars of the top-down analysis performed in Task 3.3 to assess the alignment of the stakeholders' requirements with the *R&I objectives* required to achieve the vision of a cost-efficient, sustainable, and reliable European railway system of the future. This document also gives a quick access to the content in terms of technical innovations to any reader that is less familiar with the details of the ERRAC documents.

5. Overview of R&I objectives

This chapter gives an overview of *R&I objectives*, key technical concepts and development areas, and the underlying technological inputs that are expected to shape the Railway System of the Future. As explained in the previous chapter, the MP and the strongly related MAWP are the main objects of analysis for the work described in this document. Therefore, a thorough description of the results of this analysis forms its main body, divided into the main structural units of the MAWP. These are the System Pillar (SP) and the Innovation Pillar (IP), which in turn is divided into seven Flagship Areas (FA), one Transversal Topic (TT) and Exploratory Research (ER). The methodical approach for the structured extraction of *R&I objectives* is described in Chapter 5.1.

This main body of results is completed with several additional documents that have been analysed in order to broaden the view on possible *R&I objectives* within the field of transportation technology. This allows to make an assessment of the consistency of prioritised objectives between the MAWP and other recent strategic documents. The additional documents include the underlying strategic publications by ERRAC, publications from other research projects such as *TER4RAIL* and *Mobility4EU*, and strategic publications published by other organisations or other transport sectors, such as the EU Agency for Railways (ERA), the Advisory Council for Aeronautics Research in Europe (ACARE) or the European Road Transport Research Advisory Council (ERTRAC).

In addition to the above-mentioned documents, it was envisioned to analyse and incorporate methods and results from the parallelly ongoing Shift2Rail research project *IMPACT-2*. Efforts were made to consider the relevant results that were available during this project's timeframe, as their researched topics are highly related to this project. Examples for this related research are found in *IMPACT-2 WP2 - Socio-Economic Impact*, regarding the identification of activities with the highest impact on the goals specified within the S2R JU, as well as the assessment of impacts on customer attractiveness facilitated by railway research. In *IMPACT-2 WP4 - Quantitative KPI-Tree and SPD integrated assessment* a tree of the Key Performance Indicators (KPI) is developed which can be related to the findings from other documents.

5.1. Extraction method

For the systematic extraction of *R&I objectives*, a hierarchic structure in five layers was defined. The top layer represents the intended benefits and impacts that are envisioned for the results of the research conducted in the EU-Rail JU. The choice of the top layer is in alignment with the top-down approach shown in the previous chapter and gives a clear orientation when matching the underlying R&I objects with the stakeholder requirements. To keep the description of intended benefits and impacts well-defined and clear, they are related to the seven impact target areas defined in the MP for each objective. The seven impact target areas are:

- Meeting evolving customer requirements
- Improved performance and capacity
- Reduced costs
- More sustainable and resilient transport
- Harmonised approach to evolution and greater adaptability
- Reinforced role for rail in European transport and mobility
- Improved EU rail supply industry competitiveness

Table 1: Impact target areas defined in the MP

 Meeting evolving customer requirements	 Improved performance and capacity	 Reduced costs	 More sustainable and resilient transport	 Harmonised approach to evolution and greater adaptability	 Reinforced role for rail in European transport & mobility	 Improved EU rail supply industry competitiveness
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5.1.1. Definition of extraction layers

The remaining four layers are used to gradually structure the identified research objects into *R&I objectives*, *specific concepts*, *involved innovations* and *technical examples*, as shown in Figure 2. In addition to the hierarchic division into four layers, the research objects are linked to related ones on other layers to form a tree structure. This is done for each part of the MAWP in the following chapter 5.2. This includes also that the research objects are related to the target impact areas stated above and described more in detail in the subchapters 5.2.1-5.2.9, in order to draw a coherent view of the *R&I objectives*.

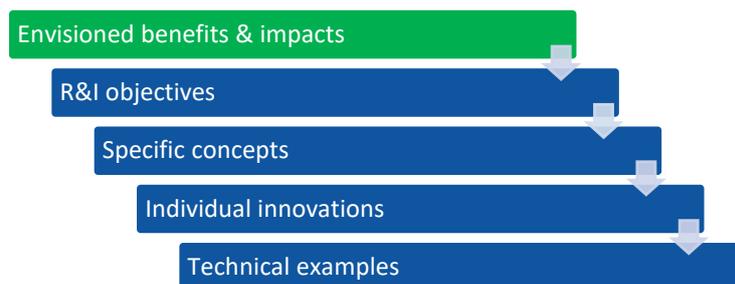


Figure 2: Layered structure for the extraction of R&I objects.

The individual layers follow, to a large extent, the structure and hierarchy suggested by the MAWP. The *R&I objectives* are the main points of research focus for each area. While they are still strongly related to the envisioned impacts and FA in which they are defined, they outline the overarching categories of research work with areas to tackle and overarching goals to reach, for example in terms of operational conditions. In this way they provide the purpose and connection between innovations and their importance for the Rail System of the Future as a service provider.

In the next layer, the *specific concepts* related to each *R&I objective* are listed. They describe operational approaches for the overarching systems, as well as methods to use in order to achieve the conditions and service standards that are lined out in the research goals of the *R&I objectives*.

The fourth layer, *involved innovations*, breaks the *specific concepts* down into more tangible systems or functions that will be added to the railway system. These can refer to new operational approaches that are supported by technical innovations as well as purely technical innovation categories. The *involved innovations* are the tools to facilitate the new methods and approaches defined in the levels above.

The *involved innovations* are in turn exemplified by the *technical examples* in the fifth layer. Even though this final layer is defined as *technical examples*, it is not strictly limited to purely technical development. It can also include standards, examples for defined architectures or specific operational routines that are developed and defined as a part of the R&I work. This final level represents the implementation level with well-defined topics to be tackled in projects.

For each structural unit of the MAWP, the original content is extracted with its key points and structure. This information is then transferred into the applicable layers as defined above. The results of this process are described in the following chapters. For an accurate representation in this analysis, the wording of *R&I objective* titles or parts of their descriptions may be taken directly from the analysed documents. A tree diagram of all *specific concepts* extracted from the MAWP is added in chapter 5.2 and as a list in Appendix A. For each structural unit of the MAWP, a more detailed tree diagram including *involved innovations* and *technical examples* is added for each objective in the following subchapters.

5.1.2. Ranking of R&I objects and benefits

As the final step of the extraction of the *R&I objectives*, their priority relative to each other is assessed as suggested in the analysed documents. Nevertheless, this assessment can only be made to the extent of available information for each layer. Therefore, no complete ranking of each single innovation is included here. Instead, the structural units of the MAWP, such as the FAs, have been ranked on the base of the estimated allocation of economic resources that is presented in the MAWP. The resulting ranked list of the highest structural layer is presented in the next subchapter.

On the underlying layers of *R&I objectives* and *specific concepts*, no information about resource allocation was available during this analysis. Instead, the priorities can be estimated qualitatively, for example based on the volume of underlying innovations and number of given *technical*

examples. In other words, the assessment must be based on the emphasis and detail that is given to each area in the documents and whether they enable further development. Such indications of prioritisation may be helpful during the assessment of stakeholder requirements against the research concepts, as they help to determine if there possibly are misalignments in their respective priorities. Therefore, such indications are given in the detailed description in each subchapter below and the resulting summarised list of ranked *R&I objectives* for each structural unit is given in chapter 6. Due to the inconsistent nature of information, it is impossible to rank all *specific concepts* against each other. As a consequence, no such fully ranked list is presented in this report.

The ranking of the intended benefits is performed based on the number of *R&I objectives* that support each respective benefit with its *specific concepts*, *involved innovations* and *technical examples*. For clarity, the benefits have been summarised to the seven impact target areas mentioned above. The contribution of each *R&I objective* is in this case weighted equally. The resulting list of ranked benefits in terms of impact target areas can also be found in chapter 6.

5.2. EU-Rail Multi-Annual Work Programme

The Multi-Annual Work Programme (MAWP) for the Europe's Rail Joint Undertaking (EU-Rail) is the document that defines the technical scope of the JU with its specific pillars and the Flagship Areas in detail. It is therefore more detailed than the MP, which outlines the overall research scope and purpose. The MAWP comprises a subset of the original range of research areas outlined in ERRAC's Strategic Research and Innovation Agenda (SRIA), which listed all areas where a research effort would be desirable for the railway sector. The scope of research areas included in the MAWP instead is a product of the boundaries posed by the funding limitations faced while setting specific aims for the coming EU-Rail JU.

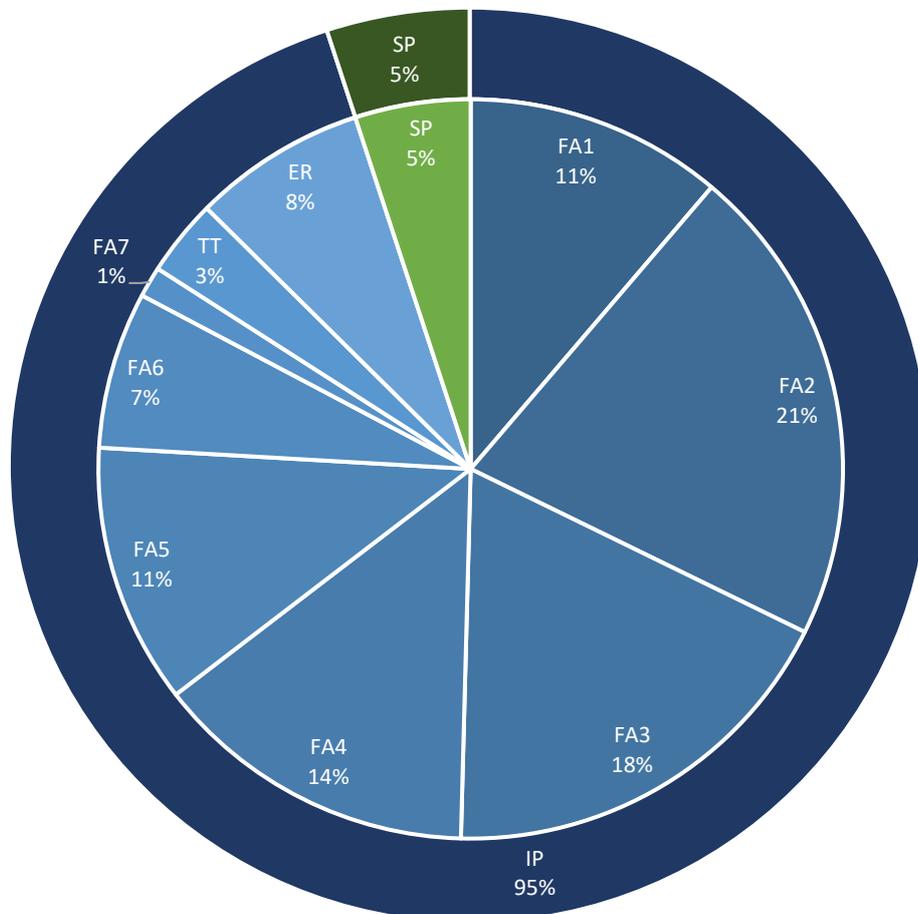
The EU-Rail JU is the direct successor to the Shift2Rail JU and one of the research programmes under Horizon Europe. The vision of EU-Rail is:

*To deliver, via an integrated system approach, a high capacity, flexible, multi-modal, sustainable and reliable integrated European railway network by eliminating barriers to interoperability and providing solutions for full integration, for European citizens and cargo.
(EU-Rail MAWP)*

The assessment of the priority distribution between structural units of the MAWP such as the FAs is based on the indicative distribution of financial resources given in the MAWP. The relative distribution of the total EUR 1 218 796 000 is shown in Figure 3. When comparing the funding proportions, one should be careful when drawing direct conclusions for a single area, as there in many cases are interactions between or direct benefits from one area to another, as indicated in each following subchapter. With this in consideration, the direct ranking ends up as follows:

1. FA2: Digital & automated up to autonomous train operations
2. FA3: Intelligent & integrated asset management
3. FA4: A sustainable and green rail system
4. FA5: Sustainable competitive digital green rail freight services
5. FA1: Network and mobility management
6. ER: Exploratory research
7. FA6: Regional rail services / innovative rail services to revitalise capillary lines
8. SP: System Pillar
9. TT: Transversal topic: digital enablers
10. FA7: Innovation on new approaches for guided transport modes

It can clearly be noted that FA 2-4 are given the highest priority in terms of funding and that the System Pillar, the Transversal Topic and FA7 are each on their own given comparatively small economical priority. These tendencies can further be confirmed by comparing the original set of five areas of priority given in the MP, which was then extended to the seven FAs in the MAWP. This means that the original area of priority *Sustainable and digital assets* was split into FA3 and FA4. The fact that both of those still are among the three most pronounced FAs shows their high importance within EU-Rail. FA7 on the other end was not represented among the original set of five areas of priority given in the MP and instead added during the later definition process, which confirms its role as the unit given the lowest priority within EU-Rail.



- FA1: Network and mobility management
- FA2: Digital & automated up to autonomous train operations
- FA3: Intelligent & integrated asset management
- FA4: A sustainable and green rail system
- FA5: Sustainable competitive digital green rail freight services
- FA6: Regional rail services / innovative rail services to revitalise capillary lines
- FA7: Innovation on new approaches for guided transport modes
- TT: Transversal topic: digital enablers
- ER: Exploratory research
- SP: System Pillar
- IP: Innovation Pillar

Figure 3: Relative distribution of financial resources for EU-Rail

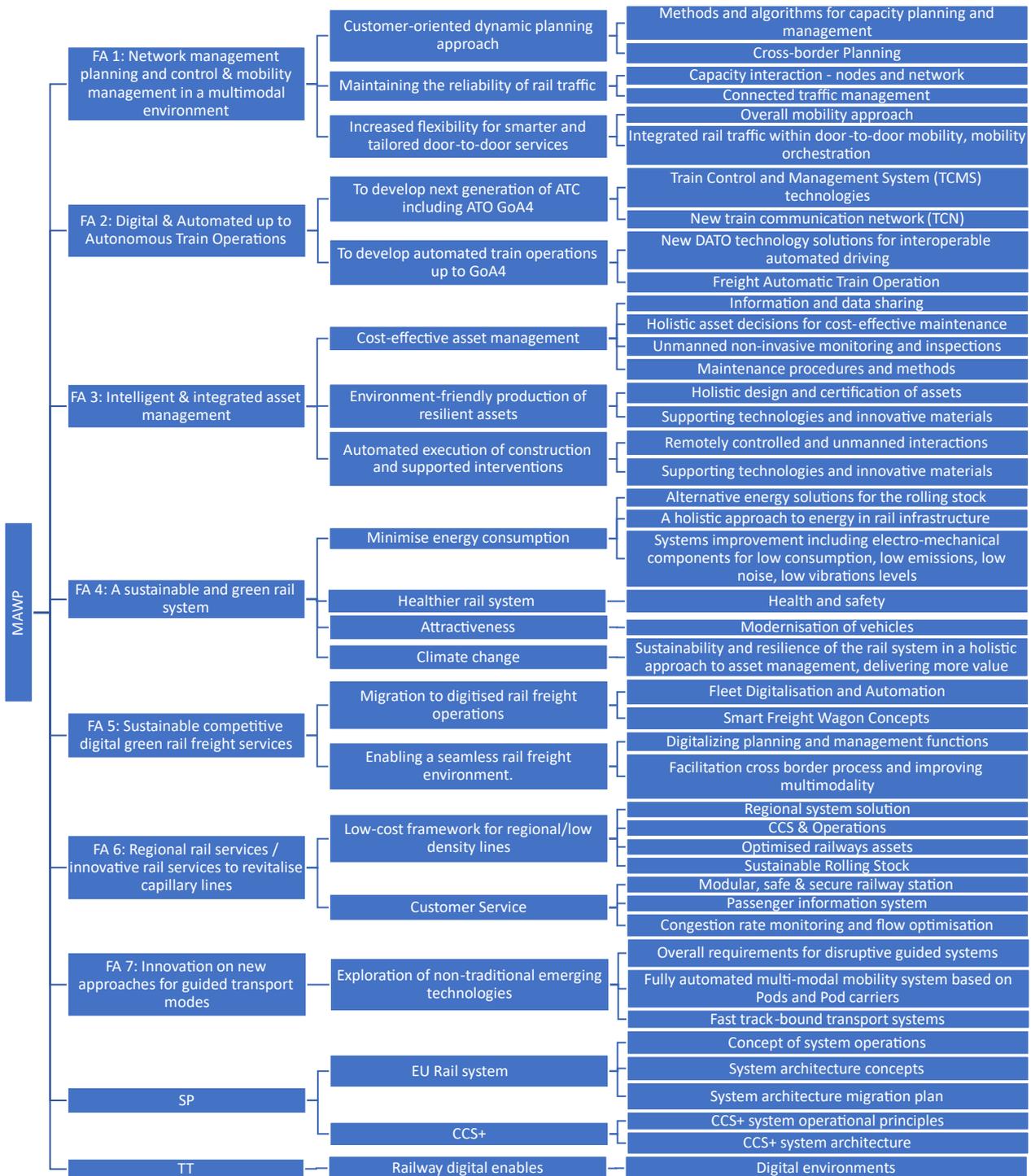


Figure 4: Overview of the extracted structure of R&I objects in the MAWP, with R&I objectives in the middle column and specific concepts in the right-hand column.

5.2.1. System Pillar

The System Pillar (SP) is built on the idea to deliver a system architecture for an integrated European rail traffic management and will improve the current railway system and thus offer better services for European citizens, passengers and freight transport. The system pillar will have a high interaction with the innovation pillar to create a coherent output for EU-Rail. The aim is to guide, support and secure the work completed within the Innovation pillar. This is done by dividing the pillar into two tasks: EU Rail System and Control Command and Signalling plus (CCS+). Whereby Task 1, the EU Rail System, is an open, shared, dynamic structure composed of assets that are fixed in space and mobile, owned and managed by different actors Task 2, CCS+, will develop the definition of CCS+ architecture requirements and specifications, and will be based on the CCS system architecture.

In the MAWP Task 2 (CCS+) is given more elaborately than Task 1 (EU Rail System), and since Task 1 is a much higher-level concept, Task 2 can be assumed to have higher priority. However, Tasks 1 and 2 cannot exist without each other and are therefore closely linked.

The System Pillar is, just as every Flagship Area related to different impact goals given by Europe’s rail master plan. As the System Pillar is an overarching architecture it relates to all impact areas:

- Meeting evolving customer requirements
- Improved performance and capacity
- Reduced costs
- More sustainable and resilient transport
- Harmonised approach to evolution and greater adaptability
- Reinforced role for rail in European transport and mobility
- Improved EU rail supply industry competitiveness

Table 2: Expected impact areas of the SP

<p>Meeting evolving customer requirements</p>	<p>Improved performance and capacity</p>	<p>Reduced costs</p>	<p>More sustainable and resilient transport</p>	<p>Harmonised approach to evolution and greater adaptability</p>	<p>Reinforced role for rail in European transport & mobility</p>	<p>Improved EU rail supply industry competitiveness</p>
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5.2.1.1. Task 1: EU Rail System

The objective of the EU Rail System task is to create open access to SERA (Single European Railways Area), be performant and competitive with a synchronised deployment and full alignment with the future system. It requires mobile assets that have either a local interaction with fixed assets or through a wide-area communication network. Both assets can be connected to a control network for operations and maintenance. As mentioned in the previous section, this creates an open, shared, dynamic structure composed of assets that are fixed in space and mobile, owned and managed by different actors.

To achieve this EU Rail System that is structurally and logically clear and consistent, several concepts need to be completed. These concepts are given in the flowchart below, together with the proposed innovations and its technical examples. For the SP and thus Task 1 the concepts and innovations are mostly related to analysis, standardisation and decision-making. These concepts should remove technical and operational boundaries.

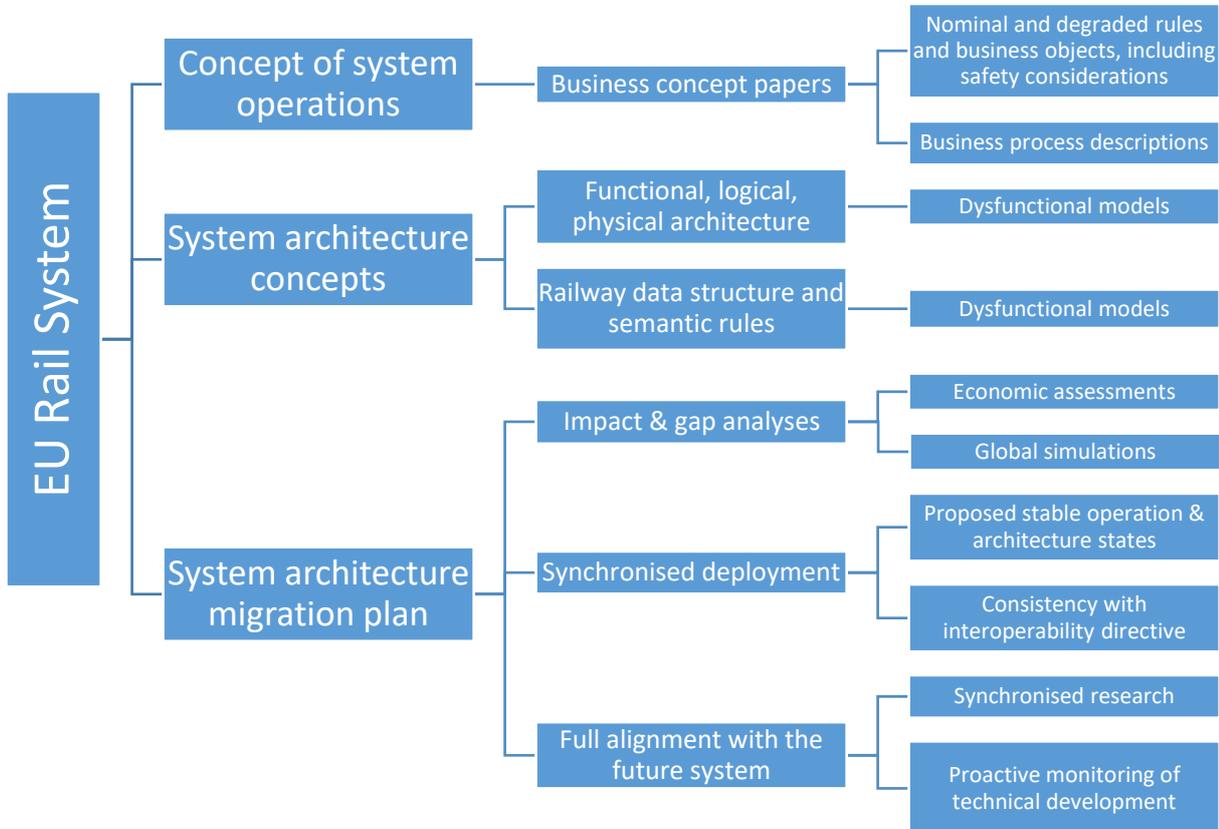


Figure 5: Extracted underlying structure to R&I objective 1 in the SP: Task 1

5.2.1.2. Task 2: CCS+

Creating a CCS+ architecture will create a general harmonisation at EU level and strive towards integrated European traffic and capacity management. Within the system pillar the task for CCS+ is to define the CCS+ architecture requirements and specifications involving the complete railway sector. It is needed to improve the CCS as there is a significant potential to improve passenger and freight services by ready-to-use digital technologies.

The CCS+ objective consists of two concepts: the operational principles and the system architecture. The operational principles are mostly related to definitions of the control & command process and the implementation of control and traffic management tools. This concept thus relates more to the general process of CCS+. The system architecture corresponds more to the technical scope of the SP. It includes the control & command activities for both the infrastructure and on-board systems and the operational railway system and its management. It

consists of three subtasks: on-board CCS+, trackside CCS+ and managing rail terminals. Task 2 depends highly on the development and results of the current CCS system.

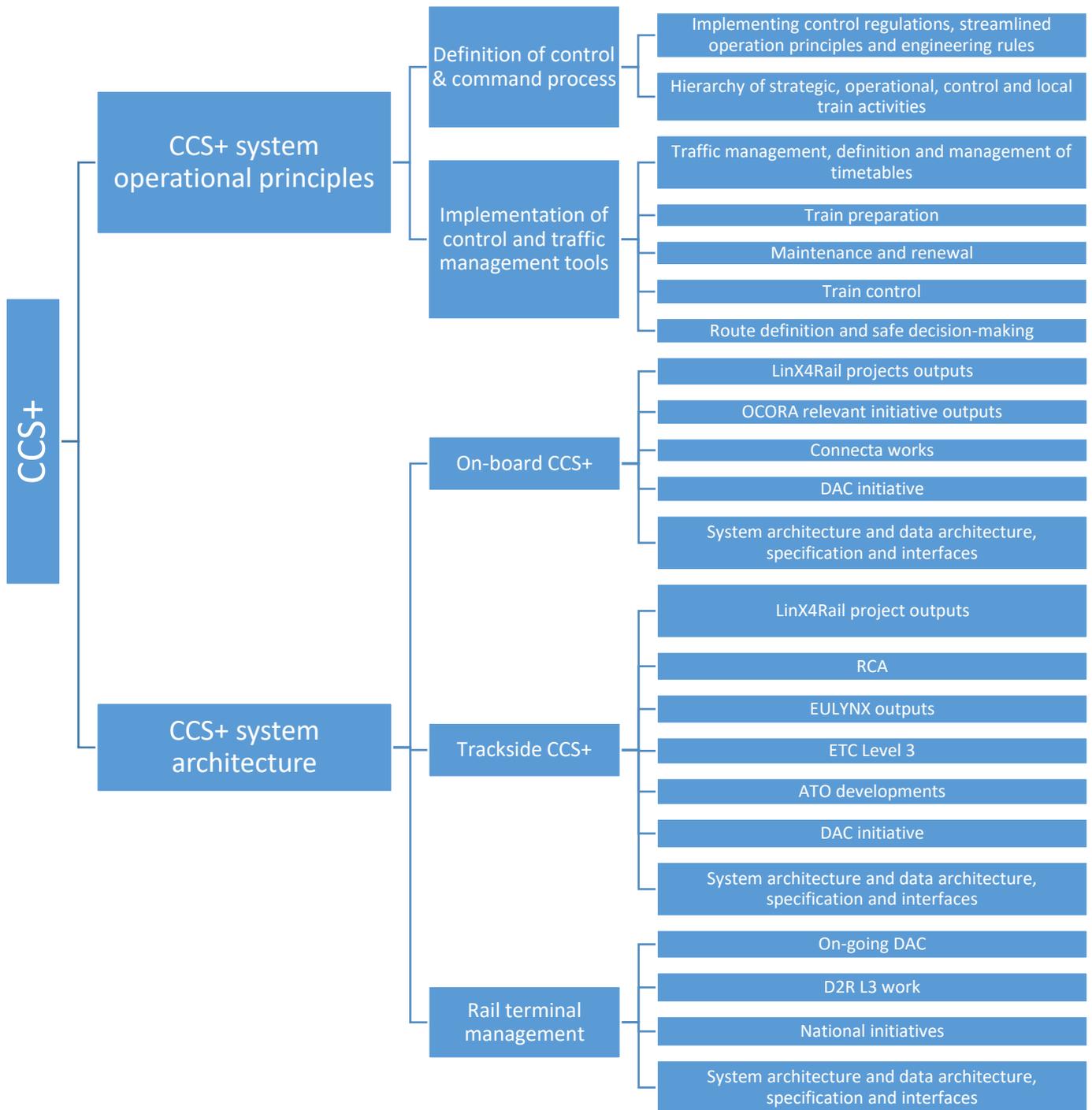


Figure 6: Extracted underlying structure to R&I objective 2 in the SP: Task 2

5.2.2. FA1: Network and mobility management

To support the development and operation of a Single European Railway Area, railways must dramatically improve the flexibility, efficiency, resilience, and capacity adaptation of the European rail network. The goal of Flagship Area 1 is to develop the functional requirements, associated specifications, and operational and technological solutions to enable future European traffic management. To achieve this goal, the requirements that enable common train operations and ticketing, as well as the design of future network management, planning and control will be included.

To accelerate the European approach, R&I in FA1 will also consider early implementation of these common functions and approaches starting from existing national TMS. This dynamic network and traffic management at European level, built on a harmonised functional system architecture to ensure agile, cross-border and mixed traffic, is the target solution to which the various existing TMSs should be migrated. The interconnection of rail networks, long-distance corridors (e.g., freight corridors) and the integration of stations and marshalling yards will make it possible to optimise capacity, improve dynamic planning and increase the resilience of the connected rail network. Information related to real-time forecasts of punctuality, available capacity, and transportation demand will make it possible to adjust supply to real-time demand. This ensures that rail remains the central element for orchestrating sustainable mobility in the future. In addition, a door-to-door mobility concept improves rail accessibility. The main risk preventing or delaying the realisation of this ambitious goal is the lack of coordination and interaction between the different actors. The organisational framework and deployment strategy must therefore be well defined or implemented, and there must be European regulations to enforce it.

5.2.2.1. R&I objective 1: Customer-oriented dynamic planning approach

To create customer-centric dynamic planning, railways must move from services with a long planning horizon to a much more dynamic approach that meets the needs of passengers and freight customers. Operators must be able to quickly adapt to potential deviations or disruptions and last-minute changes in demand. A customer-centric, dynamic approach to planning will support the delivery of much more flexible approaches to planning and traffic management for rail services and enable the railway to better meet the needs of its customers. The key impact will be the move to a coherent overall EU rail system. To achieve this, the objective will address the weaknesses of the rail system, such as lack of flexibility, lack of reliability and lack of capacity, and improve the resilience, punctuality and responsiveness of the actors.

Objective 1 of the FA1 activities is to overcome the main problems faced by railways (mainly lack of flexibility, efficiency and resilience in planning and capacity adjustment, handling of a cross-border train in the form of two or more trains instead of one train) and to ensure improved, interoperable planning and management of pan-European railway timetables, i.e., improved quality of planning that represents the systemic fulfilment and balance of all related requirements, including efficiency, robustness, efficient reserves, and fair trade-offs. The improved features and

performance of planning and simulation software enable the automation of decision support systems (e.g., to support the management of short-term path requests), the improvement of conflict resolution, the optimisation of the use of resources such as network, personnel, rolling stock, and energy, and thus the increase of the efficiency of the rail network and its operation). An important component that is often foreseen in future planning processes, namely coherence with external services and operational technologies, is ensured by considering the relevant driving modes and on-board technologies already in the planning phase. This applies in particular to the areas of cross-border planning, stabling and station processes, traffic management, and ETCS or ATO modelling. Innovations will be integrated/connected into state-of-the-art systems and used to demonstrate functionality and the ability to implement for production use. These activities will result in improved on-time performance and reduced energy consumption and CO2 emissions.

Table 3: Expected impact areas of R&I objective 1 in FA1

 <p>Meeting evolving customer requirements</p>	 <p>Improved performance and capacity</p>	 <p>More sustainable and resilient transport</p>
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Interaction with FA3 (Asset management) will ensure information exchange between the TMS and the Intelligent Asset Management System (IAMS) and enable sharing of data such as maintenance schedules, forecast faults, and asset status tracking, topics already started in Shift2Rail I2M. Both FAs will be aligned to feed cooperative planning tools in FA3 with train planning and operations information to balance train service and asset management impacts, including possession planning and possession management tools. FA4 (Energy) will interact with the TMS to optimise schedules and reduce fleet energy consumption. It will explore how to exploit vulnerabilities in the real-time schedule to send targets to the trains that enable energy savings and send back information about the onboard system's confidence in meeting the on-time target.

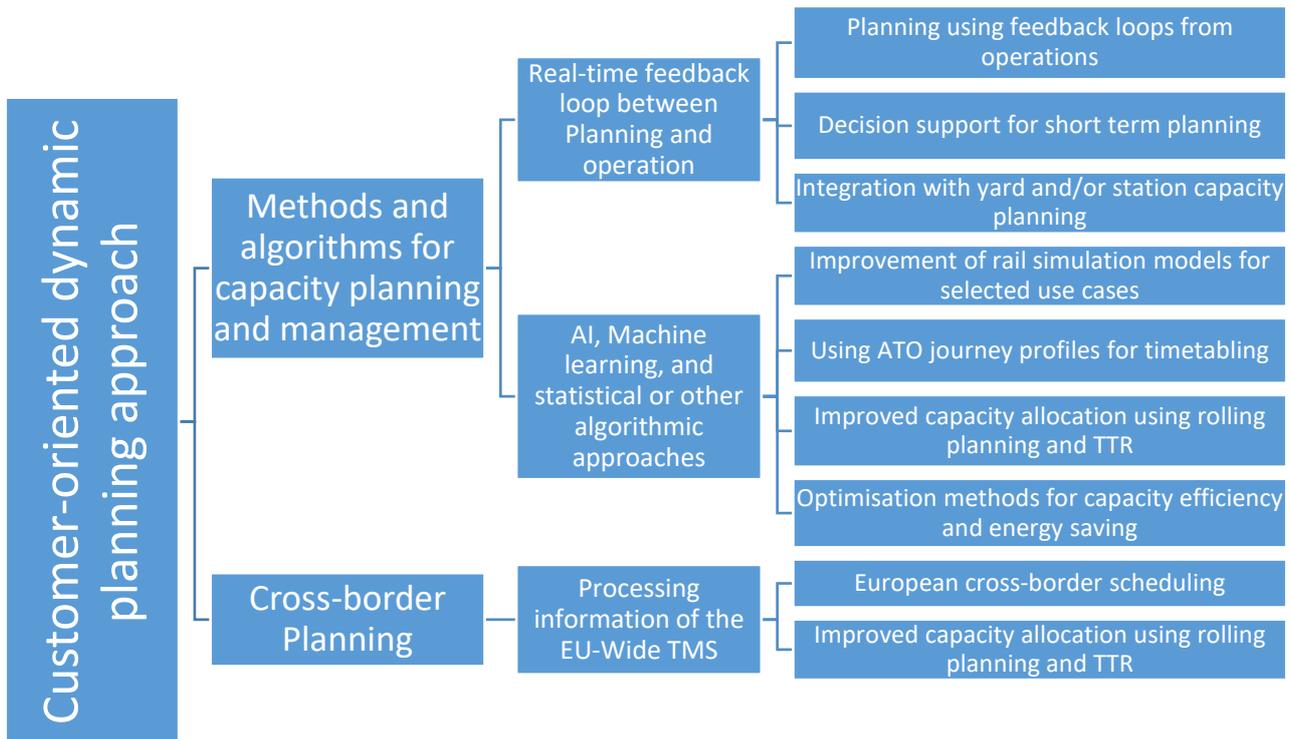


Figure 7: Extracted underlying structure to R&I objective 1 in FA1

5.2.2.2. R&I objective 2: Maintaining the reliability of rail traffic

The biggest challenge facing rail transportation is maintaining the reliability of rail service on an ongoing basis. This challenge is related to the fact that all subsystems affecting traffic must be connected to the TMS to collect real-time information. Capacity improvements through ERTMS and ATO and other improvements can be leveraged. Resilience can be improved by closely monitoring all deviations to anticipate problems and develop the best alternatives using digital technologies. Maintaining the reliability of rail transport will contribute to the joint development of the system and greater harmonisation of traffic management to facilitate the realisation of the Single European Railway Area and improve the speed of introduction of innovative technologies.

By developing a new approach to European traffic management with the system pillar, including operational and functional requirements that allow the same system architecture to be used for simple low-effort regional TMS applications as well as more sophisticated solutions for higher traffic densities and complex network topologies, FA1 strengthens the treatment of trains when different network and business models meet, such as cross-border traffic and long-distance and regional routes. Another outcome of the activities conducted in second objective of FA1 will be to improve real-time rail traffic management and operations. The goal is to enable a more flexible, optimised, and automated response to unplanned situations such as disruptions and dynamic

demand, especially in cross-border traffic. This will result in significantly improved TMS technology capable of supporting interoperable traffic management at the European level, which will increase the resilience of an interconnected "real-time" rail network in Europe. This outcome will be achieved by using the latest available methods and technologies based on best practices and operational research, new signalling technologies (e.g., ATO, ETCS Level-2 and Hybrid Level-3) and software/algorithms or by further developing them. The resulting increase in capacity is enabled by new TMS technology that feeds optimal scheduling and routing requirements to the train control components on site or in the rolling stock.

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To support pan-European traffic management, customer requirements for simplified, efficient and high-performance cross-border traffic must be met. This includes requirements such as optimizing the quality of cross-border train paths in the planning process (e.g., resource negotiation with subsystems) and the corresponding real-time deviation management. An optimised overall system architecture and operational processes must be developed together with the system pillar. The aforementioned activities will enable more accurate modelling of operations and train behaviour and thus more effective operational use of network capacity (including resources, marshalling yards, terminals, etc.), leading to reduced delays and increased comfort through optimisation of international and domestic train traffic combined with better information. Standardisation of interfaces and processes will facilitate this goal and reduce the expenditure and operating costs of the resulting technology in support of the future EU traffic management concept.

Table 4: Expected impact areas of R&I objective 2 in FA1

 <p>Meeting evolving customer requirements</p>	 <p>Improved performance and capacity</p>	 <p>Harmonised approach to evolution and greater adaptability</p>	 <p>Improved EU rail supply industry competitiveness</p>
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Collaboration with FA2 will focus on achieving an overarching system solution through the joint design of interfaces involving SP. These interfaces will facilitate the exchange of additional information according to the results of the project activities (e.g., train position and speed information as planned for the Safe Train Positioning (STP) system in FA2, as well as precise speed control information for driving permits). Under this objective, traffic management concepts, procedures, and techniques for different traffic types (e.g., high and low density) and operational profiles (e.g., short or long haul) will be shared with FA2. FA2 will provide parameters for planning and simulation tools to calculate the capacity benefits of the applied DATO technology on corridors, intersections, and routes. Results will be shown in joint demonstrations, for example with FA6 to provide the 'simplified TMS' demonstrator platform. TMS will support Regional Rail Services (FA6) by addressing FA6's TMS requirements to provide simplified TMS and on-demand Ben@Rail – GA101046258

passenger services with flexible scheduling.

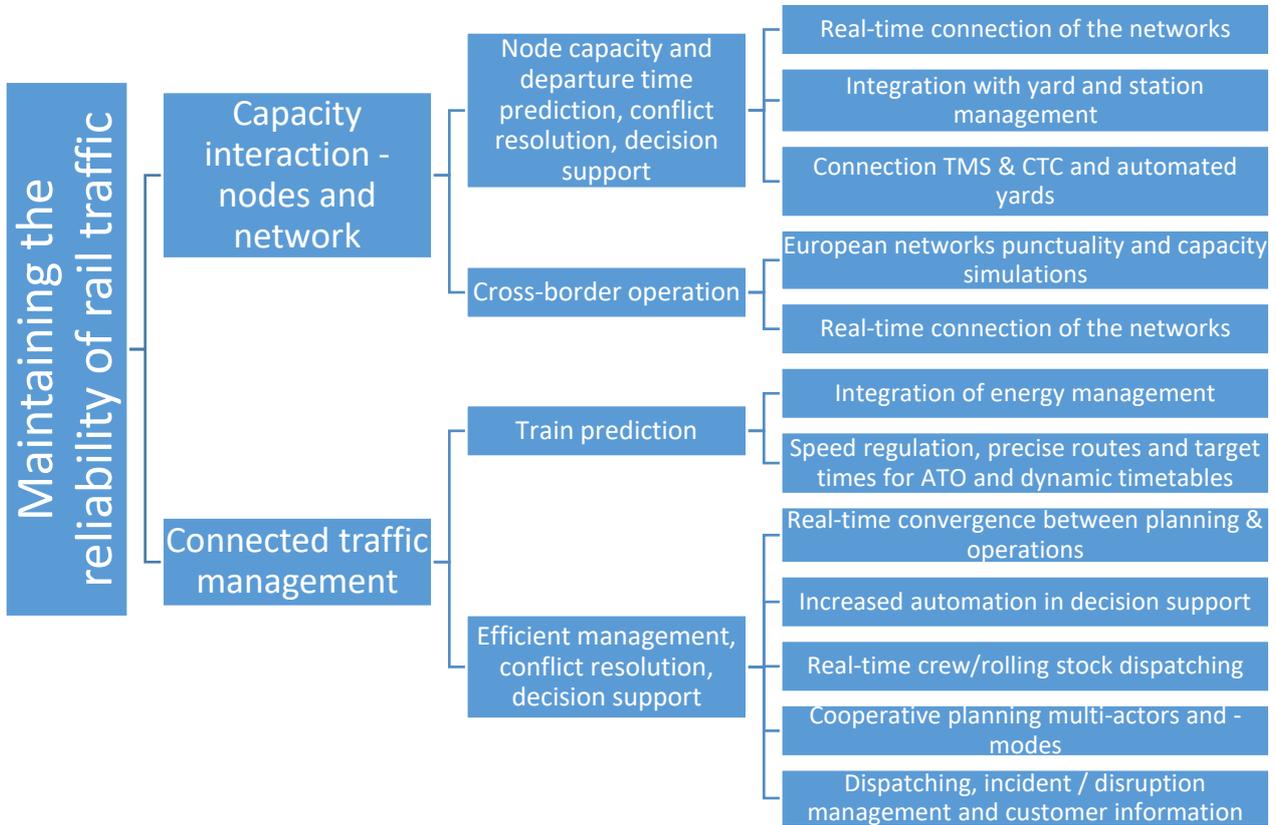


Figure 8: Extracted underlying structure to R&I objective 2 in FA1

5.2.2.3. R&I objective 3: Increased flexibility for smarter and tailored door-to-door services

To meet passenger and logistic expectations, flexibility must be increased by developing innovative mobility solutions and concepts for smarter and tailored door-to-door services and offerings. The goal of increased flexibility is to better integrate rail into a more sustainable mobility system to provide better services for passengers and freight and to achieve higher usage and passenger volumes. Linking modes and breaking down silos between public and private transport industry players will enable door-to-door mobility. Developing appropriate solutions for specific needs will make it possible to incentivise mobility choices, helping to promote rail, optimise investments, and contribute to health and well-being. Successful implementation of this objective and its outcomes will increase the attractiveness of rail for current and future environmentally friendly transport systems and increase its competitiveness with the road vehicle industry, which will strengthen the European rail industry. One of the main objectives of FA1 is to better integrate the rail mode and maintain its role as the backbone of the mobility system.

To achieve R&I 3rd goal that rail can be the backbone of door-to-door mobility, it is critical that the service be attractive and reliable, and thus competitive with private car and truck-only road transportation. At the same time, the offer and operation of the services must be improved in terms of cost efficiency for all participating operating companies, so that they can expand the offer step by step. This will be achieved through a number of prerequisites for improved planning and management of door-to-door service in real time. These include better information sharing between operators (for operational issues), long-term and short-term demand forecasts for all parts and routes of the chain, systems for dynamic best offers (including real-time availability of resources and network constraints). Other requirements include improved accessibility and attractiveness of connection points, especially for persons with reduced mobility (PRM). This operational improvement towards a more reliable and flexible door-to-door mobility ecosystem, combined with a more effective use of vehicle/train capacity, will lead to a reduction in CO2 emissions. It will also support the public transport market and ensure that rail remains the principal component of sustainable mobility.

Table 5: Expected impact areas of R&I objective 3 in FA1

 Meeting evolving customer requirements	 Improved performance and capacity	 More sustainable and resilient transport	 Reinforced role for rail in European transport & mobility	 Improved EU rail supply industry competitiveness
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FA5 (Freight) will benefit from cross-border planning and linking TMS with automated yards and ports, as well as managing the yards themselves through the flagship Seamless Freight Corridor project. Collaboration is planned for demonstration-related activities, such as interfaces with shipyards, with real-time data exchange with various resource management systems. There will also be collaboration in the area of DAC, sharing real-time data such as train formation information, train integrity and others.

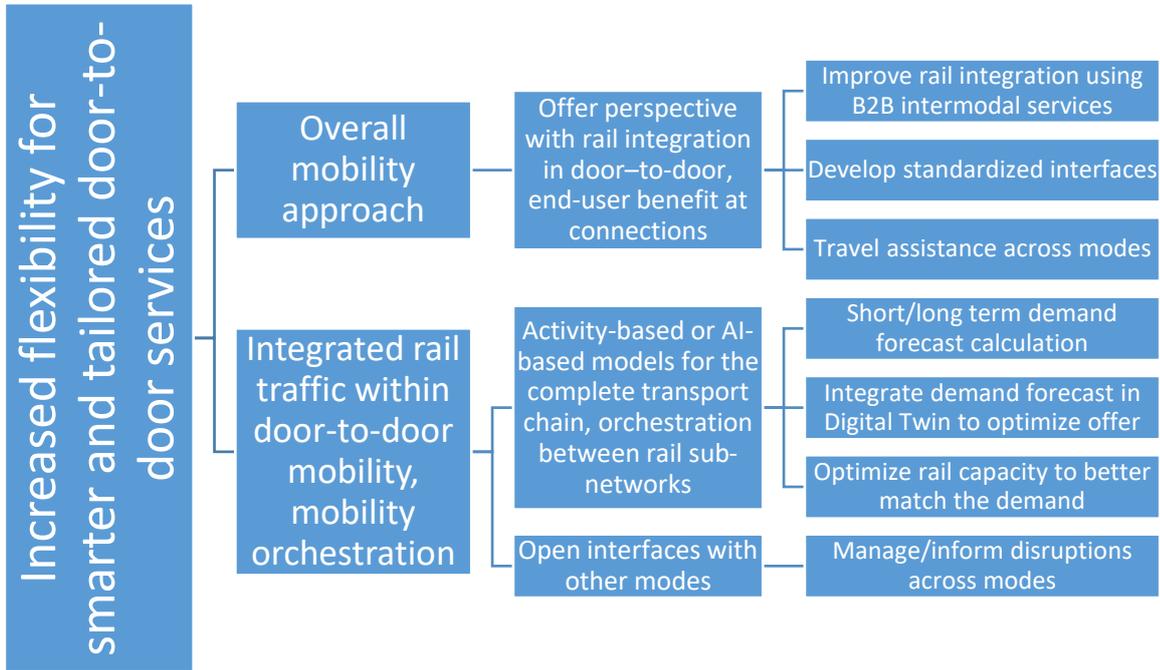


Figure 9: Extracted underlying structure to R&I objective 3 in FA1

5.2.3. FA2: Digital & automated up to autonomous train operations

To increase rail capacity, there are two main options: building new infrastructure or operating the rail system in a way that uses new technological and operational solutions. However, building new infrastructure/lines is challenging. Therefore, the goal of this flagship area is to take advantage of the great opportunity offered by the digitisation and automation of rail operations, with digital "automated" train operations (DATO) being the most visible result of a comprehensive transformation of rail operations.

The assignment of priorities or ranks is especially challenging for this FA as both the R&I objectives and the underlying concepts refer to parallel development areas that together will constitute the autonomous railway operations in the future. As all of them will make an equally important contribution on the infrastructure and vehicle side respectively, there are no explicit priorities assigned in this subchapter. However, as objective 1 lays the base for objective 2, it is ranked first.

5.2.3.1. R&I objective 1: To develop next generation of ATC including ATO GoA4

The first objective of FA2 is to increase on-time performance, rail capacity, operational quality, and (re)scheduling flexibility, and reduce energy consumption with the next generation of Automatic Train Control (ATC). The next generation of ATC, including Automatic Train Operation (ATO) Grade of Automation (GoA) 4, is based on a European approach agreed under the System Pillar under the leadership and commitment of the Commission services and built on a harmonised, adaptable and scalable trackside, and on-board CCS+ system architecture. This system will be built on a radio based European Rail Traffic Management System (ERTMS) or higher and represents the next evolution of the system. It incorporates the latest technological advances and has functionality to fully optimise performance in line with traffic management improvements.

Table 6: Expected impact areas of R&I objective 1 in FA2

 <p>Meeting evolving customer requirements</p>	 <p>Improved performance and capacity</p>	 <p>Reduced costs</p>	 <p>More sustainable and resilient transport</p>	 <p>Reinforced role for rail in European transport & mobility</p>
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An important aspect of next-generation ATC innovation is increased cost efficiency. By reducing turnaround times for train staff and rolling stock, fewer staff and fewer trains are needed to provide the same services to customers. In this way, the same number of trains can be used to serve more passengers (permanent expansion). In accordance with the technical specifications, the train and infrastructure are also subject to less wear and tear (DATO), which means lower maintenance costs and lower breakdown costs. The modular and, where possible, reduced number of ATC system components required and the support of higher train densities reduces the

infrastructure cost per train trip and enables the offering of cheaper capacity. A reduction in energy consumption will also be achieved by the next-generation ATC incorporating techniques to optimise rail operations with demand-driven network improvement technologies and route determination methods that result in an optimal speed profile that is more accurately maintained thanks to more accurate running and stopping operations. As a result, this will also lead to fewer emissions. In terms of societal impact, next-generation ATC will lead to higher levels of rail safety (e.g., through full monitoring of shunting operations), reduced travel times for passengers and freight, higher customer satisfaction, a more modern and future-oriented job profile for both train drivers and planners, a modal shift from air/car transport to rail, higher sustainability, and solutions for sociocultural developments.

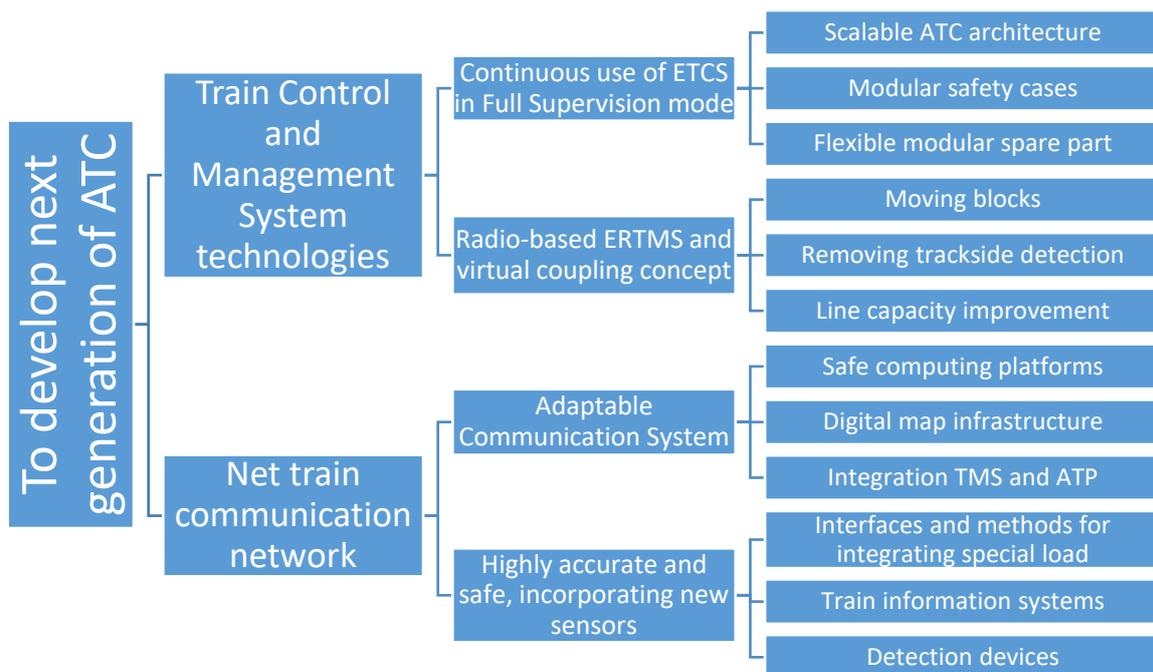


Figure 10: Extracted underlying structure to R&I objective 1 in FA2

5.2.3.2. R&I objective 2: To develop automated train operations up to GoA4

The second objective of FA2 is to develop fully automated train operation up to GoA4. This means that the rail system is ready for fully unattended train operation, including starting a train, moving, and stopping the train, opening and closing doors, remote control of the train, and recovery operation in case of interruptions. The development of ATO up to GoA4 will contribute to an increase in punctuality and rail capacity, a reduction in energy consumption and travel times for passengers and freight, and an increase in cost efficiency for Railway Undertakings (RUs) and Infrastructure Managers (IMs).

Since fully automated train operation allows more precise driving and stopping, which in turn leads

to better adherence to the timetable, greater punctuality can be achieved. Flexibility in (re)planning is also increased, because in the event of last-minute changes or disruptions, ATO trains can be rerouted in less time thanks to the precision, performance, flexibility and constant availability of "automated staff". In addition, scheduling becomes more flexible as automatic coupling and uncoupling reduces shunting times. Commuter trains, which will no longer have to change drivers, will also experience greater flexibility toward demand-driven services. As a result of more precise operation, buffer times between trains can be reduced, allowing more trains to run on the network and thus increasing rail capacity. This is also the case due to improved response time through the optimal complement of man and machine and reduced process times for turning trains, starting trains, maintenance, and cleaning operations. In addition, the integration of timings at critical infrastructures can further optimise the use of the network.

Table 7: Expected impact areas of R&I objective 2 in FA2

 <p>Meeting evolving customer requirements</p>	 <p>Improved performance and capacity</p>	 <p>Reduced costs</p>	 <p>More sustainable and resilient transport</p>	 <p>Reinforced role for rail in European transport & mobility</p>
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Certain trains or rail vehicles for diagnostic or inspection purposes, as well as maintenance rail vehicles will be subject to automatic train operation. FA2 will provide technologies from the mainline ATO to support the automation of the yellow fleet while running under normal operating conditions. FA5 will provide new solutions for freight operations, such as digital automatic coupler (DAC). FA2 will develop ATO for automated operation of trains in commercial service (i.e., on track, e.g., with a train ID) and provide technologies within an ATC architecture into which specific yard technologies can be integrated by FA5. FA2 will deliver ATP functionality for TIMS to FA5 based on the current definition, leaving room for additional development within FA5. All related developments related to DAC are within FA5. FA2 includes trip monitoring related to stabling (moving a train from the end of a train journey to the depot). The stabling function is developed in FA2, while the shunting function is developed in FA5 as an application-specific function. Specific functions for automatic and autonomous shunting for freight operations will be developed in FA5, based on the generic ATO functions developed by FA2. A digital register that serves as a data source for e.g., safe train positioning or planning and design is also being discussed between FA6 and FA2.

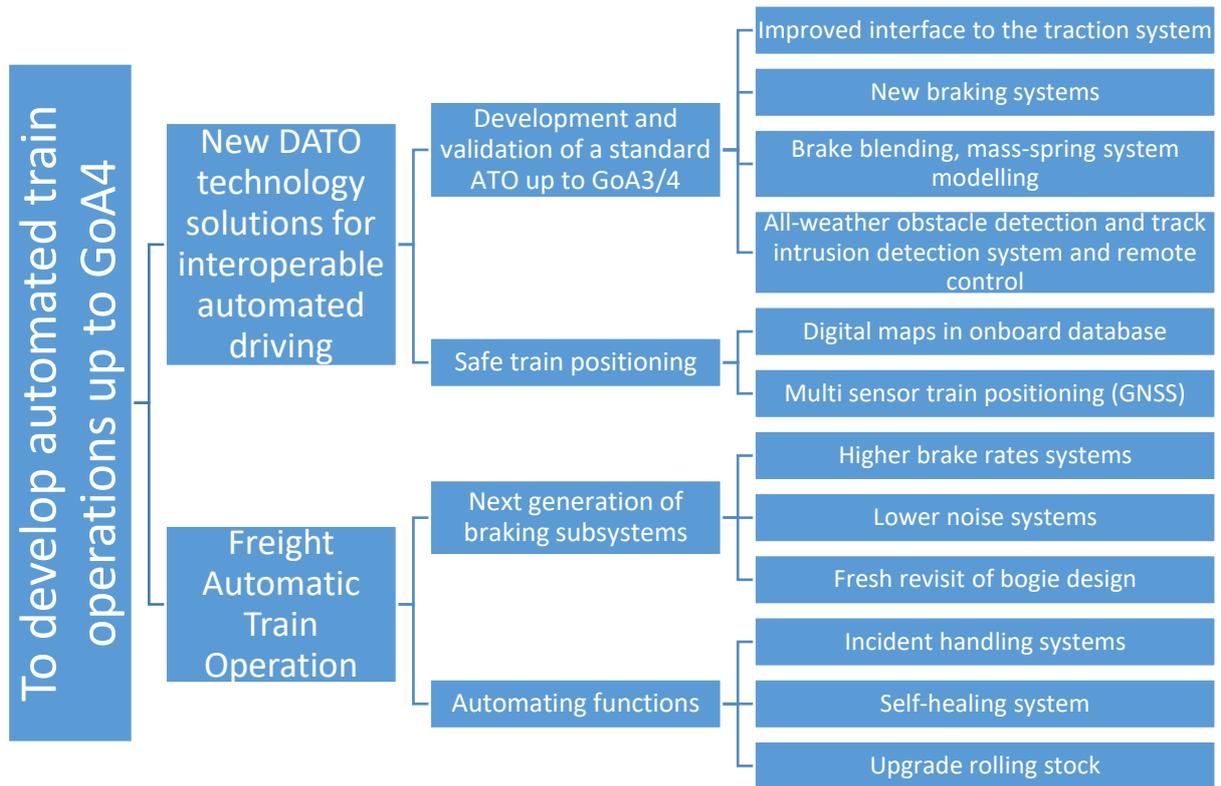


Figure 11: Extracted underlying structure to R&I objective 2 in FA2

5.2.4. FA3: Intelligent & integrated asset management

Flagship area 3 focuses on the implementation of integrated digital tools for asset management and maintenance optimisation on the full system level. It is the second largest R&I unit within EU-Rail in terms of direct funding. It consists of three objectives with its scope even including Automated execution of construction and supported interventions and environment-friendly production of resilient assets in addition to the main objective of cost-effective integrated asset management. With a holistic take on the entire life cycle of railway assets from design to decommission, the research concepts in this FA aim at enabling a better performing, more efficient and resilient railway system.

The first objective, cost-effective integrated asset management, lays the foundation of the holistic management approach by creating a common data sharing environment for increased knowledge on system behaviour and interaction. It also comprises a large set of innovations with technical examples and therefore stands out as the most prioritised objective in this FA. The other two objectives are adding supplementary aspects to this, focusing on innovative technological solutions in manufacturing, materials, and supportive technologies. Of those two, the objective environment-friendly production of resilient assets has a broader scope including design considerations of system interactions and is therefore ranked second. The third objective Automated execution of construction and supported interventions follows with a small margin on the third rank.

5.2.4.1. R&I objective 1: Cost-effective integrated asset management

Cost-effective integrated asset management addresses short, mid, and long-term interventions widely supported by digital diagnosis technologies and data analytics, thereby creating the basis for balancing operating costs, efficiency, and reliability, while maximising the value of the rail system. The envisioned benefit of this *R&I objective* is based on the delivery of modular, joint technical solutions for information sharing, thereby enabling monitoring synergies between stakeholders. The holistic monitoring is a key to refined maintenance processes that enable the above-mentioned balance while causing minimal service disruptions. Based on this, it envisions the development of new management methods and routines for synchronised processes, avoiding unnecessary disruptions and unbalanced optimisation.

By prediction and alignment of maintenance processes, the asset down-time is minimised, keeping transport volumes and cost-efficiency high and therefore supporting the rail system's capacity. By establishing technical leadership of the European rail industry within the areas of maintenance optimisation and design, while harmonising and simplifying the processes, international competitiveness is strengthened. By reducing unexpected unavailability and disruptions by system monitoring, and optimised long-term scheduling of maintenance, flexibility and punctuality are ensured. By establishing efficient maintenance methods and transitioning into a low-maintenance system with reduced demand of human intervention, durability and reliability are increased. All these factors help minimising the lifecycle costs of the railway system. All the points above also

contribute to the competitiveness of the railways within Europe, therefore reinforcing the role for rail in European transport and mobility.

Table 8: Expected impact areas of R&I objective 1 in FA3

 <p>Meeting evolving customer requirements</p>	 <p>Improved performance and capacity</p>	 <p>Reduced costs</p>	 <p>More sustainable and resilient transport</p>	 <p>Improved EU rail supply industry competitiveness</p>
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For this objective, a high resulting Technology Readiness Level (TRL) of 6-9 is expected during the course of the EU-Rail JU and it has a strong interaction with FA1, FA5 and the TT. Even though no clear prioritisation order can be deducted from the given information, it is clear that information and data sharing are the basic requirement for the other envisioned concepts. Holistic asset decisions for cost-effective maintenance then take the largest volume within the objective, followed by unmanned non-invasive monitoring and inspections. Therefore, the most likely ranking order is the one set here.

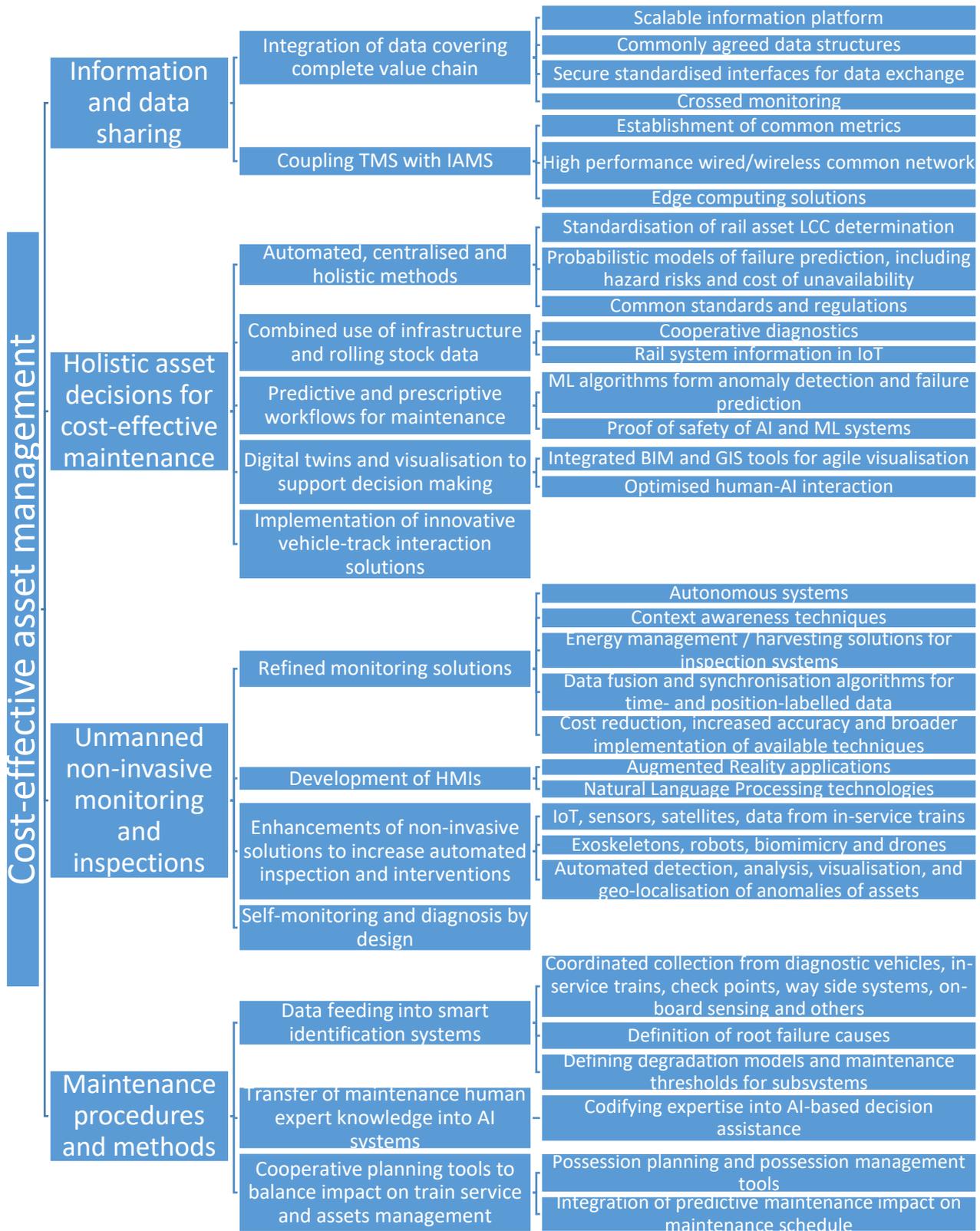


Figure 12: Extracted underlying structure to R&I objective 1 in FA3

5.2.4.2. R&I objective 2: Environment-friendly production of resilient assets

This objective aims to enable environment-friendly production of resilient assets, supported by new design principles, solutions and fabrication techniques. These shall consider the entire life cycle and create optimised products that in a sustainable way support the system in each stage of their life cycle. The central envisioned benefit of this R&I objective is to reduce the footprint and increase the resilience of newly produced assets.

The impact areas are otherwise in line with the ones of the previous objective: By introducing assets that are designed for simple and reduced maintenance, the asset down-time is minimised, keeping transport volumes and cost-efficiency high and therefore supporting the rail system’s capacity. By establishing technical leadership of the European rail industry within new design thinking, international competitiveness is strengthened. By reducing unexpected unavailability, flexibility and punctuality are ensured. By transitioning into a low-maintenance system with reduced demand of human intervention, durability and reliability are increased. All these factors ideally help minimising the lifecycle costs of the railway system. All of the points above also contribute to the competitiveness of the railways within Europe, therefore reinforcing the role for rail in European transport and mobility.

Table 9: Expected impact areas of R&I objective 2 in FA3

 Meeting evolving customer requirements	 Improved performance and capacity	 Reduced costs	 More sustainable and resilient transport	 Improved EU rail supply industry competitiveness
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For this objective, a slightly lower resulting TRL level of 5-8 is expected during the course of the EU-Rail JU and it has a strong interaction with FA4 and the TT. Even though no clear prioritisation order can be deduced from the given information, holistic design and certification of assets clearly takes a larger proportion than supporting technologies and innovative materials. Therefore, the most likely ranking order is the one set here.

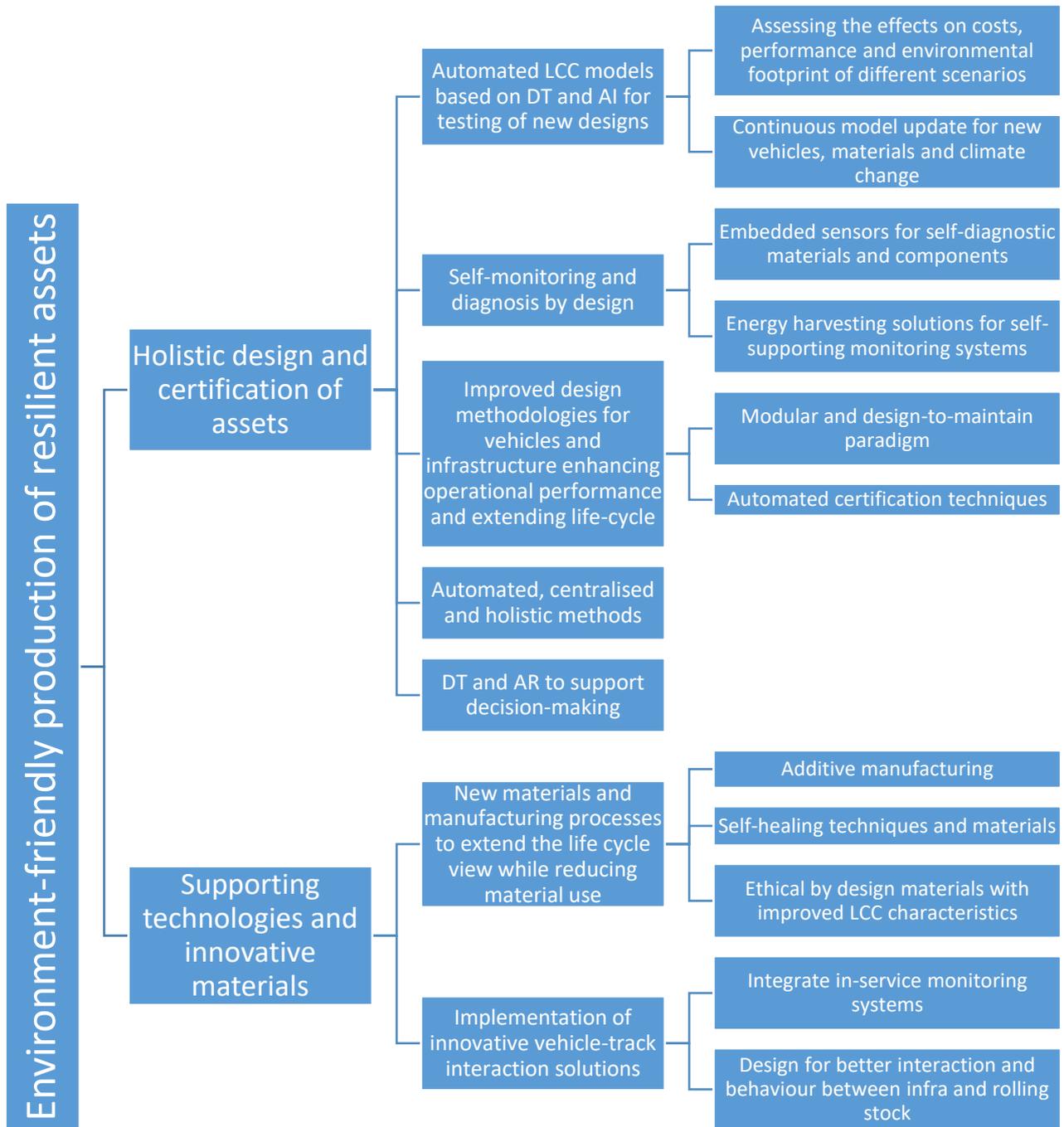


Figure 13: Extracted underlying structure to R&I objective 2 in FA3

5.2.4.3. R&I objective 3: Automated execution of construction and supported interventions

The last R&I objective in this FA shall enable advanced and high-tech automated execution of construction and interventions supported by robotics and wearables, changing the way of working and improving health conditions for workers involved. This will also increase quality and consistency of the results. The envisioned benefit of this objective is to improve safety and consistency of construction and intervention activities that were previously purely executed by manual work, including high effort, risks and need of experience.

The overall impact areas are also similar to those of the previous objective: By facilitating more time-efficient and maintenance and increasing the availability of maintenance resources, the asset down-time is minimised, keeping transport volumes and cost-efficiency high and therefore supporting the rail system’s capacity. By establishing technical leadership of the European rail industry within the development of innovative supporting technologies, international competitiveness is strengthened. By reducing unexpected unavailability by consistent maintenance quality, flexibility and punctuality are ensured. By transitioning into a low-maintenance system with reduced demand of human intervention, durability and reliability are increased. All these factors ideally help minimising the lifecycle costs of the railway system. All of the points above also contribute to the competitiveness of the railways within Europe, therefore reinforcing the role for rail in European transport and mobility.

Table 10: Expected impact areas of R&I objective 3 in FA3

 Meeting evolving customer requirements	 Improved performance and capacity	 Reduced costs	 More sustainable and resilient transport	 Improved EU rail supply industry competitiveness
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As for the previous objective, a slightly lower resulting TRL level of 5-8 is expected during the course of the EU-Rail JU and it has a strong interaction with FA4 and the TT. No clear prioritisation order can be deduced from the given information. Nevertheless, as the second concept supporting technologies and innovative materials also appears in the previous objective and has several examples already covered there, it is ranked behind the concept of remotely controlled and unmanned interactions, which introduces a set of genuine innovations to this FA’s scope.

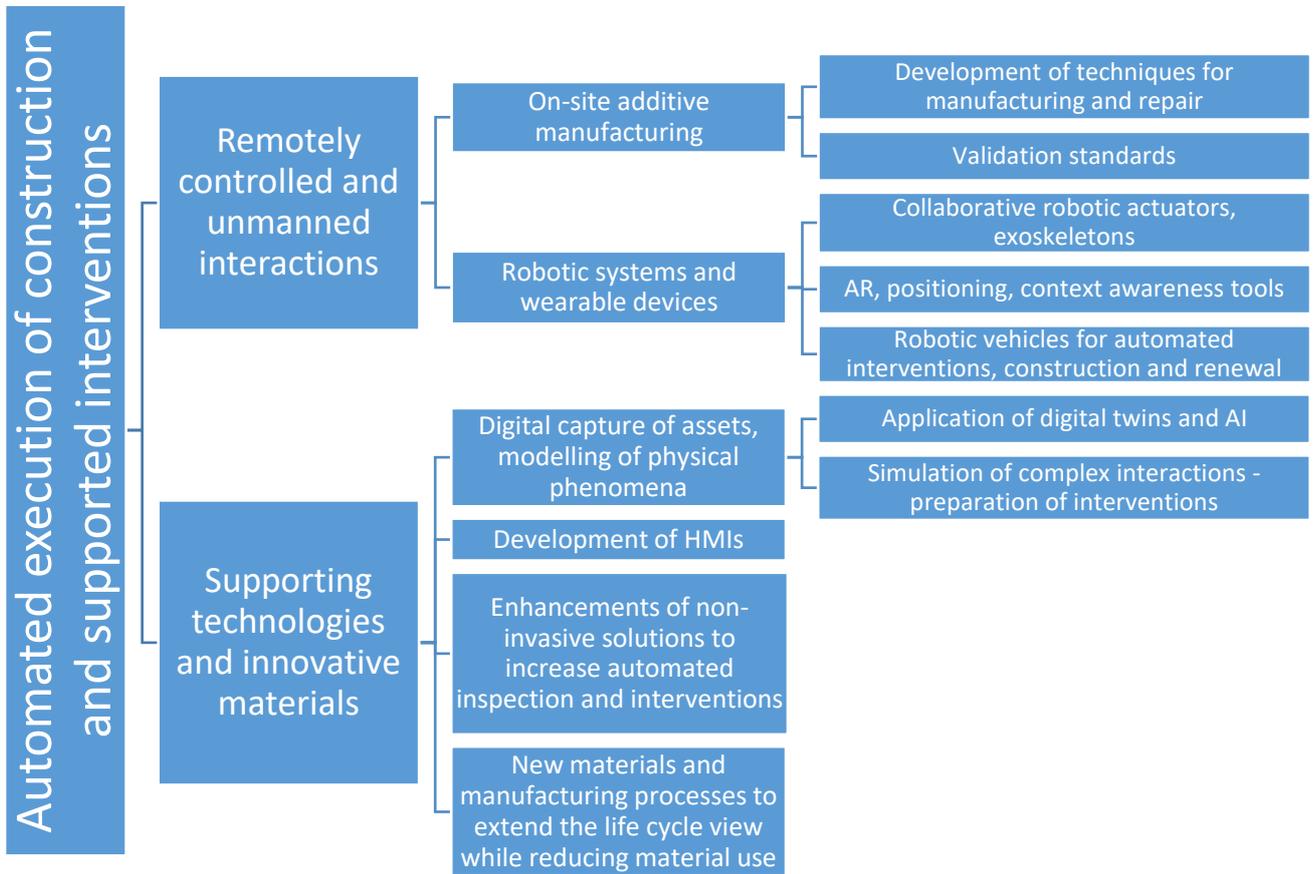


Figure 14: Extracted underlying structure to R&I objective 3 in FA3

5.2.5. FA4: A sustainable and green rail system

To make the EU rail service healthier, reduce its environmental footprint and make it more attractive several investments in the rail system need to be done. These investments, like decarbonation of the rail system are a part of the objective of a Climate Neutral Europe for 2050. The objectives in this flagship area have the goal of minimizing the overall energy consumption, make rail a more attractive and healthy transportation mode and reduce the cost of ownership while providing resilience against climate change. Within this area these objectives can be completed by upgrading the current system, while also stimulating creating new assets.

All objectives have several concepts and related innovations that can help to complete the objectives. Within the MAWP the number of concepts given for each objective is, however, different. From this the importance and priority for each objective can be derived. The first objective: minimise energy consumption has the highest priority within the flagship area, as it has concepts that stretch over different assets and components of the rail sector. As this objective is also closely linked to the goal to create a Climate Neutral Europe for 2050 it has the highest priority. The next objective 'Climate Change' is closely related to the first objective and shares concept with this objective. Therefore, this has the second highest priority. A healthier rail system shows both new concepts and concepts that are shared with the first objective. Lastly, the attractiveness, shows a low priority, as it only introduces one concept.

5.2.5.1. R&I objective 1: Minimise energy consumption

As mentioned, minimizing energy consumption is a high priority objective as it contributes to the Climate Neutral Europe for 2050 and contributes to different other objectives within the flagship area. Minimizing energy consumption is mostly supported by innovative solutions for assets like the rolling stock, infrastructure and the real estate. Therefore, three concepts are created: alternative energy solutions for rolling stock, a holistic approach to energy in rail infrastructure and systems improvement.

The innovations related to alternative energy have four related impact areas: Lower life-cycle cost, competitiveness, capacity and sustainability. The innovations within the flagship area reduce the emissions of the rail system and make the energy system more efficient. This contributes to the impact for sustainability and lower life-cycle cost. Although the rail system is already considered the greenest mode of transport, by defining industrial standards a more circular economy model can be created. Therefore, minimizing energy consumption makes the rail sector more competitive with other modes of transport. Lastly creating a more efficient energy management system and creating alternative energy solutions more capacity on the net can be achieved.

Table 11: Expected impact areas of R&I objective 1 in FA4

 <p>Improved performance and capacity</p>	 <p>Reduced costs</p>	 <p>More sustainable and resilient transport</p>	 <p>Improved EU rail supply industry competitiveness</p>
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Minimizing the energy consumption is closely related to flagship area FA6 for the alternative energy solutions. For optimizing the energy system FA4 is highly dependent on FA2 and FA5 for creating new technologies, mostly the new ATO technology solutions. For the concepts within the flagship area, the expected TRL results are the same for the alternative energy solutions for rolling stock, and the holistic approach to energy in rail infrastructure. Both will reach level 8; the systems improvement shows an expected level of 9. Which shows that the advancement of new and improved assets will have a slightly higher readiness level than the other two concepts.

Within the objective all concepts show an equally distributed number of innovations and technical examples. It therefore shows that all concepts have a similar priority and pitch in equally to achieving the result of the objective.

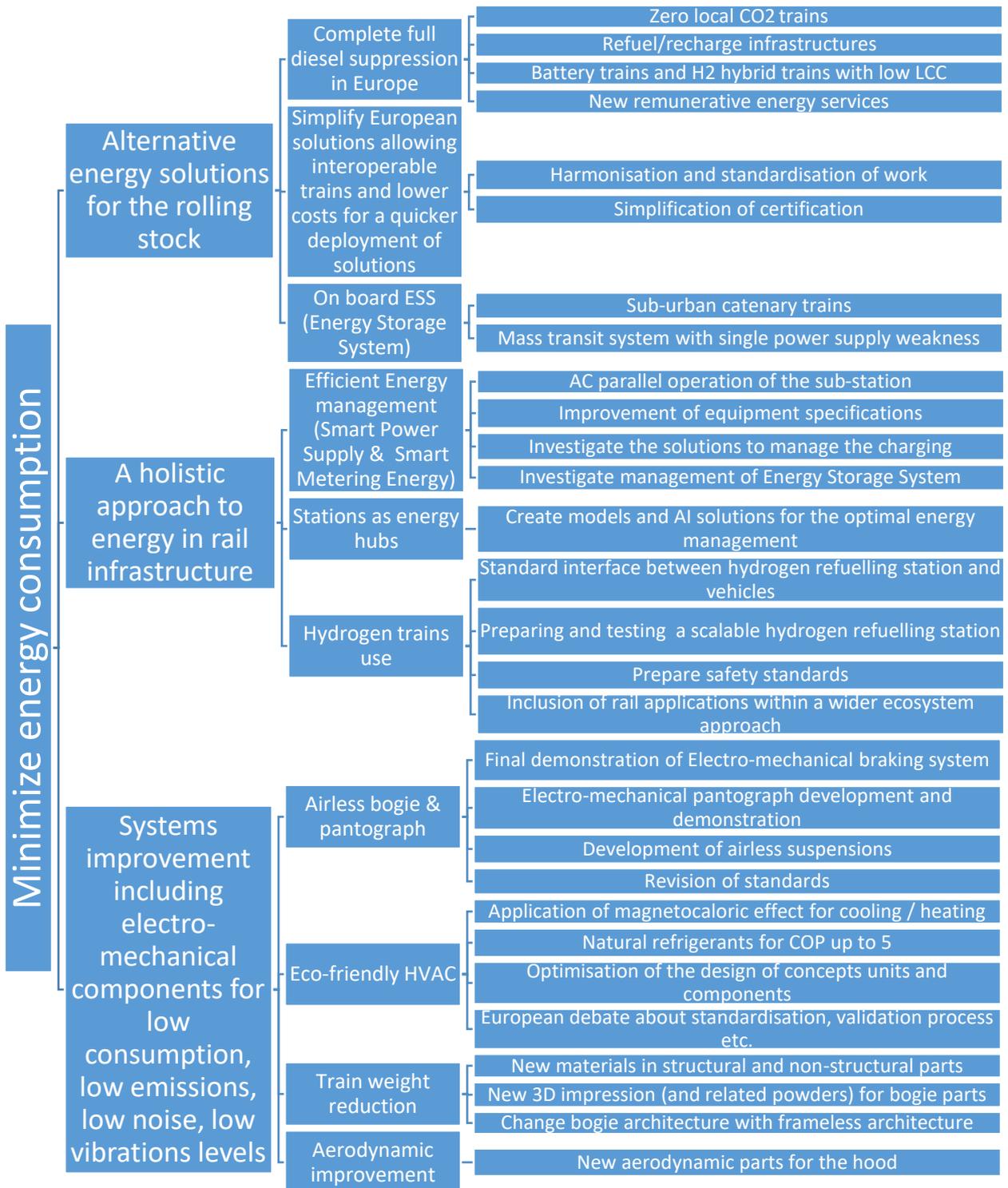


Figure 15: Extracted underlying structure to R&I objective 1 in FA4

5.2.5.2. R&I objective 2: Healthier rail system

A healthier and safer rail system is related to the passenger related subsystems. Within this flagship area this relates to the air quality on-board trains and reducing the non-exhaust emissions. In current times HVAC is important for the comfort and health of the passengers. A high influence in the air quality is thus air-filtration systems and eco and passenger-friendly HVAC. The activities within this objective will provide new adapted technologies easing the adaptation of the rail system to service to the customers.

Improvements in the current air quality system will result in a better position in competition with other modes of transport, mostly because it improves passenger comfort. The other innovation within the flagship, ‘Reduce non-exhaust emissions’, helps to improve the air quality but also helps understand effects on health and creates a map of rail emission factors that are not emitted by exhaustion. Having these emissions in view and developing solution for improvement will relate to the impact goal of sustainability.

Table 12: Expected impact areas of R&I objective 2 in FA4

 <p>Meeting evolving customer requirements</p>	 <p>More sustainable and resilient transport</p>	 <p>Reinforced role for rail in European transport & mobility</p>	 <p>Improved EU rail supply industry competitiveness</p>
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The concept and innovations in the objective are not related to other flagship areas, as the studied vehicles within the other flagship areas (mainly FA6) do not show much synergy with FA4. FA4 will share the relevant technologies if applicable. The concept shows an expected final TRL of 9, which demonstrates a desired high implementation of the proposed innovations.

The objective only considered one concept and since the priority of the objective within the flagship area is low, it can be concluded that this concept has a lower priority than the concepts within other objectives.

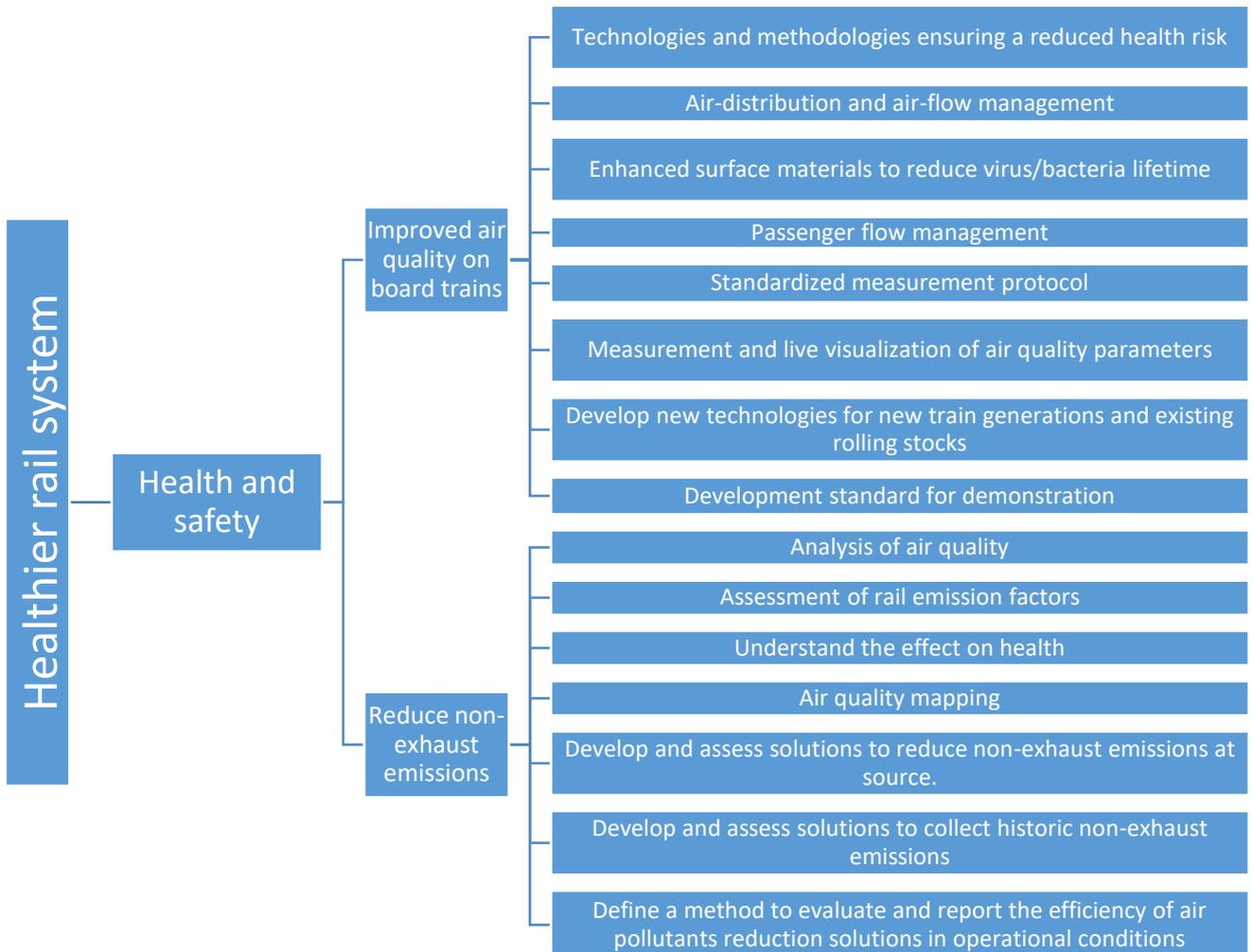


Figure 16: Extracted underlying structure to R&I objective 2 in FA4

5.2.5.3. R&I objective 3: Attractiveness

An important part of the rail system is its attractiveness. If the system is not attractive it will not be used by the customers. However, as mentioned in the flagship description, the attractiveness has a low priority within the flagship. The attractiveness is related to innovating the design and use, while increasing capacity and creating modular vehicles. It is also related to creating alternative energy solutions for the rolling stock as it increases comfort for the customers and thus makes the system more attractive.

As mentioned above, if the system becomes more attractive, it benefits the competitiveness of the rail sector. The improvements in the rolling stock will create more capacity and thus also relate to this impact area. The modularity of the vehicle creates a lower life-cycle cost, as it makes the

vehicle more adaptable, and it is easier to integrate a circular design. By creating a standard of the interiors, it will create a quicker and greener transformation and thus relate to both a lower life-cycle cost and the sustainability.

Table 13: Expected impact areas of R&I objective 3 in FA4

<p>Meeting evolving customer requirements</p>	<p>Improved performance and capacity</p>	<p>Reduced costs</p>	<p>More sustainable and resilient transport</p>	<p>Improved EU rail supply industry competitiveness</p>
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The concepts in this objective relate slightly to FA6, however, as also mentioned in the previous objective, the studied vehicles within FA6 are different than the vehicles in FA4. If applicable, concepts and results will be shared between the two flagship areas. The modernisation of vehicles has an expected TRL of 9. The starting TRL is 5, this shows that it is expected to show a significant investment and improvement within this concept. The alternative energy solution from objective 1 has a final expected TRL of 8. Thus, the modernisation of vehicles should be more advanced by the end of the project than the alternative energy solutions.

The objective only considered one new concept and since the priority of the objective within the flagship area is very low, it can be concluded this concept has a lower priority than the concepts within other objectives. The other concept has been included in objective 1 and thus shows a higher priority within all objectives. However, within objective 2, the concept of modernizing vehicles has a higher priority.

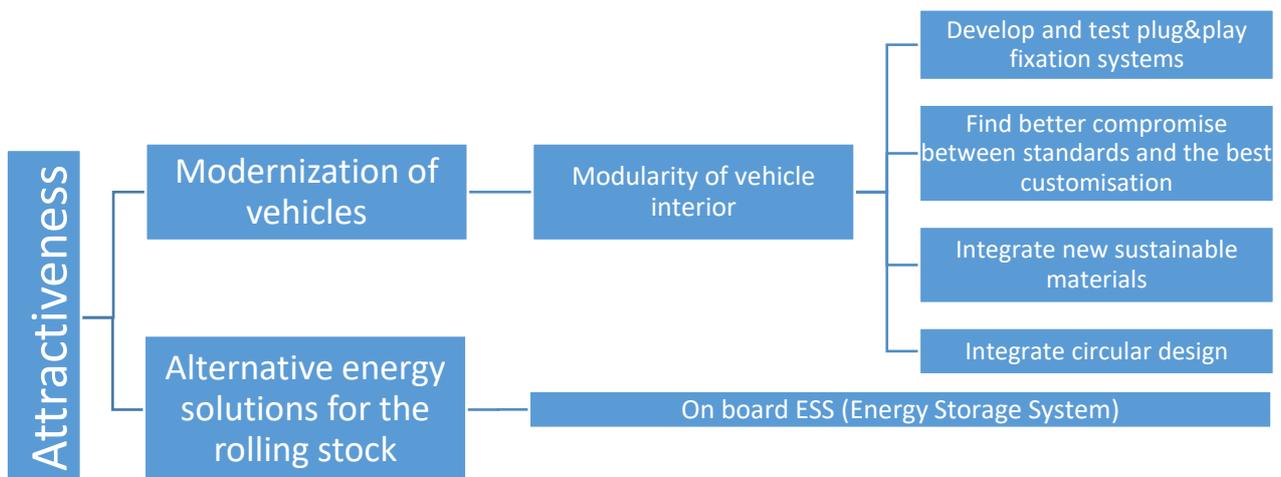


Figure 17: Extracted underlying structure to R&I objective 3 in FA4

5.2.5.4. R&I objective 4: Climate change

With the constantly changing environmental conditions the railway assets must adapt to climate change. Currently no work has been completed on this adaptation. The European Commission (EC) has implemented its new strategy on the adaptation to climate change and the rail system will contribute to this. For the rail system the specific aim of this implementation is to make the railway sector resilient at a reduced total cost of ownership. The objective consists of one new concept but is also related to other objective 1 and its concepts.

The concepts and innovation within the objective relate to four impact areas. The competitiveness of the system is improved, because creating a circular economy will reduce the cost and the concepts of alternative energy solutions and a holistic approach to energy in rail infrastructure will strengthen the position of the railway sector within European transport as well as increasing the EU rail industry competitiveness. If the adaptation to climate change can be completed successfully, combined with the concepts of objective 1, the capacity of the system can be increased. Lastly, the adaptation to climate change will make the system more sustainable.

Table 14: Expected impact areas of R&I objective 4 in FA4

 <p>Improved performance and capacity</p>	 <p>More sustainable and resilient transport</p>	 <p>Reinforced role for rail in European transport & mobility</p>	 <p>Improved EU rail supply industry competitiveness</p>
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Within the flagship area this objective 4 is closely related to objective 1. Together with FA3 the objectives will create a sustainable and green rail system, so with the adaptation to climate change the assets within FA3 should also be considered. Just as the previous objective the expected TRL is 9 and the implementation starts at level 5. Since very little investment has been completed yet the expected TRL shows a high interest in improving the adaptation to climate change.

In contradiction to the previous objective 3, objective 4 shows a higher priority. It is closely related to objective 1 and shows a significant number of suggested innovations and technical examples. Since two of the concepts are related to objective 1 these concepts will be under development within that objective. Therefore, for objective 4, the sustainability and resilience of the rail system in a holistic approach is the only and most important concept.

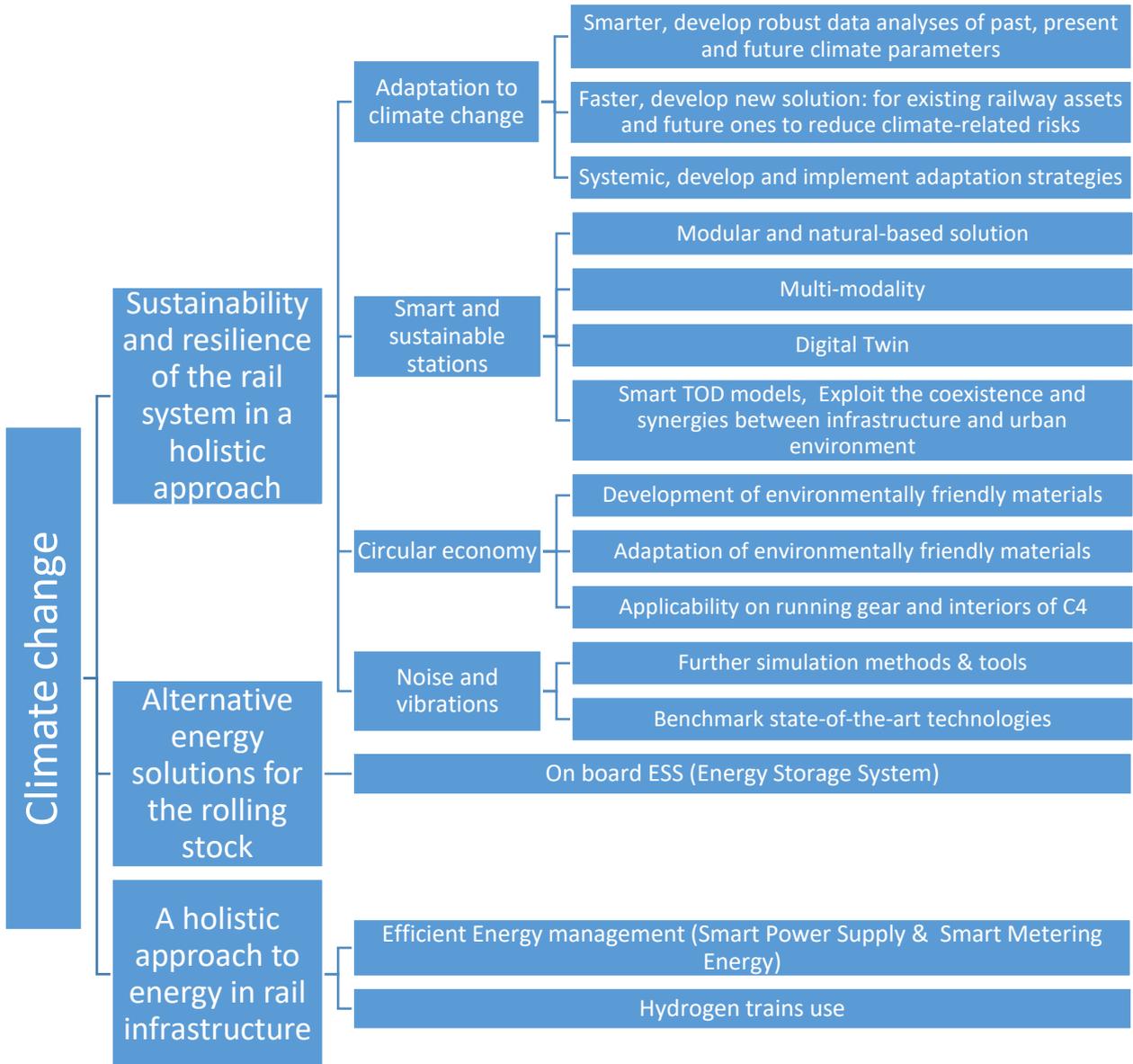


Figure 18: Extracted underlying structure to R&I objective 4 in FA4

5.2.6. FA5: Sustainable competitive digital green rail freight services

To increase attractiveness to customers and maintain reliable operation, rail freight transport needs to change many national regulations and remove technical barriers. In addition, the goal of rail freight transport should be higher capacity utilisation, greater cross-border coordination and better overall management of the rail network, cooperation between rail infrastructure managers, and the use of new technologies. To address these challenges, Flagship Area 5 establishes the goals of making rail freight more attractive with the digitisation of rail freight transport through fleet digitalisation and automation and enabling a seamless rail freight environment with improved cross-border operations and multimodal customer services.

Both objectives are fundamental to achieving the EU Green Deal, the goals of the European Union, and only together will ensure a significant improvement in rail freight transport. The objectives are crucial as they provide the necessary concepts, guidelines and technical solutions for pilot/demonstration projects that prepare appropriate market-ready solutions. Freight-focused innovations, especially in combination with developments in other flagship areas, and the corresponding investments in their implementation, will allow rail freight transport - especially on the European rail freight corridors - to increase by 50% by 2030 and to double by 2050, supporting the objectives of the European Commission's Sustainable and Smart Mobility Strategy.

5.2.6.1. R&I objective 1: Migration to digitised rail freight operations

The shift to digitised rail freight operations aims to boost rail freight performance in terms of transport time, quality, information, and volume to meet customer demands. The full digitisation and automation of operational functions and processes in yards, depots, and terminals using Digital Automatic Couplers (DAC) and associated automation components, additional subsystems, and components such as smart freight train systems, and the development of freight cars and upgrading of locomotives for the relevant DAC functions can help improve rail freight performance.

A fully digital freight train operation, enabled by key technologies to transform European rail freight, will increase productivity, efficiency through process automation, and service quality, all leading to increased competitiveness. With fully digital freight train operations, the time required for train formation/decomposition (targeted reduction of 40-50%) and train preparation/departure (targeted reduction of 40-70%) can be reduced, while the average train length can be increased to the maximum length within the existing infrastructure. Together with an increase in capacity, more freight traffic can be shifted to the European rail network, contributing significantly to the EU Green Deal, increasing worker safety, and creating added value for Europe. The development of innovative freight wagons, last mile solutions and terminals will make it possible to further improve the competitiveness of rail freight by reducing life cycle costs and operating costs and increasing the level of automation of operations.

Table 15: Expected impact areas of R&I objective 1 in FA5

 <p>Improved performance and capacity</p>	 <p>More sustainable and resilient transport</p>	 <p>Reinforced role for rail in European transport & mobility</p>	 <p>Improved EU rail supply industry competitiveness</p>
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To ensure technological consistency of the developed solutions, coordination and potential collaborations will also be setup with FA2 “ATO+” on digital & automated train operations of both passenger and freight rail transportation. In general, the relevant technical enablers such as new ATO technology solutions, automating functions, such as train preparation as well as remote driving and command will be developed in FA2. FA5 will provide all needed requirements to FA2, furthermore FA5 will work on special functions e.g., for the automatic and autonomous shunting operation / train protection system for shunting as well as reaction system (push/pull functions). To promote the use of digital technologies by means of digital twins and predictive maintenance within the railway sector, collaborations on data provision from FA5 for Condition-Based Maintenance (CBM) will be setup to ensure coherence with FA3 “Smart & integrated digital life cycle assets management”. For the efficient driving and energy management of the freight trains, technologies developed in FA1 in terms of Traffic Management System (TMS) for network management of energy, in coordination with FA2, FA4 and FA5 expertise/requirements, will be used by FA5. By nature, the FA TT will be linked to FA5 for potential coordination and collaboration on digital twin as well as data models and any kind of other transversal enabler.

Even though both concepts in this objective include many promising development directions, it is the first concept Fleet digitalisation and automation that with the Digital Automatic Coupler (DAC) and all related improvements in operational efficiency deserves particular attention within this objective.

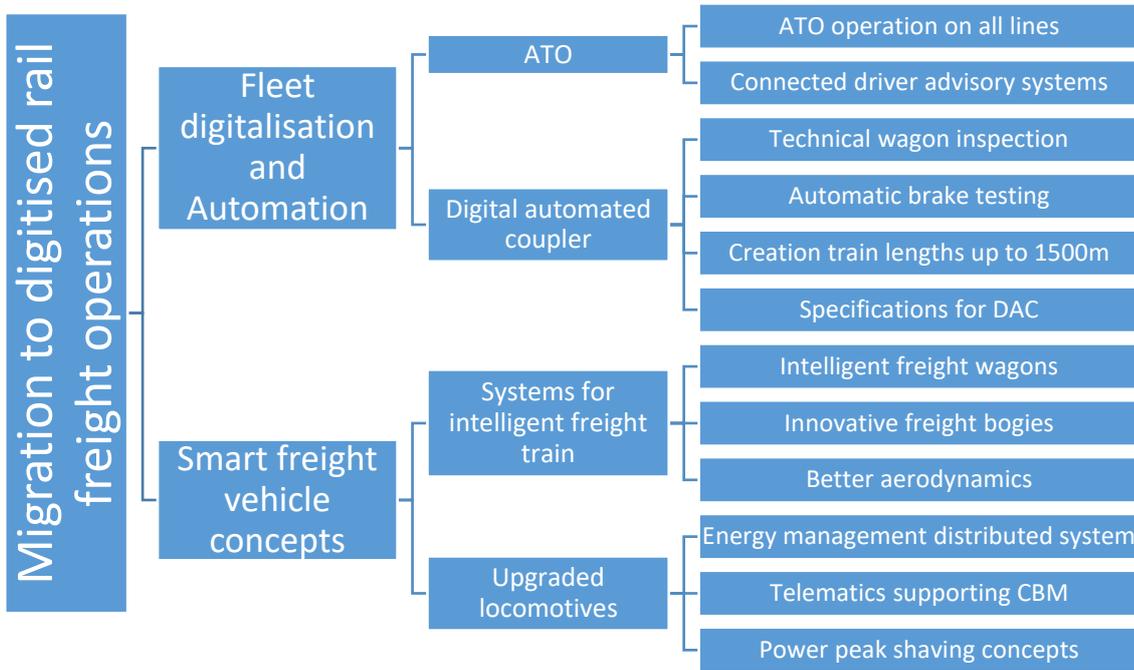


Figure 19: Extracted underlying structure to R&I objective 1 in FA5

5.2.6.2. R&I objective 2: Enabling a seamless rail freight environment

The goal of seamless rail freight is to continue to significantly increase productivity, reliability and flexibility by fully digitising planning and management functions, simplifying cross-border processes and better linking rail freight with other modes of transport. This includes easy access to service offerings, including multimodal journey planning, booking and transport companions. In addition, this goal aims at a consistent data flow from customer order to train preparation along all handover points such as yards, borders and recipients. The planning and management of fully automated marshalling operations enables fully automated marshalling yard operations and more efficient last-mile distribution and collection of waggons.

FA5 aims at seamless rail freight service with a significantly reduced average transport time based on an agile, interoperable and open environment within integrated and harmonised European mobility networks interacting with other companies; an environment in which companies can optimise their operations; for railway undertakings, this leads to higher productivity, better capacity utilisation, improved planning possibilities and, by reducing cross-border barriers and multimodality, faster transport handling, resulting in higher overall reliability. In addition, comprehensive multimodal and transparent customer information combined with simple booking and management functions lead to higher customer satisfaction and easier access to rail-based services. As the data is based on harmonised European data, this leads to higher predictability and better planning opportunities for infrastructure managers. These improvements will enable rail operators to develop new and better transport services for customers that are more efficient and flexible and can compete with road freight, and it will be much easier for customers to use rail and integrate it into their supply chains.

Table 16: Expected impact areas of R&I objective 2 in FA5

 <p>Meeting evolving customer requirements</p>	 <p>Improved performance and capacity</p>	 <p>More sustainable and resilient transport</p>	 <p>Reinforced role for rail in European transport & mobility</p>
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Enabling seamless rail freight aims to significantly further increase productivity (including average transport time and capacity utilisation), reliability and flexibility by fully digitising planning and management functions, as well as simplifying cross-border processes and better linking rail freight with other modes (both physical and digital, including marshalling yard, depot, terminal, transport network and customer-related planning, and shipping in conjunction with TMS). This includes easy access to service offerings, including multimodal journey planning, booking, and transportation assistance. In addition, this cluster aims at a consistent data flow from customer order to train preparation along all handover points such as yards, boundaries and recipients. The planning and management of fully automated marshalling operations (ASO) enables more efficient marshalling yard operations and last mile distribution and collection of waggons.

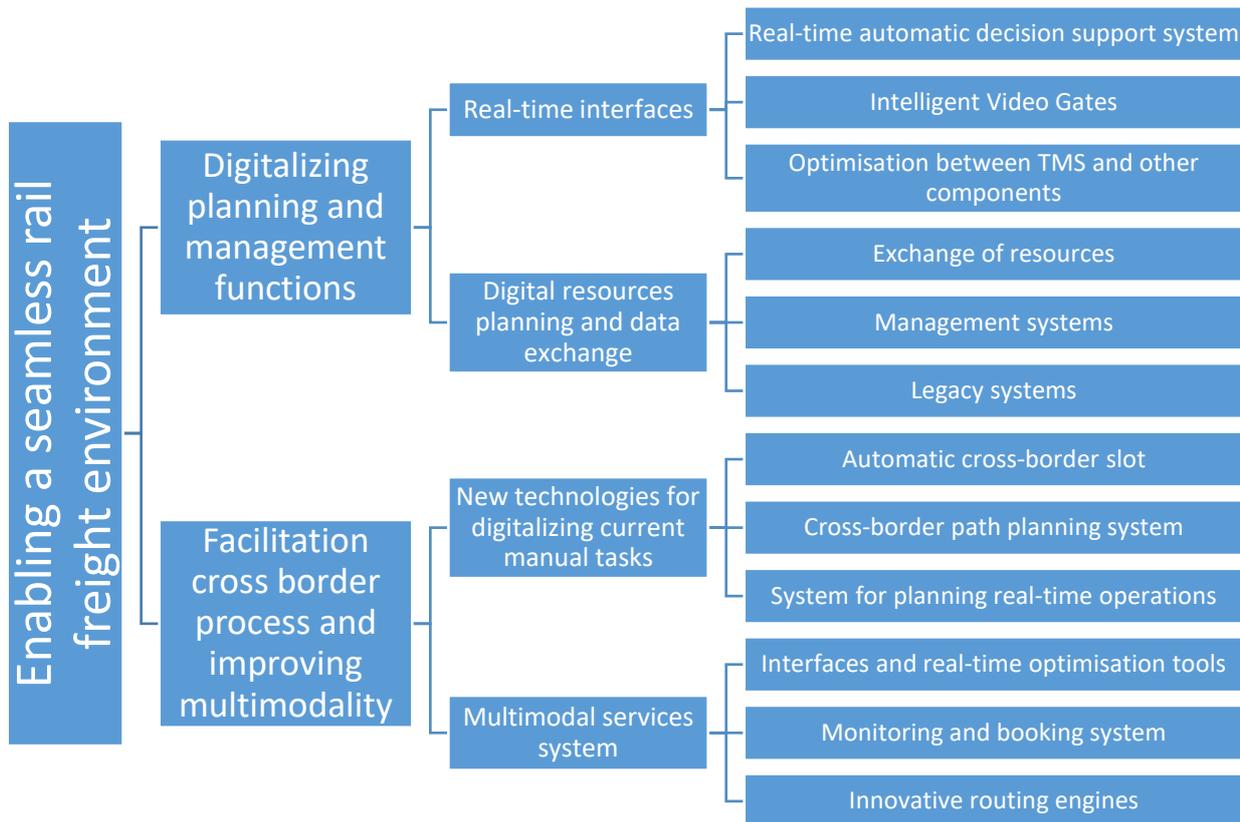


Figure 20: Extracted underlying structure to R&I objective 2 in FA5

5.2.7. FA6: Regional rail services / innovative rail services to revitalise capillary lines

In many European countries railway traffic on regional lines has suffered from losses during a long period. Several lines are even not operated anymore. As important part of the greening of transport, regional lines, however, are believed to play an important role in on one hand getting back more passenger and freight transport on the railway and as feeder traffic to mainlines. The main objective of FA6 is to develop cheaper solutions for all parts of the railway system, i.e., fixed assets, train control systems and vehicles to make regional rail transport economically more viable again.

There is no explicit prioritisation given between the different above-mentioned parts of the railway system. From the number of details given in the description of the flagship area, however, it can be concluded that most emphasis will be on the low-cost framework for regional and low-density lines. The second highest priority seem to be the customer service. In both areas, as many solutions as possible shall be taken from developments for mainline systems in other flagship areas and adapted for regional traffic solutions.

5.2.7.1. R&I objective 1: Low-cost framework for regional and low-density lines

The main objective mentioned in FA6 is “Innovative Rail Services to revitalise capillary lines”. As mentioned above, in many countries there was little focus on regional lines for many decades. In several cases, passenger services were moved to the road and only sporadic freight transport or no traffic at all remained. For a future sustainable transport system regional railway lines, however, play an important role to increase the share of environment friendly rail transport. The operation of regional lines, however, needs to become more economic and therefore in this flagship area more cost efficient solutions for all parts of the railway system shall be developed.

Table 17: Expected impact areas of R&I objective 1 in FA6

 Reduced costs	 More sustainable and resilient transport	 Improved EU rail supply industry competitiveness
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FA6 will interact strongly with many other FAs and with the SP. The general philosophy is that as many of the solutions that will be adopted for regional lines shall be derived from mainline solutions that are reduced in complexity and in functionality to reduce cost. Also, the train control solutions and the train operation shall be as similar to unified European mainline solutions as possible. Therefore, strong interactions with basically all other FAs are foreseen. The TRL are planned to be rather high, between TRL 5 and up to TRL9, so no basic research will be carried out. The more basic research activities will be in the other FAs giving input to the solutions derived in this FA.

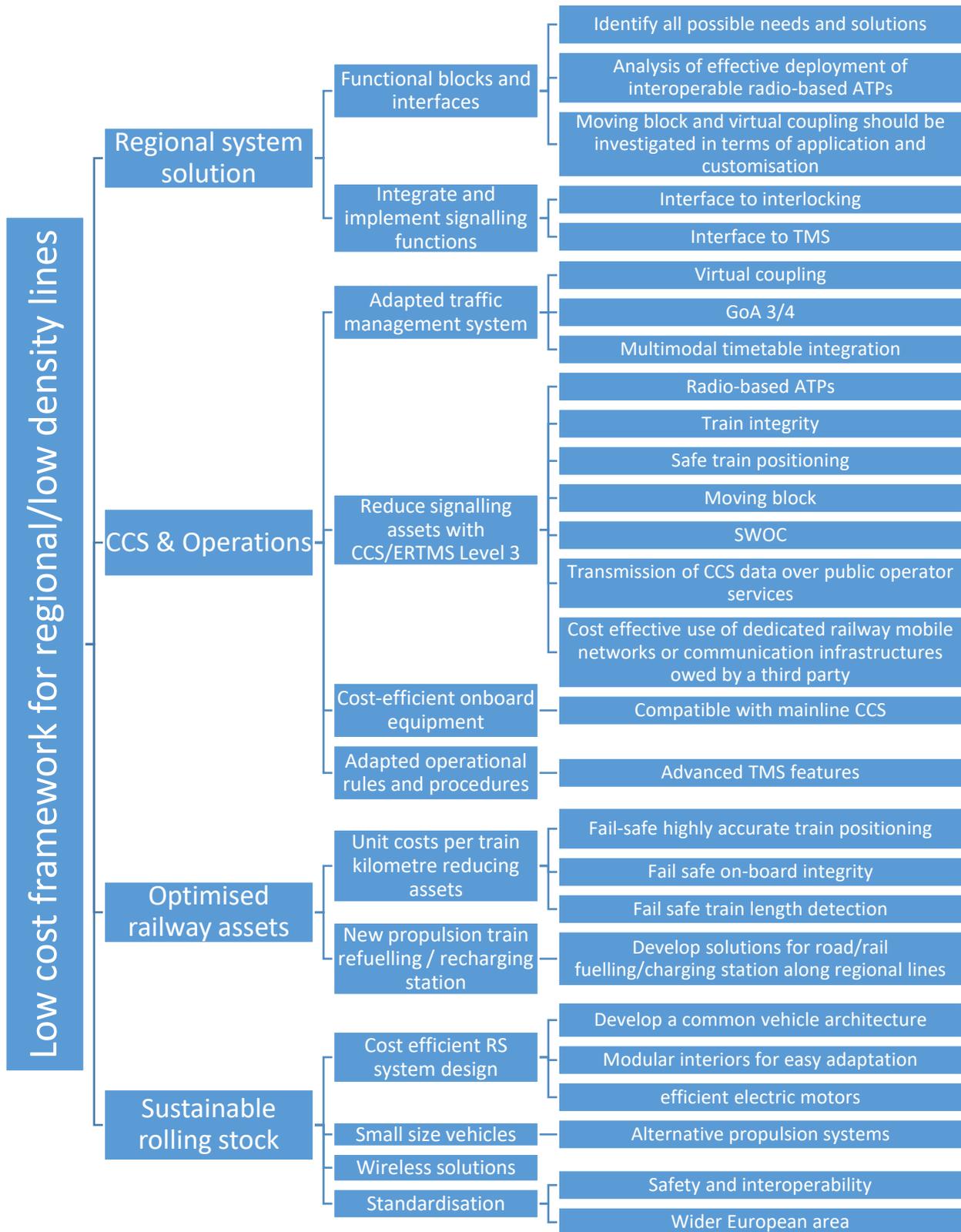


Figure 21: Extracted underlying structure to R&I objective 1 in FA6

5.2.7.2. R&I objective 2: Customer Service

Customer services are categorised as a second objective in this FA since the technical concepts here partly are different from the ones mentioned in the first objective. If the developed transport services are attractive enough for the end users, if the passenger information is adequate and if they are well connected to mainline traffic, the share of railway transport in Europe can increase not only in cities but also in rural areas which would reduce Greenhouse Gas (GHG) emissions. If these solutions are developed together with industry in EU-Rail, this would also provide the EU supply industry with increased competitiveness. Regarding customer services interaction with other FAs is desired as well, and the TRL are as high as in the first objective.

Table 18: Expected impact areas of R&I objective 2 in FA6

Meeting evolving customer requirements	Reduced costs	More sustainable and resilient transport	Reinforced role for rail in European transport & mobility	Improved EU rail supply industry competitiveness
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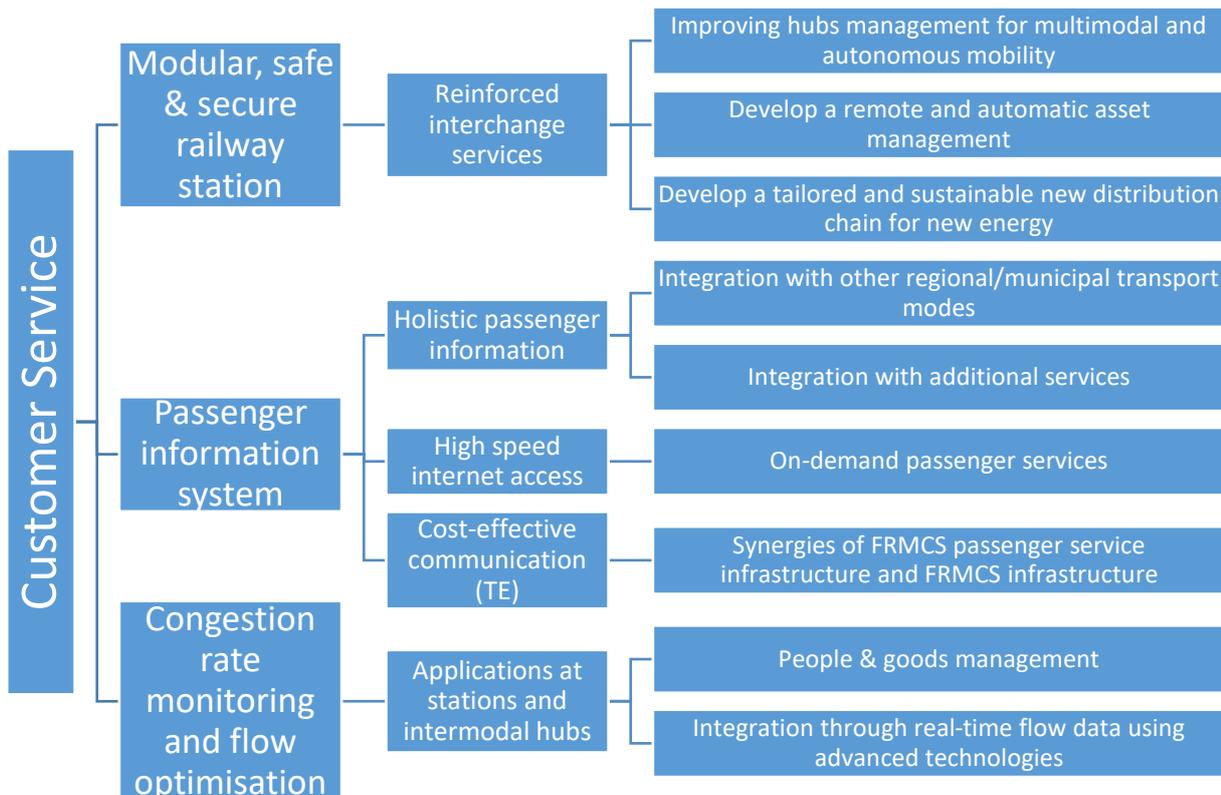


Figure 22: Extracted underlying structure to R&I objective 2 in FA6

5.2.8. FA7: Innovation on new approaches for guided transport modes

The final FA aims at opening the research work within the EU-Rail JU towards new and disruptive technologies that could broaden the range of offered transportation services and include technologies under the roof of railway research due to their nature of being infrastructure-guided systems. As an additional possible benefit for the entire railway sector there may be technological or operational innovation emerging in this area that show to be applicable to the traditional railway systems.

5.2.8.1. R&I objective: Exploration of non-traditional emerging technologies

This R&I objective aims to grant opportunities for innovators to develop new forms of socially-ecologically long-term sustainable transportation systems for a seamless integration with all modes. The envisioned benefits and impacts of this R&I objective are not clearly predictable due to its open approach. Those most likely to be expected are in the impact area of sustainability by introducing technologies with low emissions and enabling modal shift to public transport. In addition, more flexibility and punctuality for passengers or freight is expected from mobility on demand solutions, as well as improved performance and capacity in very-high-speed and automated systems. By providing higher availability and diversification of the offered services, they could contribute to a reinforced role for rail in European transport and mobility.

Table 19: Expected impact areas of R&I objective 1 in FA7

 Meeting evolving customer requirements	 Improved performance and capacity	 More sustainable and resilient transport	 Reinforced role for rail in European transport & mobility
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The expected resulting TRL for the concept examples given are overall low, as they often require a purpose-built infrastructure and therefore are limited to scale demonstrators and test facilities, resulting in TRL in the range of 2-7. An exception are command and control systems as well as technologies derived from maglev technology, which even are expected to reach TRL 8. This FA is expected to largely benefit from adapting the results in FA1 and FA2 but even interaction with FA6 in the second concept are possible. As this R&I objective does not include a complete list of envisioned concepts but rather a set of possible examples, there is no base for ranking them either. Clearly the approach of the first concept builds the backbone for any systematic development of emerging technologies though.

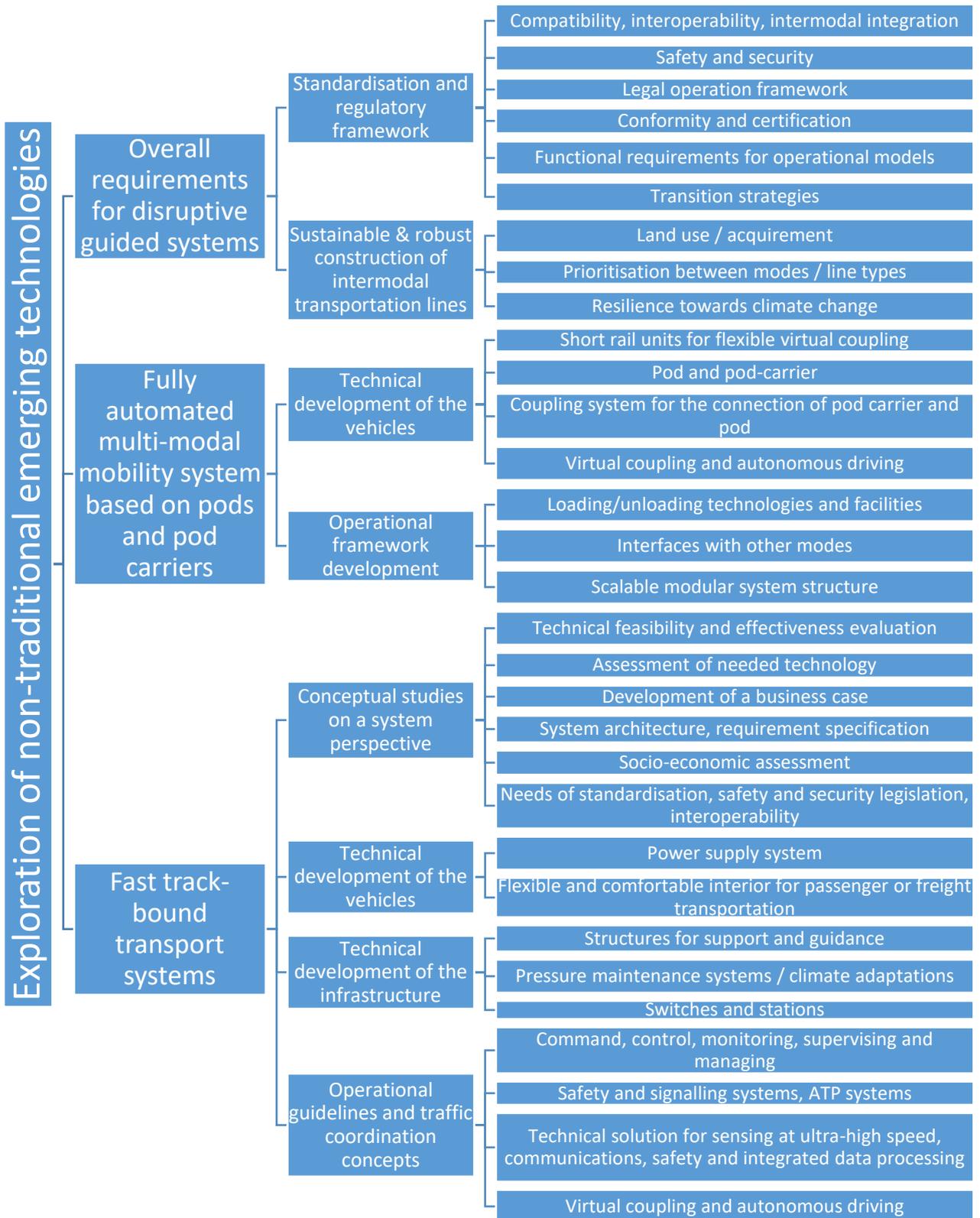


Figure 23: Extracted underlying structure to R&I objective 1 in FA7

5.2.9. Transversal Topic & exploratory research

For all flagships digitalisation is very important, because of this it has been included as transversal topics (TT). This will improve the system as all elements can work together and create a coherent and interoperable railway. For the TT the most significant digital enablers are the digital twins. The use of digital twins in the railway industry allows a more efficient way to predict and control the current and future performance of assets. Besides lowering the operational cost for the system, it also improves safety and availability.

The second objective is related to exploratory research. This will support radical system innovations and the evolution of the Innovation Programme in scope and targets.

Among these two objectives the exploratory research has more allocated funds, which indicates a higher priority than for the transversal topics. However, in the MAWP the transversal topics have been described more elaborately. Since the TT are related to and overlap with all flagship areas, the funds allocated for this topic can be lower as the development is also included in these flagship areas.

5.2.9.1. R&I objective: Digital enablers

The objective of digital enablers mostly consists of creating the digital environments. This creates an ecosystem in which data from all applications will be aggregated in a standardised way. Since the digital twins need to be fully compatible with Digital Twins (DT) of other railway applications three innovations must be considered. These are given in the flowchart below.

The digital enabler relates to three impact goals. The first goal is to reduce costs. As the digital twins can simulate scenarios and forecast alternatives for use and maintenance, this can significantly reduce the cost. The DT allow for a quicker and collaborative development cycle and thus creates a harmonised approach to evolution and greater adaptability. Lastly, the DT improves the EU rail supply industry competitiveness due to the fact that the need for real physical networks, data, and systems for the authorisation process will be significantly reduced. The DT will provide a more realistic framework for the virtual certification that will be used for the authorisation process.

Table 20: Expected impact areas of R&I objective TT: Digital Enablers

 <p>Reduced costs</p>	 <p>Harmonised approach to evolution and greater adaptability</p>	 <p>Improved EU rail supply industry competitiveness</p>
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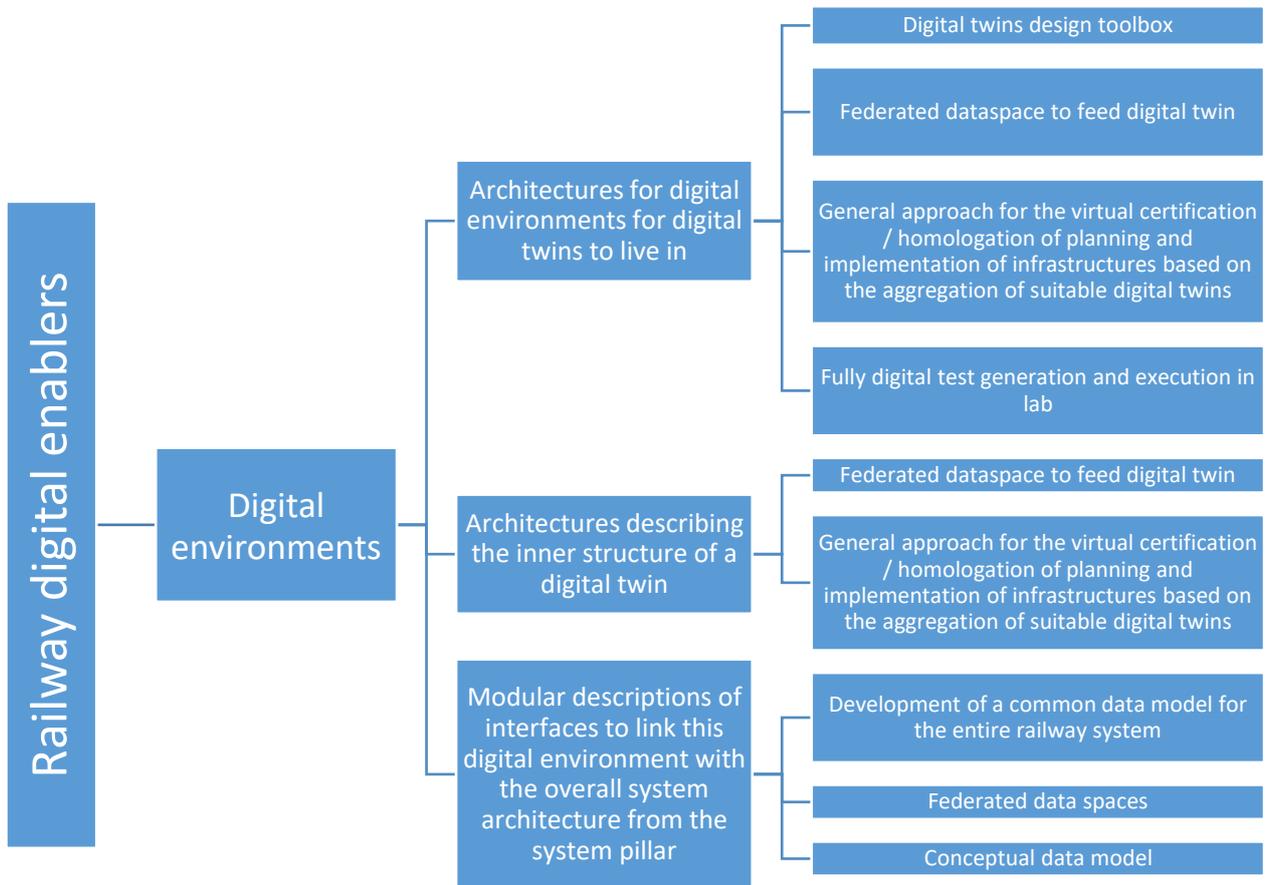


Figure 24: Extracted underlying structure to R&I objective TT: Digital Enablers

5.2.9.2. Exploratory research

The exploratory research can be related to all impact areas. It may be related to the extension of the scope of guided transport, higher speed rail service or any of the following topics stated in the MAWP:

- Study on upcoming enabling technologies and general/breakthrough innovations coming from other sectors as well, that can be applicable to the rail system and sub-systems.
- Disrupting the innovation cycle itself by applying game changing methodologies with the goal of significantly shortening time to market and significantly reducing costs of the innovation process itself and the resulting solutions.
- Socio-economic and market influencing factors analysis, including user-acceptance studies (reflecting changes in demand), taking various geographic settings into account (regional, intercity, urban, etc.).
- Research on emerging technologies or their critical subsystems, including maglev/magrail/aerodynamic propulsion and vacuum tube technologies, such as Hyperloop solutions.
- Research on business, innovation and transport models.

- Research on emerging safety, security and certification issues.
- Personalised rail infrastructure/vehicle concepts moving over different transport modes infrastructures.
- Multimodal, customer-centric and sustainable, shared-mobility solutions including full integration with other modes of transport, including in an urban environment.
- Studies of ultra-high speed (beyond 500 km/h) trains and synergies with non-conventional and/or emerging new modes of transport (e.g., Hyperloop).
- Impact of innovation on operations and human factors.
- Setting up networks bringing together different rail communities, such as in relation to regional hydrogen rail, rail research centre around specific concepts, etc.
- Programmes for PhDs on EU-Rail related activities.

The list of topics above remains on a very high level comparable to the R&I objectives that were extracted from the other parts of the MAWP and listed in the analysis above. Due to this vague formulation and the very broad range of topics covered by these rough research proposals, it is not reasonable to assign specific expected benefits to this section. Therefore, exploratory research will not be considered in the following analysis. This shall not imply that this study finds no value in exploratory research. On the contrary, many of the proposed topics relate to highly important objectives mentioned in the FAs and the disruptive research field is one of the most important opportunities for contributions from research facilities such as universities.

5.3. ERRAC documents

Since the publication of the “Rail 2050 Vision. Rail - The backbone of Europe’s mobility” in 2017, the ERRAC has been preparing the direction of upcoming research initiatives. This work was continued with “Rail 2030. Research & Innovation Priorities” in 2019 and peaked in preparation of the upcoming succession of the Shift2Rail JU in the “Rail Strategic Research and Innovation Agenda” (SRIA) in December 2020. The SRIA lists all areas where a research effort would be desirable for enabling the Railway System of the Future. The SRIA rests upon a policy background provided by the European Commission in form of policy programmes such as the European Green Deal and the Fit for 55 Package, the Digital Decade, the Sustainable and Smart Mobility Strategy, the Industrial Strategy, and the scientific research initiative Horizon Europe. Based on this background, the SRIA is directed towards the policy objectives of creating a Single European Railway Area, an attractive, user-friendly, competitive, affordable, easy to maintain, efficient and sustainable European rail system as well as a globally competitive European rail industry.

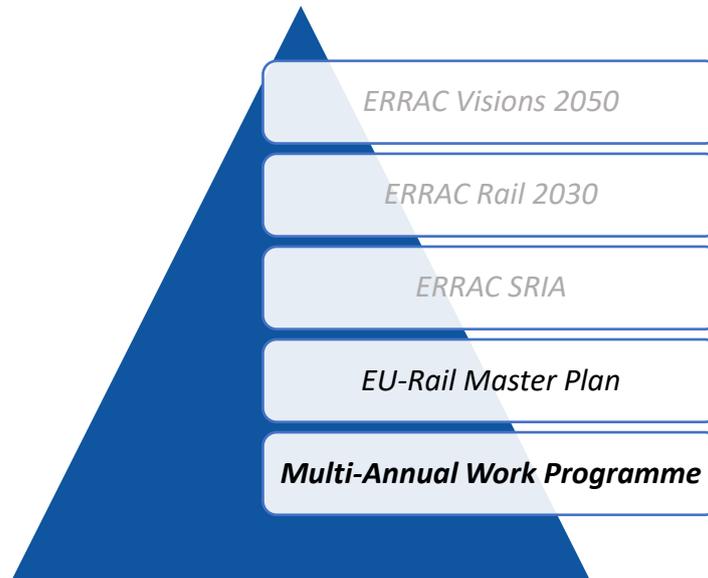


Figure 25: Hierarchical structure of ERRAC documents, going from strategic to specific and building the foundation for the MP and the MAWP.

As shown in Figure 25, the MP and MAWP are directly based on the strategic research directions envisioned in the first three documents, putting them into a more tangible technical context and defining specific research areas. As mentioned above, scope of the MP and MAWP comprises a subset of the research directions envisioned by the SRIA, being a product of considerable funding limitations faced in the establishment of the EU-Rail JU.

A comparison between the content of the MAWP and the SRIA was performed on the level of overall topics and R&I objectives, taking concepts into consideration where they gave clear indications about the level of agreement. The full list of innovations and technical examples was not compared, neither were the expected TRLs in the respective documents. When comparing the structural setup of the SRIA and the MAWP, it can first be noticed that both share the division into SP and IP. In the SP, there is a high level of alignment between the two documents. In the IP, there are however some differences. The originally nine overarching research categories, called Transforming Projects (TP) in the SRIA, have been reorganised into seven FAs for the MAWP. Of the nine original TPs six have been directly converted into equivalent or highly similar FAs. These are

- TP n°2: Rail as the Backbone of a Green Freight Logistic Chain (FA5)
- TP n°4: Network Management Planning and Control (FA1, also FA3+FA5)
- TP n°5: Environmentally Friendly and Attractive Sustainable Mobility (FA4)
- TP n°6: Assets for Automated, Autonomous and/or Remotely Piloted Operations (FA2)
- TP n°7: Smart Asset Management and Maintenance of the Future (FA3)
- TP n°8: Non-traditional and Emerging Transport Models and Systems (FA7)

Of the remaining three TPs, TP n°9: Railways Digital Twin, Simulation & Virtualisation is directly represented in the TT and strongly represented in FA3.

TP n°3: Connected and Open Rail Framework for European Mobility does not have a full representation in a dedicated FA, but its main topics are to some extent covered by FA1 and the SP. These main topics are:

- A European Rail System Architecture Framework covering the overall railway system
- Ability and agility for the introduction of the new technologies
- Connected IT services and information to other transport modes

The last TP to discuss, TP n°1: Smart Integration for Railways within Door-to-Door Mobility, is partially covered in FA1 and the newly defined FA6. Nevertheless, some of its research topics are not explicitly mentioned in the MAWP, including public transport coordination and customer experience applications. Also, multi-modal logistics/travel services provide end-users seamless access to all services associated with their multi-modal journey or logistics chain remains a small point among others in FA1 whereas it was a main objective in TP n°1.

Of the topics emphasised outside the framework of SP and IP, the socio-economic assessment, as well as crisis management & recovery planning strategies are tangentially mentioned, for example in FA6, but not given more central priority. Increased safety & security on networks and assets is lifted in the context of other development objectives, for example in FA2, FA3 and FA4, but not given a dedicated objective in the MAWP either.

As mentioned above, FA6 does not have a direct equivalent in the SRIA but was added as a new collection of research application to the dedicated purpose of regional lines. Another extension of research topics in the MAWP is the list describing possible topics to follow in the ER. Some of the topics mentioned above as not fully covered are mentioned among the topics for the ER, but this remains very open and does not ensure that they will be developed in practise.

5.4. TER4RAIL

The Shift2Rail project TER4RAIL (Transversal Exploratory Research Activities for Railway), which was conducted between the end of 2018 and the end of 2020, has its main focus on transversal exploratory research and knowledge transfer between actors in the different transport sectors. It was building on a Rail Innovative Research Observatory and promotes interactions between technology platforms.

Within the early work described in deliverable 1.1. “A comprehensive map of rail

innovative research and key rail stakeholders” and deliverable 1.2 “A report on the features of the next scenarios: Overview of the rail missions 2050”, topics to address and actors to focus on were identified and prioritised. These topics of high concern were 5G, automation, batteries, big data and energy for a short term, digitalisation and materials for a medium term, and artificial intelligence, automation, power sources and autonomous mobility for a long-term perspective. In addition to the deliverable which is most relevant to this work and summarised below, several additional activities and publications were delivered by TER4RAIL which are not mentioned here.

5.4.1. Key technical areas and gap analysis

The deliverable 2.2 “Review of the state of progress of roadmaps” contains a systematic analysis of the most relevant transport roadmaps. As a part of that, a database of keywords which appear in the roadmaps with high frequency is created. The central themes can be divided into nine categories which are:

- Technologic solutions
 - Digitalisation, robotics, information management systems, cognitive computing
- Economy
 - Balanced investment in infrastructure, cost efficient reliable vehicles and infrastructure, new business cases
- Sustainable consumption
 - Decarbonisation, alternative fuels, energy efficiency
- Holistic view
 - Delivering the vision, long term aspects for the network, new intelligent
- Scale of transport
 - Urban mobility, city dynamics, connectivity, long-distance transport
- EU level
 - Safety and security, EU as innovation leader, education
- Connectivity
 - Accessibility, interconnecting network, physical transport network, sharing economy solutions, cross-sectoral / disciplinary research
- Policies
 - Trends and policies impacting, user behaviour and needs
- Infrastructure
 - Electric and hydrogen charging stations infrastructure for all vehicles

As a final result, this deliverable describes the results of a gap analysis focusing on the shortcomings that are common in the roadmaps. The identified gaps are clustered into three areas, namely:

1. User perspective and on-demand mobility

For the user perspective it is stressed that there are shortcomings in the attempt to understand the needs and habits of the prospective users in a user-centred approach. This is closely linked to on-demand mobility services for boosting public transportation with support in booking, trip planning and connectivity.

2. Policymakers

Policymakers refer to the fact that roadmaps do not adequately stress the needs for political support in the development of connectivity, infrastructure and hard technologies.

3. Multi-modal approach

The final area, multi-modal approach, is actually present in the rail roadmaps, but much less so in those of the other sectors. This shows that there is a need for its establishment in other roadmaps to succeed with the implementation of common solutions.

5.5. Mobility4EU

Mobility4EU is a Shift2Rail research project that has formulated an action plan for the entire transport sector in Europe. It provides recommendations for research, innovation, and implementation from a user-centred and cross-modal perspective. The action plan consists of six main action areas:

- Low / zero emission mobility
- Automation and connected transport
- Safety and (Cyber-)security in transport
- Mobility planning
- Cross-modal / Cross-border transport and integration of novel mobility services in public transport
- Inclusion: putting the user in the centre

For the rail sector several research objectives can be identified within the document. However, the majority of the document is related to the overall transport system and other transport modes. For the low-zero emission mobility five objectives have been included:

- Enhance electrification rate in rail targeting more than 80%
- Enhance energy efficiency in rail transport
- Set-up a broad stakeholder group to plan for full electrification of rail infrastructure and support member states to derive national plans
- Implement electrification of rail infrastructure according to the plan agreed on national and EU level and promote standardised concepts
- Agree on European wide tax scheme for road and rail for freight.

Within the Automation and connected transport section a few more objectives have been identified:

- Enhance efficiency and capacity in rail projects for automated maintenance and transfer of goods between modes
- Increase projects and pilot regions for testing of infrastructure-supported rail tracks for autonomous trains.
- Evaluate pilot regions and provide a comprehensive cost analysis for certain user scenarios.

- Promote the deployment of automated transport systems by the definition of harmonised standards for rail vehicles and infrastructure.

The last two objectives are found in the Cross-modal / Cross-border transport and integration of novel mobility services in public transport action:

- Promote the development of train sharing concepts by R&D on autonomous rail vehicles for individual group routes
- Develop concept and management system for sharing of (public) transport infrastructure and fleets by different operators/providers and across borders with a focus on rail.

5.6. IMPACT-2

The Shift2Rail project IMPACT-2 was running in parallel with Ben@Rail. Due to the high alignment level of the respective research topics, relevant results that were available during this project's timeframe are summarised here. As the available documents refer to ongoing research work, some of the results need to be seen as preliminary and the content can be changed in the final result documentation.

For assessment of the socio-economic impact, an identification of activities with the highest impact on the goals specified within the S2R JU, as well as the assessment of impacts on customer attractiveness facilitated by railway research is of interest. The societal benefits, expressed in consumer and producer surpluses, are in the available documents summarised over all research activities of the S2R JU and instead compared with different case scenarios of development on the road transport sector. What can be summarised is that the impact positive impact on freight and high-speed passenger traffic is the largest, but in the latter mainly due to producer surpluses. This means that operator benefits exceed customer benefits. The impacts on urban rail and metro are more modest, there is however an opportunity to create societal benefits by improved accessibility. The development of Key Performance Indicators (KPI) is developed which can be related to the findings from other documents. The work is based on the general definition of a scenario approach, where a baseline scenario, representing the state of the art before a specific research activity, is compared to a new scenario including innovations from research. This comparison process is fed with a large volume of data in order to ensure quantitative comparability. It is important to note that this method relies on the availability of research results, or the quantification of specific research aims. The three central defined KPIs life-cycle costs, punctuality, and capacity can be directly related to the three first impact target areas in this document, which are reduced costs, meeting evolving customer requirements, and improved performance and capacity, respectively. The results of applying this model on System Platform demonstrators show that impact estimates increase with more specific research descriptions and that there is a large variation of how each Innovation Programme of the S2R JU impacts on the respective traffic type. Infrastructure affects all types, whereas signalling innovations mainly benefit passenger traffic, whereas freight traffic is more impacted by freight-specific innovations.

For further consideration of the research results of either IMPACT-2 or Ben@Rail, it is highly recommended to also study the final documentation of the other respective project's results to Ben@Rail – GA101046258

draw a more holistic conclusion about the topic of aligning railway research to achieve a high societal impact, systematically evaluating the impact of research activities and optimising attractiveness to the customers.

5.7. Objectives lined out by other sectors' documents

The following sections contain summaries of research objectives, concepts and technical areas that are emphasised in other documents, such as "A compelling vision for the target railway system" published by the European Union Agency for Railways (ERA) or research agendas from other transport modes. Adding further with the latest perspective to the results of the research projects above, they allow to draw first rough conclusions about consistency between the transport sectors. Main purpose is to be considered in the evaluation of the research concepts and recommendations towards the MAWP and other upcoming research initiatives. This could include a discussion whether some of the objectives stated here that exceed the MAWP scope could be identified as concepts that could fill possible gaps between the stakeholder requirements and the concepts stated in the MAWP.

5.7.1. ERA – A compelling vision for the target railway system

The European Union Agency for Railways (ERA), which is also considered as an important stakeholder in D1.1 "Simplified stakeholder tree and weighting matrix of requirements", has published a vision in 2020. There it is stated that in addition to transport's primary role of moving goods and people from origin to destination, it must also meet the goals of decarbonisation, economic growth, and social inclusion. However, the role of railway in achieving these goals and its role in the future transportation system should be considered. The future path and guidelines for the evolving target railway system were outlined in ERA document. Over the past centuries, railways have been a cutting-edge technology that has transformed people's lives and the economy. This vision pictures railways becoming the backbone of an automated and integrated multimodal transportation system. The envisioned railway system defines an optimal level of technical and safety harmonisation that builds on cutting-edge technologies and makes it possible to facilitate, improve, and expand railway services within the Union and with third countries. The envisaged railway system should be introduced gradually within a reasonable timeframe. Technological progress, societal needs, and new policy objectives may require subsequent reviews and updates.

To develop the targeted railway system, it is necessary to develop each element of the targeted railway system in a structured manner involving key stakeholders and considering constraints and opportunities. By analysing these elements, it is possible to determine what needs to be further developed and what needs to be harmonised. Where possible, the following principles should always apply: 'users first', sharing of information, sharing of facilities, tools (e.g., testing facilities, training tools), 'plug and play', cost effective solutions and 'products from the shelf'. Prerequisites include better access to data and the involvement of specialists from different fields. For railway to fulfil its role as the backbone of an integrated multimodal transport system, the focus should

be on the necessary changes and elements such as users and traffic patterns, financial arrangements, regulation, data management including telematics, harmonised operations, rolling stock and infrastructure, cross-border traffic with third countries, ticketing and information, traffic management including CCS, energy, infrastructure and rolling stock, and staff skills, competencies and qualifications.

5.7.2. ERTRAC – Strategic Research Agenda 2018

In 2018 ERTRAC has published a strategic research agenda for the 9th EU framework programme. It provides innovation challenges and research and development topics for the timeframe 2020-2030. Many of the prioritised research areas are very similar to those in the railway sector, like automation and digitalisation, environmental sustainability, and competitiveness of the European industry. Compared to strategic documents from ERRAC, visions for future urban mobility are described in more detail. The user perspective is more pronounced and the wider societal aspects of “the city of the future” with its conflicts between transport needs, land use, more liveable cities, etc. are discussed. Safety aspects play a more important role, since the statistical risk for accidents is higher in road than in railway traffic. Inter-modality is mentioned several times as one important contributor to a sustainable future transport system. This should be a chance for more cooperation between the road and railway sector in future transport solutions and should perhaps be pronounced more specifically in railway related research agendas. In general, the ERTRAC strategic agenda has somewhat more customer focus than railway related agendas that still are based primarily on the technological development needs and less by stakeholder and societal needs.

The document is structured into six different areas that are shortly summarised below:

5.7.2.1. Ensure mobility in Urban areas

The section focusses on understanding the changes in cities: interactions between land use, transport, technologies and users. It also mentions planning tools and assessment methods to support evidence-based decision-making. Interchange infrastructures and services for smart and seamless inter-modality are mentioned as new sustainable and smart ways of delivering goods to make better use of urban space. The section ends with requirements and concepts for new vehicles for urban use.

5.7.2.2. Environmental sustainability

Alternative fossil fuel free powertrains for road vehicles, e.g., hybrid or fully electrified vehicles are described. One section is reserved for material recycling. The concepts are comparable to those mentioned in the railway related research agendas.

5.7.2.3. Ensure an efficient and resilient road transport system

This section calls for an intelligent traffic management system that provides highly efficient road network services with minimised congestion. Also, a transport management system across all

modes of transport and door-to-door mobility is mentioned.

5.7.2.4. Connectivity and automation

The section deals with the deployment of automated passenger and heavy commercial vehicles in mixed traffic. The need of user acceptance is stressed, and new services enabled by connectivity and automation are mentioned. Also new models for sharing of transport assets is a topic.

5.7.2.5. Safety

Safety related issues are important in road traffic. Crash safety is mentioned, but mainly research needs to ensure safe operation of automated road vehicles in mixed traffic situations are described. Although automated driving is less demanding in rail traffic because of the guidance by the track, the topic is today more advanced in road transport.

5.7.2.6. Europe as world leaders in innovation, production and services

This section calls for enhanced competitiveness of the European road vehicle industry to maintain a world leading position. Terms as excellence in research and education, cross sectoral cooperation and sustainable manufacturing processes are mentioned. Also, the necessity of new skills and competences for the future is observed. Specifically, the development of advanced digital tools exploiting the 'digital-twin' concept with high-performance computing to enable rapid optimisation and customisation of next generation vehicles is mentioned here.

5.7.3. ACARE – Strategic Research & Innovation Agenda 2017

According to the Advisory Council for Aeronautics Research in Europe (ACARE) Strategic Research & Innovation Agenda (SRIA), which was updated in 2017, aviation is considered one of the leading high-technology sectors in Europe, producing innovations that benefit society far beyond its immediate field of application. Demand for air transportation in Europe is expected to grow steadily through 2050 and beyond. Satisfying this growth will require sustainable mobility, and it is vital that travel remains safe, fast, affordable and environment friendly. In 2011, a European group of individuals laid out a vision for European aviation with the publication of Flightpath 2050. In response, ACARE produced a SRIA in 2012 that defines the path to achieving these ambitious goals. The sector must develop solutions that support the Flightpath 2050 goals to meet the mobility needs of European citizens in a sustainable way, strengthen the economy, and ensure that the industry's edge in this high-tech sector is maintained. The ambitious goals of Flightpath 2050 were intended to meet two objectives: first, to meet society's needs for safer, more efficient and environmentally friendly air transport; and second, to maintain Europe's global leadership in the sector with a competitive supply chain and operators.

The roadmap to achieve the goals can be met by addressing key challenges, such as meeting
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societal and market needs, maintaining and expanding industrial leadership, protecting the environment and energy supply, ensuring safety and security, and prioritising research, testing capabilities, and education. Meeting societal and market needs relates to true, customer-centric mobility for passengers and freight. The three key areas of this challenge are the design of a customer-centric intermodal transportation system, travel process management, and integrated air transportation. As the global air transport market continues to grow, it is necessary to maintain its industrial competitiveness within Europe. Competition comes not only from established players, but also from emerging challengers that receive national support. Significant investments in innovation, research and technology are needed and must be supported by adequate, strong and positive policies. With the goal of addressing environmental and energy challenges and meeting the demand for new and improved products and services, high levels of automation, new materials, clean fuels, and information resources are emphasised. It is concluded that research and innovation in aviation is the key to tomorrow's mobility and prosperity, and to meeting environmental and energy challenges.

6. Conclusions

This deliverable gives the technical input which, together with the list of stakeholder requirements from D1.1 "Simplified stakeholder tree and weighting matrix of requirements", determine how well the set of *R&I objectives* and concepts envisioned for the Europe's Rail Joint Undertaking (ERJU) are in line with the stakeholder requirements.

The objectives and concepts have been compiled from documents published by the EU-Rail Joint Undertaking and ERRAC. Also, several documents from other modes of transport have been studied. The documents have been analysed with a top-down method. The Flagship Areas (FAs) from the MAWP have been separated into *R&I objectives*, *specific concepts*, *involved innovations* and *technical examples*. From this document 20 *R&I objectives* have been extracted. The objectives include 45 *specific concepts*. These *R&I objectives* have been allocated to the set of seven impact areas that are defined in the MP.

From the extracted list it can be concluded that *R&I objectives* and *specific concepts* are in most cases related to one single FA, but that either within the System Pillar (SP) or in overlapping ideas there can be correlations between the FAs. It can be seen that digitalisation has a particularly high priority and on top of the focus on infrastructure for the digital system, assets from several FAs are related to the digitalisation in some way. Besides digitalisation, concepts related to sustainability and a green transport mode also overlap between different flagship areas.

The ranking of structural units of the MAWP was assessed quantitatively based on the indicative distribution of financial resources. It should be interpreted with reservation, due to the fact that there in many cases are interactions between or direct benefits from one area to another. The ranking of the underlying *R&I objectives* was only possible based on a qualitative assessment. It is therefore of limited reliability and only valid within each structural unit. The prioritisation of *R&I objectives* is for example not comparable across different FAs. The ranked list of structural units and *R&I objectives* is given below:

1. FA2: Digital & automated up to autonomous train operations
 - a. Next generation of ATC
 - b. Automated Train Operations up to GoA4
2. FA3: Intelligent & integrated asset management
 - a. Cost-effective asset management
 - b. Environment-friendly production of resilient assets
 - c. Automated execution of construction and supported interventions
3. FA4: A sustainable and green rail system
 - a. Minimised energy consumption
 - b. Climate change action
 - c. Healthier rail system
 - d. Attractiveness
4. FA5: Sustainable competitive digital green rail freight services
 - a. Migration to digitised rail freight operations
 - b. Enabling a seamless rail freight environment
5. FA1: Network and mobility management
 - a. Customer-oriented dynamic planning approach
 - b. Maintaining the reliability of rail traffic
 - c. Increased flexibility for smarter and tailored door-to-door services
6. ER: Exploratory research
7. FA6: Regional rail services / innovative rail services to revitalise capillary lines
 - a. Low-cost framework for regional/low density lines
 - b. Customer Service
8. SP: System Pillar
 - a. CCS+
 - b. EU Rail system
9. TT: Transversal topic: Digital enablers
10. FA7: Innovation on new approaches for guided transport modes
 - a. Exploration of non-traditional emerging technologies

The resulting ranked list of intended benefits, which is based on the contribution of the *R&I objectives* to each of the seven impact target areas is as follows:

1. More sustainable and resilient transport
2. Improved performance and capacity
3. Meeting evolving customer requirements
4. Improved EU rail supply industry competitiveness
5. Reduced costs
6. Reinforced role for rail in European transport and mobility
7. Harmonised approach to evolution and greater adaptability

A possible shortcoming in the results was that the list of *specific concepts* could not fully be ranked as originally envisioned. Even if all the *specific concepts* within one *R&I objective* were ranked, it would have been difficult to draw conclusions about their prioritisation relative to *specific concepts* from other *R&I objectives*. This does not negatively affect the consecutive work in WP3 however, as the ranking is not required as an input to WP3. Instead, the very detailed rating of all extracted *specific concepts* against stakeholder requirements will be conducted in a neutral way regarding the *specific concepts*, in order to quantitatively assess the importance of each *specific concept* from the stakeholder perspective. Therefore, the ranking that was possible to present in this deliverable will support the assessment of the results of this rating by comparing priorities on both sides. The layers below *specific concepts* are of use as supplemental information for the rating process in WP3, regardless of if they are ranked or not.

The assembled coherent overview of *R&I objectives*, *specific concepts*, *involved innovations* and *technical examples* was used to compare with documents published by ERRAC and other transport sector's representatives. This comparison focused on consistency in prioritised research topics. The general research topics found to be prioritised in the MAWP correlate strongly with the findings from other documents, where digitalisation, automation, sustainability in manufacturing and operation, resilience, a holistic system approach and competitiveness of the European industry are mentioned as key focus areas. The list of *specific concepts* agrees especially well with the ERA's compelling vision for the target railway system.

One topic that is given as less important in the MAWP than in other sectors is safety and security, as there is no fully dedicated *specific concept* to either of those. Nevertheless, the MAWP mentions safety and (cyber) security in numerous occasions, especially often in FA2 for the autonomous systems but also in FA3 and FA4 with an emphasis on safety at work.

Another important topic is the user perspective with on-demand mobility, which is also emphasised in the gap analysis performed in TER4RAIL. It is stated several times in the MAWP that customer and user needs shall be considered and fulfilled by the overall quality of service, but user-centred development methods and services are not explicitly mentioned.

The ERRAC SRIA is an agreed document of the rail sector platform in which the paramount necessities and roadmaps for the future rail research are identified. A comparison between the SRIA and the MAWP of ERJU has been made. The areas related to rolling stock development, vehicle-network automation, network management, assets for infrastructure, freight and non-traditional systems research did make it almost 1:1 into the ERJU Flagship Areas, being allocated the first five largest budgets. The areas of digital twins and systems integration are covered by the subjects developed in the Transversal Topic and the System Pillar of ERJU, as well as the previously mentioned FAs. The remaining area of door-to-door mobility which includes public transport coordination and customer satisfaction (TP1 of ERRAC SRIA) has not a particular dedicated Flagship in ERJU, being partially integrated among the context of the other Flagships. The newly defined Flagship 6 "Regional rail services / Innovative rail services to revitalise capillary lines" of ERJU was not mainly listed as Transforming Project in ERRAC SRIA.

To summarise, the expected outcomes of R&I activities that promise achievements towards societal challenges, are as follows:

- a) Sustainability: As the most prioritised benefit, sustainability is broadly rooted in almost all proposed R&I activities. It is well aligned with the central role that is ascribed to sustainability across all studied documents.
- b) Digitalisation: It is broadly promoted as a crucial means to achieve the intended benefits instead of a benefit by itself and well represented all across the MAWP. There is a good agreement with other documents and sectors, even though it is more pronounced for the railway system with a larger remaining scope and therefore higher beneficial potential.
- c) Manufacturing: It is not as broadly represented as the above-mentioned aspects, but still given a big importance and covered by own *R&I objectives* in the highly prioritised FA3. Therefore, it is still well aligned with the importance it is accredited to across the sectors.
- d) Urban mobility: Due to the incorporation of the original TP1 from the SRIA into other FAs in the MAWP, large-scale achievements towards urban mobility are not guaranteed. This stands in contrast to suggestions by other documents and visions proposed in other sectors, where user-centred mobility solutions are expected to largely affect the transportation systems.

It is suggested to consider these results in the final stage of WP3 when assessing the alignment of the MAWP *R&I objectives* and *specific concepts* to stakeholder requirements making recommendations for the upcoming EU-Rail JU.

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Project IMPACT-2 (GA 777513), Deliverable D 4.6 "Iterative SPD integrated assessment"

Project IMPACT-2 (GA 777513), Deliverable D 2.3 "Societal benefits"

8. Appendices

8.1. Appendix A: Objectives and concepts list

1. Flagship 1: Network management planning and control & mobility management in a multimodal environment
 - 1.1. Customer-oriented dynamic planning approach
 - 1.1.1. Methods and algorithms for capacity planning and management
 - 1.1.2. Cross-border Planning
 - 1.2. Maintaining the reliability of rail traffic
 - 1.2.1. Capacity interaction - nodes and network
 - 1.2.2. Connected traffic management
 - 1.3. Increased flexibility for smarter and tailored door-to-door services
 - 1.3.1. Overall mobility approach
 - 1.3.2. Integrated rail traffic within door-to-door mobility, mobility orchestration
2. Flagship 2: Digital & Automated up to Autonomous Train Operations
 - 2.1. To develop next generation of ATC including ATO GoA4
 - 2.1.1. Train Control and Management System (TCMS) technologies
 - 2.1.2. New train communication network (TCN)
 - 2.2. To develop automated train operations up to GoA4
 - 2.2.1. New DATO technology solutions for interoperable automated driving
 - 2.2.2. Freight Automatic Train Operation
3. Flagship 3: Intelligent & integrated asset management
 - 3.1. Cost-effective asset management
 - 3.1.1. Information and data sharing
 - 3.1.2. Holistic asset decisions for cost-effective maintenance
 - 3.1.3. Unmanned non-invasive monitoring and inspections
 - 3.1.4. Maintenance procedures and methods
 - 3.2. Environment-friendly production of resilient assets
 - 3.2.1. Holistic design and certification of assets
 - 3.2.2. Supporting technologies and innovative materials
 - 3.3. Automated execution of construction and supported interventions
 - 3.3.1. Remotely controlled and unmanned interactions
 - 3.3.2. Supporting technologies and innovative materials
4. Flagship 4: A sustainable and green rail system
 - 4.1. Minimise energy consumption
 - 4.1.1. Alternative energy solutions for the rolling stock
 - 4.1.2. A holistic approach to energy in rail infrastructure
 - 4.1.3. Systems improvement including electro-mechanical components for low consumption, low emissions, low noise, low vibrations levels
 - 4.2. Healthier rail system
 - 4.2.1. Health and safety
 - 4.3. Attractiveness
 - 4.3.1. Modernisation of vehicles

- 4.4. Climate change
 - 4.4.1. 4.1. Sustainability and resilience of the rail system in a holistic approach to asset management, delivering more value
- 5. Flagship 5: Sustainable competitive digital green rail freight services
 - 5.1. Migration to digitised rail freight operations
 - 5.1.1. Fleet Digitalisation and Automation
 - 5.1.2. Smart Freight Wagon Concepts
 - 5.2. Enabling a seamless rail freight environment.
 - 5.2.1. Digitalizing planning and management functions
 - 5.2.2. Facilitation cross border process and improving multimodality
- 6. Flagship 6: Regional rail services / innovative rail services to revitalise capillary lines
 - 6.1. Low-cost framework for regional/low density lines
 - 6.1.1. Regional system solution
 - 6.1.2. CCS & Operations
 - 6.1.3. Optimised railways assets
 - 6.1.4. Sustainable Rolling Stock
 - 6.2. Customer Service
 - 6.2.1. Modular, safe & secure railway station
 - 6.2.2. Passenger information system
 - 6.2.3. Congestion rate monitoring and flow optimisation
- 7. Flagship 7: Innovation on new approaches for guided transport modes
 - 7.1. Exploration of non-traditional emerging technologies
 - 7.1.1. Overall requirements for disruptive guided systems
 - 7.1.2. Fully automated multi-modal mobility system based on Pods and Pod carriers
 - 7.1.3. Fast track-bound transport systems
- 8. System pillar
 - 8.1. EU Rail system
 - 8.1.1. Concept of system operations
 - 8.1.2. System architecture concepts
 - 8.1.3. System architecture migration plan
 - 8.2. CCS+
 - 8.2.1. CCS+ system operational principles
 - 8.2.2. CCS+ system architecture
- 9. Transversal Topic
 - 9.1. Railway digital enables
 - 9.1.1. Digital environments

