Deliverable D17.1
Requirements Specification for Automated Decisions and Decision Support for Traffic Management optimisation

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1. Executive Summary

This report is the deliverable of Task 17.1 "Requirements Specification for Automated Decisions and Decision Support for Traffic Management Optimization" of the Flagship Project 1 – "Network management planning and control & Mobility Management in a multimodal environment and digital enablers" of the EU-MAWP. The aim of this work package is to specify European standardized requirements for a system to provide automated decisions and decision support for traffic management optimization.

The main results contained in this document are specified functional, non-functional, and operational requirements that have been agreed upon between all partners involved in the work package. These requirements were developed with a view towards both technical enablers associated with Work Package 17: Technical Enabler 16 "Automation of very short-term train control decisions" as well as Technical Enabler 17 "Real-time conflict detection and resolution for main line and optimization". The implementation of these technical enablers represents a stepping-stone towards the development of an overall general level system. The requirements delivered here were developed with a focus on the demonstrators developed in Work Package 18. The whole product requirements have only been mentioned and defined where they are needed to understand the setting and scope of the demonstrators' requirements. The requirements specification for the final product will be developed within the next ERJU calls. The European standardization of the requirements delivered here supports the System Pillar in achieving the interoperability of the European railway networks by 2031. In the last chapter of this report, we provide benchmarking criterion for the development of a testbed for the standardized testing and comparison of methods developed in later stages of the work package.

The requirements delivered in this report are further classified into the following classes and sub-classes:

- **Functional requirements:** System Interaction with User Groups, System Scope, System Forecast and Conflict Detection, System Solutions, System Integration, and User Interaction.
- **Non-functional requirements:** System, Scalability, Performance, and Regulations and Security.
- **Operational requirements:** Compliance and Automation.

These requirements were obtained systematically through the collaboration of three groups of industrial and infrastructure partners: an Author Group, an Expert Group, and a Review Group. The delivered requirements are the result of an iterative querying of the Expert Group by the Author Group using specially designed requirements questionnaires. Subsequent phases of the deliverable were quality controlled by the Review Group – consisting of EU-wide and cross-industry representatives.

Overall, more than 80 requirements have been developed. A special focus has been put on the system scope, the integration into the existing IT-infrastructure and processes, conflict detection, and conflict resolution and mitigation. To reflect the differences in the technical enablers, requirements for Technical Enabler 16 and Technical Enabler 17 were developed separately.

The results of this document are the basis for the later stages of Work Package 17, in which methods for automated decisions and decision support for traffic management optimization are

developed on a demonstrator level. Furthermore, these results feed into the subsequent Work Package 18, in which systems with a higher maturity level incorporating Technical Enabler 16 and Technical Enabler 17 are to be developed. There is also a symbiotic interaction between Work Package 17 and Work Package 10: In Work Package 10 high-level requirements and specifications for both technical enablers were developed, which were taken as input here. In turn, the standardized requirements contained in this report will be taken as inputs into Task 10.2 of Work Package 10, in which specifications for high-level Use Cases and demonstrators of Work Packages 11-17 will be developed. The developments of Work Package 17 are also interacting for Work Package 2, which is responsible for technical coordination.

2. Abbreviations and acronyms

Abbreviation / Acronym	Description
AI	Artificial Intelligence
APS	Advanced Protection System
CCS	Control Command Signalling
CDM	Common Data Model
CELENEC	European Committee for Electrotechnical Standardization
ERJU	Europe's Rail Joint Undertaking
ERTMS	European Railway Traffic Management System
ETCS	European Train Control System
EU-MAWP	European Union Multi Annual Working Program (synonym of MWAP)
FA	Flagship Area
FP	Flagship Project
GoA	Grade of Automation
GPDR	General Data Protection Regulation
GUI	Graphical User Interface
IM	Infrastructure Manager
IT	Information Technology
KPI	Key Performance Indicator
MAWP	Multi-Annual Work Programme
ML	Machine Learning
MOTIONAL	Mobility Management Multimodal Environment and Digital Enablers
RBC	Radio Block Center
RU	Railway Undertaking
SCI-CMD	Service Control Interface - Command
SCI-OP	Service Control Interface - Operational Plan
SP	System Pillar
TAF/TAP	Telematic Applications for Freight Services/Telematic Applications for Passenger Services
TE	Technical Enabler
TMS	Traffic Management System
TRL	Technical Readiness Level
TSI	Technical Specifications for Interoperability
WP	Work Package
WS	Work Stream

3. Introduction

Within the framework of the Innovation Pillar FP 1: "Network management planning and control & Mobility Management in a multimodal environment and digital enablers" (MOTIONAL) of Europe's Rail Joint Undertaking (ERJU), Work Package (WP) 17 focuses on the integration of artificial intelligence (AI) and machine learning (ML) techniques in solutions to provide decision support and handling for traffic management optimization.

Within this context, WP 17 develops a set of **European standard requirements** for traffic management optimization for decision support and, whenever possible, automated decision making. Furthermore, benchmarking criteria as a basis for the comparability of different algorithms are provided. A testbed incorporating these criteria will allow for the benchmarking of algorithms developed both within and outside of WP 17. WP 17 covers the technical enablers (TE) from the Multi-Annual Work Program (MAWP) of the ERJU

- Technical Enabler 16 (TE 16): Automation of very short-term train control decisions [TRL5]
- Technical Enabler 17 (TE 17): Real-time conflict detection and resolution for main line and optimization [TRL4/5]

A detailed description and alignment of these technical enablers with the requirements can be found in Chapters 7 and 8 respectively. The following chapters contain the deliverable of Task 17.1, in which standardized requirements for a system providing automated decisions and decision support for traffic management optimization have been developed, covering both mentioned technical enablers. The development of the requirements was guided by a set of high-level requirements and specifications coming from WP 10 (Task 10.1). The results of WP 17 are relayed back into Task 10.2, in which specifications for high-level use cases and demonstrators of WP 11-WP 17 are developed. We note that WP 17 is contained within Work Stream (WS) 1.2: "Operation" of MOTIONAL. WP 17 also interacts with WP 2, which is in charge of technical coordination.

The requirements specified in this report provide a basis for both the implementation of demonstrators within WP 17 as well as European standard requirements. The requirements contained in this deliverable focus on the demonstrators, the whole product requirements only have been mentioned and defined where they are needed for an understanding of setting and scope. The requirements specification for the final product will be developed within the next ERJU calls. This list is subject to change as implementation experiences are gathered, the technologies involved continue to advance, and new legislation and regulations (concerning, e.g., the integration of AI technologies in critical infrastructure) are introduced.

The structure of this deliverable is as follows: Chapter 4 details the current state of practice; Chapter 5 summarizes the methodology that was applied to specify the requirements; Chapter 6 provides an overview of the categories into which the requirements are sorted, the requirements being specified in Chapters 7 and 8 for TE 16 and TE 17 respectively; Chapter 9 describes the benchmarking criteria for performance of algorithms; and Chapter 10 summarizes the results and provides some concluding remarks.

4. Current state of practice

With an increasing demand on the European rails resulting in higher frequencies and the need for higher capacities, it is expected that the number of conflict situations in operations will also increase. Currently, adverse downstream effects of conflict situations are limited by the manual quick intervention of dispatchers. Driven by digitalization and new data streams (e.g., the implementation of advanced ETCS levels), new potentials for automation are arising. The multitude of data that is or will be available, combined with state-of-the-art algorithms, offers the possibility to automatically identify conflicts in real-time, and to subsequently support dispatchers with proposed conflict resolutions.

At the time of release of this report, monitoring of the network and intervention in conflict situations is, for the most part, still carried out by dispatchers of the Infrastructure Management (IM) in coordination with the Railway Undertaking (RU). The IM monitors the information in one or several systems in parallel and intervenes in the event of train delays, infrastructure disruptions, or other unforeseeable deviations in the timetable. Due to the complexity of the network, the effects of conflict resolution actions are difficult to predict, and resolution decisions are usually made based on a combination of the personal experience of decision-makers and pre-defined operational rules. Of course, many resolution decisions that are made by the dispatchers have large impacts on other players in the rail operation –and may lead to the creation of new (derived) conflicts. To minimize this domino effect, resolution decisions are made in consultation with the other involved parties.

With the rapid development of fields such as AI and ML, there are already initial pilot projects in Europe aimed at exploiting the potential of the multitude of operations data that may be obtained from the network. In particular, techniques such as mathematical optimization, supervised learning, and reinforcement learning are in the beginning stages of being phased-in for the optimization of traffic flow – even in real-time. By mapping the current situation on the railway infrastructure in a digital twin, forecasts of deviations can be generated – if conflicts arise, resolutions to these can be suggested. While there is great intention to incorporate these new technologies to support daily operations (and also for support in timetable planning), developments in this direction are still in their infancy. In addition, various players in railroad operations are developing their own systems for optimizing their part of operations. For example, based on historical data, some RUs are developing systems that suggest real-time actions (such as early turns-arounds), and IMs are designing systems to optimize the operations on their railway networks (to, e.g., increase their network capacity). One trait that all of the approaches share is that high quality data and an appropriate simulation approach are required in order to monitor the current state of the network, and also to simulate future states over the next minutes and hours.

Similarly to the on-going pilot projects mentioned above, WP 17 focuses on decision support for traffic management optimization and is intended to facilitate and support the work of dispatchers. Whenever possible, WP 17 also focuses on the automation of decision making (with an emphasis on very short-term decisions). The timeframe which is referenced as “very short term” is at this point still variable, the intention being that the length of the time frame is so short that manual intervention in conflict situations may be difficult for operational staff. Throughout the course of WP 17, the goal is to apply state-of-the-art AI and ML techniques to gain insights into rail operations in real-time and generate solution proposals for any conflicts that may be detected. In

this sense and in contrast to the currently on-going pilot projects, innovation is generated by the following aspects:

- **Integration into the development of a European Railway Traffic Management System (ERTMS)**
  The implementation and subsequent deployment of a ERTMS is a central focus of the ERJU. The intention is to take a holistic view of rail operations – Europe-wide and cross-industry – and break down the silo thinking that may exist not only in a cross-border context, but also between different industrial players (e.g., between different RUs or the RUs and the IM). Within WP 17 special focus is placed on the generation of non-discriminatory proposals, and also on the issue of cross-border operations.
- **Alignment with other innovations in the railway sector**
  The alignment of the WP with other subprojects of the ERJU allows for the development of demonstrators that take into consideration other innovations in the railway sector. Examples of such subprojects are demand-based utilization optimization and the integration of multi-modal solutions.
- **Digitalization of train control decision process**
  While the dispatcher still needs to be responsible for accepting or rejecting the system's recommendations, the communication between RU and IM can be supported by digital systems and semi-automized – thereby reducing the number of consultations that the dispatcher must have with other stakeholders. Automation of communication can also eliminate errors that may occur due to miscommunication amongst the various parties. The exact specifications of the degree of automation that should incorporated remain to be determined within the process of future development – with baseline specifications being contained within the requirements listed in this report.

All developments that are delivered within the context of WP 17 will have a European-wide focus and, through their incorporation into the development of the ERTMS, will support the standardization of conflict detection, semi-automated decision making, and communication between the various parties involved in railway operations within the European rail network.

5. Methodology

In this chapter we give a detailed overview of how the requirements delivered in this report were developed. In particular, we present the overall workflow of Task 17.1 of WP-17 "Requirements Specification for Automated Decisions and Decision Support for Traffic Management Optimization" and expand upon how information was gathered and processed.

We recall that the purpose of this report is to provide standardized core requirements for a European-wide system with respect to TE 16 and TE 17, to be aligned with the System Pillar (SP).

5.1 Description of the approach to develop the requirements

To develop a Europe- and industry-wide catalogue of requirements, the requirements of IMs, RU, and suppliers were elaborated. Companies involved in this process were Administrador de Infraestructuras Ferroviarias, AZD Praha SRO, Deutsche Bahn AG, Deutsches Zentrum für Luft- und Raumfahrt EV (DLR), Enclavamientos y Señalización Ferroviaria (ENYSE), Hacon Ingenieurgesellschaft mbH, Hitachi Rail STS S.p.A., INDRA SISTEMAS S.A., MERMEC, ÖBB-Infrastruktur AG, ProRail B.V., Société Nationale SNCF, Thales, and The Norwegian Railway Directorate. Throughout the course of the project, the partners participating in the work package were divided into three groups with different roles:

- **Author Group:**
  The Author Group was responsible for the creation of questionnaires to query requirements from stakeholders –and the subsequent consolidation of the received answers into standardized requirements for a traffic management optimization algorithm for automated decisions and decision support.
- **Expert Group:**
  The Expert Group provided important input into the requirements specification by completing the requirements questionnaires, thus providing the basis for the creation of the standardized requirements. The members of the Expert Group were each asked to complete the requirements questionnaires for TE 16 and/or TE 17 separately. The members of the Author Group were a subset of those in Expert Group, which made it possible for entities that were part of the Author Group to, at hand of their expertise, simultaneously provide requirements as members of the Expert Group.
- **Review Group:**
  The Review Group examined the requirements developed by the Author Group and, if necessary, inserted new perspectives into the requirements specification. The members of the Review Group were disjoint from those in the Author Group and the Expert Group.

For the implementation of the requirements specification, the three groups worked together to iteratively refine and expand the requirements. The generation of the standardized requirements followed a classical requirement engineering framework. In order to obtain an unbiased view, the collection of specific requirements from the members of the Expert Group was performed through means of an initial "requirements questionnaire"– described in detail below – and a secondary follow-up questionnaire. The purpose of the secondary follow-up questionnaire was to align and review the consolidated requirements that had resulted from the initial querying. In particular, the

following steps were followed:

1. Development of a requirements questionnaire by the Author Group (see appendix 12.1).
2. Completion of the requirements questionnaire by the Expert Group.
3. Consolidation of requirements and first writing process – this led to the creation of the first version of the requirements specification by the Author Group.
4. Review of the first version of the requirements specification by the Review Group – suggestions were implemented by the Author Group.
5. Development of a secondary follow-up questionnaire by the Author Group. This questionnaire was designed to answer any outstanding issues that arose during the first writing process, or any questions posed by the Review Group (see appendix 12.2).
6. Completion of the secondary follow-up questionnaire by the Expert Group.
7. Consolidation of the second questionnaire and second writing process – this led to the creation of the updated version of the requirements specification by the Author Group.
8. Review of the updated version of the requirements specification by the Review Group – suggestions were implemented by the Author Group.
9. Compilation of the final version of the requirements specification by the Author Group.
10. Final version of the requirements specification is given to WP-external reviewers for approval and quality assurance.
11. Final version of the requirements specification is forwarded to the WP Leader for approval.
12. Final version of the requirements specification is handed over to the Project Coordinator for final approval and submission to EU.

In the following sections, we describe these steps in more detail, with special focus on step 1 as well as steps 2 - 7.

5.2 Development of the requirements questionnaire

The initial requirements questionnaire was specifically tailored to the requirements specification for a system handling automated decisions and decision support for traffic management optimization. It was split into three overarching sections: functional requirements, non-functional requirements, and operational requirements, with questions in each of these sections being further allocated to finer subgroupings.

The section of the questionnaire concerned with **functional requirements** comprised the majority of the questionnaire and was intended to determine what the desired functions of the system are. For this purpose, the questionnaire was designed for querying the requirements for the Technical Enablers TE 16 and TE 17. The questions in this section were split into the subgroups: Role Information and Stakeholders, Decision, Scope, Recommendations, Technical Requirements, and User Interaction.

In the first set of questions – Role Information and Stakeholders – the intention was to determine which roles are interacting in which way with the system. Since the vocabulary for the roles varies across countries, the roles' tasks and responsibilities were additionally queried for a consistent mapping/naming. This information was requested because within the operation of the system, different roles with accordingly different needs should be able to work with the tool. For example,

train dispatchers will interact with the system differently and have different needs than the IT personnel in charge of system maintenance. The description of interactions with the system was merged with the more detailed information which was later queried in the group of questions concerning User Interaction.

The second intention in the first section of questions was to identify relevant stakeholders. This was important information for the requirements specification because a future system will be integrated into existing IT-infrastructures and be expected to interface with various stakeholders (e.g., different RUs). This line of questioning then naturally segued into the next section of questions: Decisions. In this section, the demarcation of who would be accepting or rejecting solutions provided by the algorithm was addressed.

The third set of questions under functional requirements – Scope – comprised the majority of the functional requirements' section. For the requirements specification, it was essential to know the desired geographic coverage of the system, the types and number of conflicts to be detected by the system, and the types of railway traffic to be included. To ensure user acceptance of a developed system, it was necessary to determine how the calculated conflict resolutions should be displayed to the various roles. With respect to the calculated conflict resolutions, it was also essential to ascertain the calculation speed, foresight (spatially and temporally), and range (spatially and temporally) that should be conflict-free. The experts were also asked about the temporal intervals at which the system should perform conflict-detection and conflict-resolution runs. As these demands drastically shape the intended complexity of the system and also influence the system performance, the requirements developed in correspondence with this section of questions play an essential role in facilitating the selection of appropriate algorithms for implementation.

The fourth set of questions under functional requirements – Recommendations – focused on properties of conflict resolutions calculated by the system. When operated in semiautomatic mode, the system still relies on a human decision-maker who accepts or rejects suggested conflict resolutions. In this mode, it was supposed that it would facilitate user acceptance and also increase effectiveness if the human decision-maker has the choice of enacting one of multiple conflict resolutions. Towards determining a requirement in this direction, the Expert Group was asked if the system should calculate multiple solutions, and, if yes, how many? This naturally raised the issue of conflict resolution ranking: If and how should conflict resolutions be ranked? In particular, the goal was to provide a series of key performance indicators (KPIs) for this ranking.

The fifth set of questions under functional requirements – Technical Requirements – was intended to, as the name already indicates, aid in the specification of technical requirements pertaining to, e.g., system integration into the existing IT-infrastructures of the various members of the Expert Group. It was necessary to determine which other systems would be providing input to the system or receiving output from the system, also which APIs the system should be able to access. The issue of integration of external data sources (e.g., weather data) was also considered. To facilitate user acceptance and foster confidence in the reliability of proposed conflict-resolutions, the explainability of the system generated proposals was queried. This starts to address requirements aimed towards potential future certifications issues (this might be complicated for learning-based algorithms).

The second section of the questionnaire was concerned with **non-functional requirements**, the intention being to specify a set of requirements pertaining to system attributes. Accordingly, the

questions in this section were further divided into the subgroups: Regulations and Security, Operations, Scalability, Quality and System.

In the first set of questions under non-functional requirements – Regulations and Security – information regarding regulations that the system would have to comply with (e.g., user anonymization) was obtained. Also, the experts were asked if the system should undergo audits while operating – this question led into the direction of IT security, which would be relevant during future certification proceedings. In the set of questions grouped under Operations, the experts were asked which system downtimes would be acceptable and the effect that these could have. This question will determine if the system should be set-up in a redundant environment. Further information pertaining to the integration of the system into operations was queried in Scalability. The set of questions grouped under Quality, were intended to facilitate the specification of a set of KPIs that can be used for system benchmarking. Finally, in the section System the intention was to specify requirements concerning cross-border operation: One would expect that the requirements pertaining to intended cross-border operation would be quite different for a demonstrator of TE 16 and/ or TE 17 and for a general level system. Of course, requirements in this direction have the function of facilitating future interoperability of the European railway networks – as previously mentioned, here the Europe-wide standardization of these requirements is key.

The third section of the questionnaire was concerned with **operational requirements**, making sure that relevant rules and regulations pertaining to the operation of a tool for automated decision making and decision support are followed. In this section, the questions were split into only two subgroups: Operational Regulations and Other Operational Requirements. In these questions the experts were asked concerning EU, national, and internal regulations that the system has to comply with. It is worthwhile to note that in this context rules and regulations may come not only from railway guidelines, but also from national or EU policies regulating the use of AI (in particular, in critical infrastructure). Going further into the direction of automation, the intended degree of automation –along with definitions of exactly what these degrees entail for such a system— was also queried.

The format of the questionnaire was such that responses to questions were to be given in the form of desired requirements. In order to generate a set of standardized core requirements, the respondents had to classify each of their requirements as “Must have” or “Nice to have”. If “Nice to have” was chosen, the requirement could then be further prioritized as “High”, “Medium”, or “Low”.

5.3 Requirement consolidation and analysis

The initial requirements questionnaire was given to each company in the Expert Group, where it was enriched through means of organization-internal discussion and with a view towards the specific needs of that company with respect to the technical enabler they were assigned (TE 16 and/or TE 17). The completed questionnaires were then consolidated into one document – To maintain oversight of the submitted requirements, under each question the responses of all members of the expert group were inserted. Following the consolidation of the requirements into one document, the Author Group performed a thorough requirements analysis with respect to both TE 16 and TE 17. For this task, for each technical enabler, the Author Group was further partitioned into three subgroups: one group preparing functional requirements, another

formulating non-functional requirements, and yet another specifying the operational requirements. Requirements that had been marked “Must have” in the initial requirements questionnaire or had been indicated to have a high prioritization were included in the first draft of the requirements specification. If it was chosen to not include such a requirement, this was clarified with the Expert Group in the secondary follow-up questionnaire. Conversely, if a requirement with a low prioritization was chosen to be included in the requirements specification, then this was also clarified with the Expert Group.

Through means of the cooperation of the various companies involved in the work package – their internal and collaborative discussions – and the iteratively refining nature of the overarching workflow, the requirements generated here represent an objective overview of a European-wide standard.

5.4 Review phase and finalization

Once a second draft of the requirements specification was generated and finalized within the Author group, this document was then again reviewed by the Review Group. Final suggestions were implemented by the Author group. Based on this input the final version of the requirement specification was generated and forwarded to the external reviewers and the WP Leader for final approval of the document.

The requirements for a system for automated decisions and decision support for traffic optimization with respect to TE 16 and TE 17, that were obtained using this workflow, are contained in the following chapters.

6. Structure of the requirements specification

To gain a better overview of the requirements that are contained in this report, we provide a breakdown of the various categories of requirements. We remark once again that the requirements specified in this document represent Europe-wide standard requirements for a system intended for automatic decision making and decision support for traffic optimization, with a view towards the implementation of TE 16 and TE 17. The specified requirements for TE 16 and TE 17 are contained in Chapters 7 and 8 respectively.

In both Chapters 7 and 8 the delivered requirements are broadly categorized into functional, non-functional, and operational requirements. The functional requirements specify the intended features and functions of the system, the non-functional requirements define system attributes and give specifications as to how the system should perform, and the operational requirements ensure compliance with RU-/IM-internal, national, and EU-wide regulations. Regulations that must be complied with may come not only from railway operational rules, but also from legislation concerned with the integration of AI technologies.

The broad types functional, non-functional, and operational requirements are further divided into categories, each with a dedicated topic. An overview of these topics is visualized in the following table.

Category		Description
Functional	**System Interaction with User Groups**	Roles that should be able to interact with the system (e.g., train dispatcher) are identified. The notifications that these roles should receive and the responsibilities of the roles are defined. The issue of multiuser operation of the system is considered. Furthermore, stakeholders that the system should be able to interact with are defined.
	System Scope	The intended scope of the system is specified. This includes the geographical scope and the types of included railway traffic. Furthermore, the required kinds of detectable conflicts and the number of simultaneous manageable conflicts are specified.
	System Forecast and Conflict Detection	Requirements on the type of forecasting, the forecast duration, and the notice time of the system are specified.
	System Solutions	Operational actions that may be included in conflict resolutions suggested by the system are determined. Requirements on the conflict resolutions calculated by the system are specified. Possible KPIs for proposal rankings are determined.

	System Integration	Interfaces to other systems that need to provide input or that require output from the system are defined.
	User interaction	The system information that is shown to the user, how this information is visualized, and how the user can provide feedback are specified.
Non-functional	**System**	To allow an EU-wide interoperable system, requirements resulting from cross-border operations are specified. Furthermore, the maximum number of conflicts that should be possible for the system to detect is determined.
	Scalability	For possible future scaling of the system, requirements for the integration into existing tools are specified.
	Performance	This category focuses on aspects like system availability and redundancy of system elements. These requirements are intended to ensure a stable system operation. Furthermore, key aspects on quality like maintainability and calculation time of the system that the tool needs to satisfy are defined.
	Regulations and Security	System requirements derived from compliance with laws, regulations, and possible audits (e.g., in the area of cybersecurity or to verify non-discrimination in solution rankings) are specified.
Operational	**Compliance**	Requirements resulting from adherence to EU-wide, national, or RU-regulations are specified.
	Automation	The needed degree of automation and the integration into ETCS is specified.

7. Requirements for TE 16

Within technical enablers overarching abilities that need to be developed to achieve the aim of one or multiple WPs in the MAWP of the ERJU are defined. TE 16 is defined within the MAWP as "Automation of very short-term train control decisions". In the following chapter, the definition and alignment (with other destinations) of TE 16 are discussed and the corresponding requirements for a system implementing TE 16 are outlined.

7.1 Definition of TE 16: Automation of very short-term train control decisions

When conflict situations arise in operations, resolutions must be implemented as quickly as possible to avoid a major impact on the network downstream. In some cases, the time window in which conflict resolutions must be enforced in order to avoid network disturbance is so short that it is difficult for dispatchers to respond fast enough. The automation of very short-term train control decisions can help with the specified solution. In real-time, an automated process can detect deviations in the schedule, calculate the impact of conflict mitigations, and replace non-vital functionality of train control with automated processes. This can lead to an increase in the quality of resolutions, reduce the susceptibility to human-error in a fully mature system, and increase the handling capacity of dispatchers.

To implement such an automated workflow, algorithms must be in place to perform an impact analysis of mitigating actions and also to validate these actions before an automated execution. The impact analysis detects whether a deviation in the schedule leads to an actual or extrapolated (in time) conflict in operations. Within the framework of mitigating actions, AI algorithms can be used to avoid deadlocks in rail operations, potential emergency stops with high impact, knock-on effects which can lead to delays, or reversing future actions.

We remark that the requirements for TE 16 that are delivered in this chapter are communicated in a technology-open way. The selection of appropriate algorithms for the implementation of TE 16 is within the scope of the second part of WP 17, i.e., Task 17.2. The technological readiness level (TRL) of the demonstrators of TE 16 to be delivered within the scope of later parts of WP 17 will be 4 –meaning that the technology has been validated in a laboratory setting. In WP 18, demonstrators with TRL 5 will be developed –meaning that the technology has been validated by simulation in a relevant environment.

7.2 Alignment of TE 16 with the System Pillar and the Innovation Pillar

To take advantage of synergies and dependencies between different WPs, TE 16 should be aligned to the requirements and specifications of the other WPs and the System Pillar. The System Pillar develops generally applicable requirements for the ERJU systems. In doing so, the System Pillar has all of the sub-projects and the entire railway system in mind. The goal of the System Pillar is to secure the vision of an efficient integrated railway system by 2031, and to guide the Innovation Pillar towards the achievement of this goal. WP 17 is part of WS 1.2 FA 1: "Network management planning and control & Mobility Management in a multimodal environment and digital enablers" (MOTIONAL) of the ERJU. The main focus of this WS is to develop and demonstrate solutions for a TMS that integrates and supports the processes of operational traffic management and timetable planning. In addition to being strictly aligned with the requirements of the System Pillar, the

requirements for TE 16 that are obtained in the following chapter should also be relayed back to the System Pillar – in this way, the System Pillar can respond to developments that are obtained within the WPs. Within the broader scope of WS 1.2, WP 17 interacts with other WPs – in particular, with WP 10 in which high-level requirements for TEs 8-17 are specified.

The goal of the following chapter is to align and deliver all requirements for TE 16 and form the basis for implementations of demonstrators for the technical enabler "Automation of very short-term train control decisions".

7.3 Functional Requirements for TE 16

The requirements are grouped into the following subsections: System Interaction with User Groups, System Scope, System Forecast and Conflict Detection, System Solutions, System Integration, and User Interaction.

7.3.1 System Interaction with User Groups

Requirement ID	**TE16_FRQ_001**
Requirement	Automated decisions system allows the specified roles for defined User Groups.
Category	System Interaction with User Groups
Priority	Must
Main goal	Ensure that the developed solution provides the roles necessary for daily operation to the relevant User Groups.
Assumptions	The roles apply to IM and RU, since both will interact with the system in a future solution.
Specifications	The system should interact directly or indirectly with the following roles: ▪ Train driver: Operates the train and is in charge of the train handling. ▪ Signaler: Responsible for controlling the trackside signals ▪ Train dispatcher: Their operational scope is wider than a network section. They can solve conflicts and incidents located between two or more operational control points. They are, e.g., able to take decisions concerning track or order changes that affect two or more network sections. ▪ Regional dispatcher: Operates locally, normally in a network section. The regional dispatcher may take decisions that only affect their region, e.g., track or order changes which only affect their region. The regional dispatchers make decisions concerning the operational points in their region (e.g., decisions at stations).
Additional information and background	-

Requirement ID	**TE16_FRQ_002**
Requirement	Automated decision system sends information concerning system decisions and technical notifications to the specified User Groups.
Category	System Interaction with User Groups
Priority	Must
Main goal	Ensure that the developed solution provides the appropriate information to the relevant User Groups to facilitate seamless operations within the railway network.
Assumptions	The roles of the User Groups interacting with the system are defined in TE16_FRQ_001.
Specifications	▪ Train dispatcher: Must be informed of automated system actions, and their impact on real-time operations. ▪ Regional dispatcher: Must be informed of automated system actions, and their impact on real-time operations within their region. ▪ Train driver: Must be informed of decision effects on train speed and remaining headway (using the already established communication channels – e.g., ETCS MA). ▪ Information distribution staff (station announcements, travel info systems): Extracting the decision information, inactive in the process.
Additional information and background	A definition of train dispatcher and regional dispatcher is provided in TE16_FRQ_001.

Requirement ID	**TE16_FRQ_003**
Requirement	Automated decision system interfaces with the specified stakeholders.
Category	System Interaction with User Groups
Priority	Must
Main goal	Ensure that the system is using available interfaces to communicate with the relevant stakeholders.
Assumptions	Since both RU and IM will use the system, they both act as stakeholders.
Requirements	The system should interface with following stakeholders: ▪ Regional dispatcher ▪ RU Both parties should receive information about system decisions and their impact on real-time operations via TMS.
Additional information and background	-

Requirement ID	TE16_FRQ_004
Requirement	The system should be able to take fully automated decisions when allowed.
Category	System Interaction with User Groups
Priority	Must
Main goal	To streamline the railway network through the implementation of very short-term automated decision making should be possible.
Assumptions	Automated decisions are allowable by legislation and what kind of decisions may be taken in an automated manner is configured.
Specifications	▪ The system must be able to take fully automated decisions ▪ Operations (train dispatcher, regional dispatcher, train driver, and information distribution staff) must be informed of automated system actions. ▪ Operations (train dispatcher, regional dispatcher, and train driver) may overwrite automatic system decisions.
Additional information and background	-

7.3.2 System Scope

Requirement ID	TE16_FRQ_005
Requirement	Automated decision system must be able to handle actions for all trains within a configured time slot.
Category	System Scope
Priority	Must
Main goal	Ensure the uninterrupted operation of the railway network. To allow for the complete enforcement of operational decisions made by the automated system within the context of a conflict resolution.
Assumptions	The time slot in which the impact of re-steering on all trains is computed is configurable (see TE16_FRQ_011). A framework for train priorities within the system and bandwidths for steering them should be in place as baseline for the algorithms.
Specifications	There should be no predetermined upper bound on how many trains the system can handle.
Additional information and background	-

Requirement ID	**TE16_FRQ_006**
Requirement	The system should cover a specified geographical area.
Category	System Scope
Priority	Must
Main goal	To ensure that the automated system takes a well-defined geographic region into consideration.
Assumptions	The scheduled driving distances of trains can be derived by comparing the geographical locations that are reachable in the configured time slot.
Specifications	The geographical scope of the automated decision system must be derived from the scheduled driving distance within the time slot configured in TE16_FRQ_011.
Additional information and background	-

Requirement ID	**TE16_FRQ_007**
Requirement	Automated decision system must include all types of railway traffic.
Category	System Scope
Priority	Must
Main goal	Ensure that the system can incorporate all types of railway traffic influencing the network.
Assumptions	System can handle all types of railway traffic, as provided by the operational plan/ timetable.
Specifications	The railway traffic included within a certain application instance of the system depends on the geographic scope defined in TE16_FRQ_006.
Additional information and background	It should be noted that the railway traffic included in the algorithm on which the automatic system is based will be dynamic. In particular, trains might enter the geographic region defined in this requirement, or they may leave it. Here the extrapolation of delays of incoming traffic may take place in time.

Requirement ID	TE16_FRQ_008
Requirement	Automated decision system will take action if a real-time deviation from the planned timetable has a simulated/predicted impact on the railway network which exceeds a parameterizable threshold.
Category	System Scope
Priority	Must
Main goal	Ensure that the system can detect relevant conflict types that occur in the railway network.
Assumptions	The impact of a real-time deviation from the planned timetable must be determined in a systematic impact analysis. The parameterizable threshold will be defined.
Specifications	The impact analysis for a deviation must include: ▪ Secure operation time for interaction ▪ Train priority ▪ Delay The decision will be executed when the measured impact of a deviation exceeds a configurable threshold, and this threshold is only raised within the pre-defined forecast duration (see TE16_FRQ_011).
Additional information and background	How the system detects the deviation (e.g., by simulating all trains continuously to allow a proper overview of irregularities in the traffic flow) needs to be elaborated in the development process.

7.3.3 System Forecast and Conflict Detection

Requirement ID	TE16_FRQ_009
Requirement	The automatic decision system should perform a forecast relying on the specified data.
Category	System Forecast and Conflict Detection
Priority	Must
Main goal	Ensure that the system provides the intended type of forecast.
Assumptions	The geographic scope in TE16_FRQ_006 depends on the scheduled driving distance and the time slot configured in TE16_FRQ_011.
Specifications	The forecast should rely on real-time deviations from the planned timetable within the geographic scope defined in TE16_FRQ_006.
Additional information and background	-

Requirement ID	**TE16_FRQ_010**
Requirement	The system must provide an impact analysis for deviations.
Category	System Forecast and Conflict Detection
Priority	Must
Main goal	Ensure that the system provides the intended type of forecast and also that the impact calculation is performed as intended.
Assumptions	The impact calculation for a deviation should be made at hand of a deviation simulation with time horizon given by the time slot determined in TE16_FRQ_011.
Specifications	The impact analysis for a deviation should rely on simulations of the propagation of the effects of the deviation in the railway network.
Additional information and background	How the extrapolation of effects is executed in the simulation (e.g., by calculating the extrapolated traffic flow with conflict resolutions when conflicts occur) is defined in the development process.

Requirement ID	**TE16_FRQ_011**
Requirement	The forecast duration must be configurable.
Category	System Forecast and Conflict Detection
Priority	Must
Main goal	Ensure that the automated decision system is taking into consideration deviations and deviation simulations within a practical time window.
Assumptions	-
Specifications	The duration for forecasts should be configurable in a time window between 0 seconds to a few minutes, where no manual interaction by an operator is possible and the interlocking allows intervention.
Additional information and background	What a practical time window could be is an open research question (which will be considered, e.g., in WP 15). The configured forecast duration may depend on location in the network. At a busy intersection the forecast duration might be set to be very low, whereas in a single track stretch the forecast duration might be significantly higher.

Requirement ID	TE16_FRQ_012
Requirement	When the automatic decision system is triggered, notice has to be sent to the roles determined in TE16_FRQ_002 within a configurable notice time.
Category	System Forecast and Conflict Detection
Priority	Must
Main goal	Time slot for allowed automated decision making can be extended by a configurable veto time to ensure that operations have a sufficient time window to veto automatic decisions made by the system. The automated operational action will be postponed until veto time expires or is accepted/overwritten by operations.
Assumptions	Triggering of the system is determined in TE16_FRQ_008.
Specifications	▪ The veto time should be configurable between 0 seconds to a few minutes. ▪ If no veto time is set, the default notice time should be the minimum of the forecast duration set in TE16_FRQ_011 and 10 minutes.
Additional information and background	Similarly, to the forecast duration, the notice time may be configured differently in different network locations.

7.3.4 System Solutions

Requirement ID	TE16_FRQ_013
Requirement	When triggered, the automatic decision system may take the specified actions.
Category	System solutions
Priority	Must
Main goal	Ensure that the system has access to all necessary operational decisions that may be needed to mitigate conflicts in train operations.
Assumptions	As specified in TE16_FRQ_005, the automatic decision system has access to all railway traffic within the configured time slot.
Specifications	The system should be able to modify the planned setting time (of a signal) and length of a movement authority for a given train path.
Additional information and background	-

Requirement ID	**TE16_FRQ_014**
Requirement	The automatic decision system must measure the specified KPIs.
Category	System solutions
Priority	Must
Main goal	Ensure that the overall system aim is achieved and can be measured in a quantitative way.
Assumptions	The aim of the system is to minimize the impact of short-term conflicts.
Specifications	The reduction of impact on the train network of the automated decisions compared to no decisions should be measured.
Additional information and background	One way that this may be achieved is to measure the overall punctuality in a specific area over a large representative time period and compare this finding to the situation before the use of an automatic decision system.

Requirement ID	**TE16_FRQ_015**
Requirement	The automatic decision system needs to provide the cause information for all of its automated decisions.
Category	System solutions
Priority	Must
Main goal	For explainability of the system, solution necessary information needs to be provided by the system.
Assumptions	An event is triggered when the impact analysis for a real-time deviation exceeds a pre-defined threshold. The impact analysis is performed at hand of simulations of the deviation.
Specifications	Necessarily, the automatic decision system must provide information concerning the detected deviation that has triggered the execution of an automated decision. Furthermore, the system should provide the subsequent impact analysis.
Additional information and background	▪ The provided information on explainability might be stored for future certification of the system. ▪ Root causes should be insertable in the system by signallers or network controllers.

7.3.5 System Integration

Requirement ID	**TE16_FRQ_016**
Requirement	The automatic decision system must be capable of interoperating with the specified internal systems and data.
Category	System integration
Priority	Must
Main goal	Ensure the interoperability of the developed system with existing systems and the whole IT infrastructure. This is ensured through the capability of the system to process the specified data and to operate with the specified interfaces.
Assumptions	A Traffic Management System (TMS) and Advanced Protection System (APS) is in place to communicate with the developed solution.
Specifications	The solution needs to be able to process the following input data from the TMS: ▪ Operational plan data ▪ Actual real time operational data with all trip schedules and activities ▪ Train status information ▪ Train speed ▪ Train positions ▪ Infrastructure status information The solution needs to provide an output interface for: ▪ APS (for sending movement authority requests) ▪ Signalling and Traffic Management Systems (for sending notifications)
Additional information and background	For the output interfaces, standardized structures and interfaces should be used that are present at time of implementation (based on RailML, resp. its successor X2RAIL4/CDM, Eulynx SCI-OP, TMS2ext).

Requirement ID	TE16_FRQ_017
Requirement	The automatic decision system needs to be capable of interoperating with specified external systems and data.
Category	System integration
Priority	Must
Main goal	For the automated decision-making system external data needs to be integrated. A minimum set of data that the system needs to be able to process is defined in this requirement.
Assumptions	Data from external systems might influence the system's conflict mitigation process and, therefore, should be integrated.
Specifications	The system should be able to interoperate with the following external systems: ▪ Neighbouring Traffic Management Systems ▪ Neighbouring Advanced Protection Systems
Additional information and background	-

7.3.6 User interaction

Requirement ID	TE16_FRQ_018
Requirement	The automatic decision system needs to provide the specified visualizations and information for the user.
Category	User interaction
Priority	Must
Main goal	For the system to meet with a high level of acceptance among users, the system should map all relevant information and visualize it in a useful way.
Assumptions	Since roles (defined in TE16_FRQ_001) can veto system actions within a specified time window (see requirement TE16_ORQ_002), all necessary information needs to be pro-actively displayed to the user as a needed user activity.
Specifications	The system should visualize deviations in a map view including the following information: ▪ Trains with movement authority ▪ Speed status information The impact of rescheduling should be visualized in a time distance graph provided by the Traffic Management System.
Additional information and background	-

7.4 Non-Functional Requirements for TE 16

To ensure that the automatic decision system performs the required functionalities with appropriate quality in later operation and is also properly scalable, the following non-functional requirements are defined for TE 16.

7.4.1 System

Requirement ID	**TE16_NFRQ_001**
Requirement	The automatic decision system must be able to integrate information from cross border systems via the specified interfaces.
Category	System
Priority	Must
Main goal	To develop a system that is capable of communicating across borders.
Assumptions	In general, the system needs to support cross border operations.
Specifications	An integration of cross border systems should be possible via the following specifications: ▪ Service Control Interface – Operational Plan (SCI-OP) for Traffic Management Systems ▪ Service Control Interface – Command (SCI-CMD) for Advanced Protection Systems
Additional information and background	-

Requirement ID	**TE16_NFRQ_002**
Requirement	The automatic decision system must be able to handle a specified minimum number of conflicts at the same time.
Category	System
Priority	Must
Main goal	A minimum number of conflicts that the system should be capable of handling simultaneously guarantees that realistic situations that occur in the railway network will be addressable within the context of future applications of the system.
Assumptions	-
Specifications	The system should be able to handle at least 50 conflicts in parallel.
Additional information and background	This requirement is intended for a demonstrator level system. For a general level system TE16_NFRQ_003 applies.

Requirement ID	TE16_NFRQ_003
Requirement	The automatic decision system must be able to handle an arbitrary number of trains and simultaneous conflicts.
Category	System
Priority	Must
Main goal	To ensure that the system can handle the complexity required to be used in operations.
Assumptions	-
Specifications	-
Additional information and background	▪ This requirement is intended for future implementations with TRL above 5. ▪ Guidelines to measure whether the system can handle the defined complexity need to be elaborated.

7.4.2 Scalability

Requirement ID	TE16_NFRQ_004
Requirement	The system must be able to be integrated into a Traffic Management System and communicate with an Advanced Protection System.
Category	Scalability
Priority	Must
Main goal	A future integration of the system into existing systems keeps the amount of operation systems to a minimum and decreases the number of system interfaces.
Assumptions	-
Specifications	It should be possible to integrate the system in compliance to the following specifications: ▪ Service Control Interface – Operational Plan (SCI-OP) for Traffic Management Systems ▪ Service Control Interface – Command (SCI-CMD) for Advanced Protection Systems
Additional information and background	-

7.4.3 Performance

Requirement ID	**TE16_NFRQ_005**
Requirement	The duration for calculating the impact of system actions and submitting movement authority requests should be evaluated and needs to satisfy a specified threshold.
Category	Quality
Priority	Must
Main goal	Ensure that the system performance is of a sufficient quality to be used in daily operations. For this the impact analyses and resulting system actions (such as movement authority requests) should occur within an appropriate time range.
Assumptions	The impact analysis is performed at hand of deviation simulations.
Specifications	The process of performing the impact analysis and calculating a movement authority request to triggering the process at the RBC should take no longer than five seconds after receiving all needed information.
Additional information and background	What kind of simulation is used for the impact analysis remains open for the development process.

7.4.4 Regulations and Security

No requirements are specified for Regulations and Security.

7.5 Operational Requirements

The requirements specified in this chapter are intended to ensure that a system implementing TE 16 complies with national and EU-wide regulations and should, furthermore, be designed to comply with relevant new technologies like ETCS Level 3.

7.5.1 Compliance

Requirement ID	**TE16_ORQ_001**
Requirement	The automatic decision system must comply with national/EU-wide regulations.
Category	Regulation
Priority	Must
Main goal	Ensure that the system complies with national as well as EU-wide regulations.
Assumptions	Overarching specifications for TE 16 were defined in WP 10 –they are refined in the current report.
Specifications	The system should comply with the national and EU-wide regulations that are defined in the overall requirements of the MOTIONAL project.
Additional information and background	The overall requirements for TE 16 are elaborated and specified in WP 10.

7.5.2 Automation

Requirement ID	**TE16_ORQ_002**
Requirement	The decision process of the system is automated.
Category	Automation
Priority	Must
Main goal	The dispatcher does not need to react to every proposed resolution except manual rejection or intervention.
Assumptions	-
Specifications	If the system is triggered it will automatically take operational actions to mitigate disturbance in the railway network unless those actions are vetoed by Operations within a certain pre-defined veto time.
Additional information and background	The veto time can be configured based on a company's preference.

Requirement ID	TE16_ORQ_003
Requirement	The automatic decision system must be compliant with ETCS L3 and L3 Hybrid.
Category	Automation
Priority	Must
Main goal	The system must be implemented such that it is capable of interacting with planned future developments in railway infrastructure systems developed in FP 2 of ERJU.
Assumptions	During the next years the use of ETCS L3 will increase.
Specifications	The system should be designed for ETCS Level 3, including also L3 hybrid with block occupancy and block release information.
Additional information and background	-

7.6 Requirement disambiguation: Demonstrator level and general level system

In this chapter we have given a complete set of requirements for demonstrators of TE 16 (intended to have TRL 4). To make steps towards further future development, we have also collected some preliminary requirements on a general level integrated system performing TE 16 (TRL 8/9). Of course, as the landscape in this area of research is changing at a rapid pace, the requirements collected here for a general level system are subject to modification in correspondence with the situation at time of development and deployment of a general level system.

The requirements are as follows:

Requirements for demonstrator level of TE 16:

- **Functional requirements:** All of the functional requirements listed in Section 7.3.
- **Non-functional requirements:** All of the non-functional requirements listed in Section 7.4, except TE16_NFRQ_003.
- **Operational requirements:** All of the operational requirements listed in Section 7.5.

Preliminary requirements for a general level system with respect to TE 16:

- **Functional requirements:** All of the functional requirements listed in Section 7.3.
- **Non-functional requirements:** All of the non-functional requirements listed in Section 7.4, except TE16_NFRQ_002.
- **Operational requirements:** All of the operational requirements listed in Section 7.5.

8. Requirements for TE 17

Next to the development of a method for automated train control processes (TE 16) a system to provide automated decisions and decision support for traffic management optimization requires the implementation of real-time conflict detection and resolution. In order to support the decision making process, the system needs to detect situations that require an action (e.g., specific conflict situations) and propose actions to resolve the situation. Therefore, WP 17 is also closely related to the technical enabler 17 "Real-time conflict detection & resolution for main line and optimization". In the following chapter, the definition of TE 17 and its alignment (with other destinations) is discussed and corresponding requirements for a system implementing TE 17 are outlined.

8.1 Definition of TE 17: Real-time conflict detection & resolution for main line and optimization

TE 17 is concerned with developing a methodology that detects conflicts from the current traffic situation in the network and determines actions to resolve these. Conflict situations and their resolutions can be multifaceted, and their effects can range from minor delays of individual trains to a disruption of the entire network (due to, e.g., infrastructure restrictions).

Different approaches and methods are available for the implementation of TE 17. On the one hand, simulations of real-time operations offer the possibility to diagnose deviations from the timetable and disruptions as well as to forecast the near future and conflict situations that may occur. A simulation can also be the basis for analyzing recommended conflict solutions and their downstream effects in the railway network. On the other hand, based on the current traffic situation in the network and possibly also on historical data, methods such as mathematical optimization or reinforcement learning can be used to generate conflict solutions that optimize traffic. Depending on the technology that is chosen for the implementation of TE 17, optimization or learning processes may have a close link to simulations. For example, in reinforcement learning, past conflict scenarios may be mapped into simulations so that the method can learn from these situations (and their resolutions) and then apply this knowledge to the current traffic situation. This might have performance advantages compared to solving optimization problems in real-time.

The selection of suitable technologies for implementing the requirements described in this document is part of the implementation phase of WP 17 (i.e., Task 17.2). The developments related to TE 17 that are achieved within WP 17 are designed to reach a technical readiness level of 4 (TRL 4) – defining the required maturity of a developed technology. In WP 18, demonstrators with maturity level TRL 5 of TE 17 are developed. We mention that TRL 4 means that the technology has been validated in a laboratory setting, whereas TRL 5 means that the technology has been validated in a relevant environment. To facilitate the future selection of the appropriate technologies for implementation, the requirements contained here have been formulated in a technology-open manner. This is to ensure that the right technology can be selected, since the appropriate technology depends on the given conditions.

8.2 Alignment of TE 17 with the System Pillar and the Innovation Pillar

The alignment of the requirements developed for TE 17 is the same as that specified for the requirements for TE 16 (in Chapter 7). In particular, TE 17 has to conform to any specifications

handed down by the System Pillar. Since there is an interactive relationship between the System and Innovation Pillars, the results of WP 17 (including those related to TE 17) feed back into the System Pillar. Furthermore, WP 17 takes as input a set of high-level requirements for TE 16 and TE 17 as determined previously in WP 10. The requirements delivered in this report will, in turn, feed back into WP 10 -Task 10.2-, in which high-level use cases and demonstrators for Workstream 1.2 of MOTIONAL are specified. In Subtask 10.2.2 the development of demonstrators from WPs 11-18 are aligned, when necessary, also with other WSs or destinations.

The goal of the following chapter is to align and deliver all requirements for TE 17 and form the basis for implementations of demonstrators for the technical enabler “Real-time conflict detection & resolution for main line and optimization”.

8.3 Functional Requirements for TE 17

The functional requirements are grouped into the following subsections: System Interactions with User Groups, System Scope, System Forecast and Conflict Detection, System Solutions, System Integration, and User Interaction.

8.3.1 System Interaction with User Groups

Requirement ID	**TE17_FRQ_001**
Requirement	Infrastructure managers (IMs) are users of the system.
Category	System Interaction with User Groups
Priority	Must
Main goal	Ensure that the users of the system are defined.
Assumptions	The dispatchers on the IM side are responsible for all of the decisions affecting the infrastructure. The IM dispatchers are in communication with the operators on the RU side. The RU may request to take decisions concerning their own trains, but the final word rests with the IM dispatchers.
Specifications	The system must be capable of handling infrastructure managers as users. Specific IM roles are further defined in the requirements TE17_FRQ_002 and TE17_FRQ_003.
Additional information and background	-

Requirement ID	TE17_FRQ_002
Requirement	The system must distinguish between the IM roles of regional dispatcher, train dispatcher, and traffic control centre, as specified below.
Category	System Interaction with User Groups
Priority	Must
Main goal	Ensure that regional dispatchers, train dispatchers, and the traffic control centre from the IM side can use the system, and that these roles are clearly defined.
Assumptions	Both regional dispatchers and train dispatchers are part of the IM. The dispatchers are jointly in charge of network flow management. They distinguish themselves from the traffic controllers, who are in charge of the signaling system (and sometimes also safety measures).
Specifications	The roles of regional dispatcher, train dispatcher, and traffic control centre distinguish themselves as follows: **Regional dispatcher:** Operates locally, normally in a network section. The regional dispatcher may take decisions that only affect their region, e.g., track or order changes which only affect their region. The regional dispatchers make decisions concerning the operational points in their region (e.g., decisions at stations). **Train dispatcher:** Their operational scope is wider than a network section. They can solve conflicts and incidents located between two or more operational control points. They are, e.g., able to take decisions concerning track or order changes that affect two or more network sections. **Traffic control centre**: Their operational scope is the long-haul traffic. The regional dispatcher and train dispatcher are also differentiated in their possibilities for transferring/ requesting control of an area/ zone. Both regional dispatchers and train dispatchers are in communication with the RUs.
Additional information and background	There is the possibility of tension between the optimization of local networks and the network-wide balancing of all the players. This issue will be a main issue addressed in a PhD project affiliated with WP 15.

Requirement ID	**TE17_FRQ_003**
Requirement	The system allows the specified roles for the indicated User Groups.
Category	System Interaction with User Groups
Priority	Must
Main goal	Ensure that the developed solution provides the roles necessary for daily operation to the relevant User Groups, and that the system is properly maintained and configured.
Assumptions	The distinction of IM and RU is made in TE17_FRQ_001 and “train dispatcher” and “regional dispatcher” are defined in TE17_FRQ_002.
Specifications	The system should be able to cover the following roles with the specified responsibilities: ▪ Train dispatcher / regional dispatcher (as defined in TE17_FRQ_002): User of the system. In charge of evaluating system solutions and accepting/ rejecting solutions. ▪ Traffic Control Centre (as defined in TE17_FRQ_002): User of the system. Responsible for the long-haul traffic control requests, these are sent to the train dispatcher. ▪ IT-Organization: In charge of system maintenance, upgrades, expansion, user management, etc. ▪ Operational Management: Making strategic decisions on how to operate the system and configuring the system parameters. They should tune the system to consider more or less conflict types and/ or regarding the influence of different actions (track change, delays, etc.) on solution rankings.
Additional information and background	There are several other roles that are not active system users or are only meant to use the system in emergencies.

Requirement ID	**TE17_FRQ_004**
Requirement	System sends conflict and technical notifications to the specified User Groups.
Category	System Interaction with User Groups
Priority	Must
Main goal	Ensure that the developed solution provides the appropriate information to the relevant User Groups to facilitate continuous and seamless conflict detection and resolution.
Assumptions	The roles of the User Groups interacting with the system are defined in TE17_FRQ_003. The information included in the notifications is further specified in TE17_FRQ_031.
Specifications	▪ Train dispatcher (or also called network train dispatcher) should receive all conflict notifications. Regional dispatcher (or local dispatcher) should receive all relevant conflict notifications in their area of responsibility. This includes notifications of conflicts projected to occur in their area of responsibility as well as conflicts that may influence their area. If a suggested conflict resolution affects the regional dispatcher's region (e.g., train re-routing), then they should receive a notification. Conflict notifications should include when/ where a conflict is projected to occur and what kind of conflict it is. ▪ If the system detects or projects trackside equipment or rolling stock equipment errors / failures, then a notification should be displayed. Since equipment errors/ failures may impact train cancellation or train scheduling, the train dispatcher should receive notification, as well as any regional dispatchers whose regions may be impacted. The notification information should be filtered in line with their responsibilities.

Additional information and background	▪ To avoid distracting users, following an initial audible notification of a conflict, conflict notifications should be mainly visual. ▪ The notification content and types of visualizations are discussed in Section 8.3.5. ▪ The passenger information system (PIS) should also receive notifications regarding changes to the schedule resulting from resolved conflicts. ▪ In general, the notification distribution should match the logic of the responsible players. ▪ If possible and if the system detects or predicts an In-Circuit-Test (ICT) error that can easily be fixed via a bypass system, then maintenance can be triggered in an advanced system development stage. ▪ To increase user acceptance, only the appropriate roles should receive notifications, and these should include only the minimum set of information needed to evaluate or process the conflict.

Requirement ID	TE17_FRQ_005
Requirement	System sends IT notifications to the specified User Groups.
Category	System Interaction with User Groups
Priority	Must
Main goal	Ensure that the developed solution is seamlessly maintained and operated. That technical errors may be fixed in a timely manner, and relevant system users are informed of possible temporary system limitations.
Assumptions	The roles of the User Groups interacting with the system are defined in TE17_FRQ_003.
Specifications	▪ IT Organization/ Operational Management: Should receive all IT notifications (e.g., runtime errors, system errors, system overload, failed plausibility checks, etc.). ▪ Train dispatcher and regional dispatchers should receive IT notifications that are relevant to their operational regions. ▪ All users should receive notification of a system downtime.
Additional information and background	▪ To avoid distracting users, following an initial audible notification, IT notifications should be mainly visual. ▪ For IT Organization/ Operational Management, it makes more sense to send e-mails of high priority as they might not be physically located at their desks ▪ In IT notifications to Operations, it is important to stress the consequences of an error, rather than the error itself. E.g., the system should communicate the lack of information on localization of certain trains for a certain time, rather than a system overload for localization data.

Requirement ID	**TE17_FRQ_006**
Requirement	The system should interface with the specified essential stakeholders.
Category	System Interaction with User Groups
Priority	Must
Main goal	Ensure that the system is using available interfaces to communicate with essential stakeholders.
Assumptions	▪ On both the RU and IM side there are stakeholders which are compulsory to interface with. ▪ "Rolling stock management" is referring to maintenance-oriented steering of the trains, rather than dispatching of rolling stock (in some countries this may be the responsibility of dispatchers).
Specifications	The system should interface with following stakeholders: ▪ Operations: dispatchers, train drivers, signallers, etc. ▪ Event logger: To check case incidents, the conflict detection and resolution should be saved. ▪ Customer information services ▪ RU transport controller ▪ Manager of yards
Additional information and background	The refined definition of needed technical interfaces to communicate with the specified stakeholders will be part of the development process. Other stakeholders that should interfaced with, with a "Nice to have" priority, include: ▪ Staffing ▪ Rolling stock management ▪ Emergency services ▪ Incident management ▪ Vehicle monitoring systems Stakeholders that are not interfaced with via the system should still be communicated with using the current methods (i.e., often telephone).

Requirement ID	TE17_FRQ_007
Requirement	The general level system must interface with the specified stakeholders.
Category	System Interaction with User Groups
Priority	Must
Main goal	Ensure that the general level system is using available interfaces to communicate with the relevant stakeholders.
Assumptions	▪ On both the RU and IM side there are stakeholders which are compulsory to interface with. ▪ "Rolling stock management" is referring to maintenance-oriented steering of the trains, rather than dispatching of rolling stock (in some countries this may be the responsibility of dispatchers).
Specifications	The refined definition of needed technical interfaces to communicate with the specified stakeholders will be part of the development process. The system should interface with following stakeholders: ▪ Train control (dispatchers, RU transport controllers, signallers, etc.) ▪ Train operation (train drivers, etc.) ▪ Operational communication ▪ Event logger: To check case incidents. ▪ Emergency services ▪ Customer information services: Customers should have access to real-time information concerning conflict resolution consequences (e.g., modifications in the timetable). ▪ Staffing ▪ Rolling stock management ▪ Vehicle monitoring systems ▪ Manager of yards
Additional information and background	It should be noted that if a system is integrated into a TMS, then many of these stakeholders might be interfaced with through the TMS.

Requirement ID	**TE17_FRQ_008**
Requirement	The system shall be flexible to varying decision-takers for conflict resolution.
Category	Decision
Priority	Must
Main goal	Ensure that the decision-taking process is streamlined and allocated correctly to the different User Groups, that different User Groups do not interfere with each other's decisions, and that there is a clearly defined flow for the decision-making process which is in line with all users' responsibilities.
Assumptions	The roles of the User Groups interacting with the system are defined in TE17_FRQ_003.
Specifications	▪ The system is flexible to varying decision-takers depending on region and what kind of action is required by the decision. (The User Group that is the decision taker depending on locality or action taken is parameterized by Operations.) ▪ Train dispatchers (as defined in TE17_FRQ_002) may take decisions concerning re-routing or early turnaround recommendations. ▪ Regional dispatchers (as defined in TE17_FRQ_002) may take decisions concerning platform change or order change within their operational regions.
Additional information and background	▪ As a general principle, regional dispatchers may take decisions that affect only their operational region. ▪ With further future development of the solution, the system should be able to take decisions in a fully automated manner. ▪ "Route" is defined as the list of localities that the train has to service.

Requirement ID	TE17_FRQ_009
Requirement	Multi-user-operation shall be possible.
Category	Decision
Priority	Must
Main goal	Ensure that the system can allow for the necessary number of simultaneous users.
Assumptions	-
Specifications	Any number of simultaneous users should be possible, there should be no upper bound.
Additional information and background	▪ The number of users might be the number of regional dispatchers and the train dispatcher. In this case, the number of users would depend on the number of regions. ▪ The number of simultaneous users may also depend on the current load on the railway network and the chosen degree of automation.

Requirement ID	TE17_FRQ_010
Requirement	The system should have a well-defined approval hierarchy for collaborative decision-taking.
Category	Decision
Priority	Must
Main goal	Ensure that an efficient workflow in collaborative decision-taking.
Assumptions	Consider the case that a conflict is projected to occur in Region A and the resolution requires a general re-routing and platform change in Region B.
Specifications	▪ A clear set of guidelines must be in place to coordinate the various dispatchers that may be involved in each conflict resolution. ▪ The guidelines developed may be network dependent.
Additional information and background	▪ In the situation stated above the application of such guidelines may, e.g., be: Solution is chosen by the train dispatcher, approved by Regional Dispatcher B, and then approved by Regional Dispatcher A. ▪ In an automatic system such decision-taking hierarchies become obsolete.

8.3.2 System Scope

Requirement ID	**TE17_FRQ_011**
Requirement	System must cover a geographically restricted railway network[1].
Category	Scope
Priority	Must
Main goal	Ensure that the system covers a well-defined (part of a) railway network.
Assumptions	Within the geographic region specified in this requirement, the types of railway traffic that should be included are determined in TE17_FRQ_012.
Specifications	Intended (parts of) railway networks should be clearly defined in terms of geographical restrictions and be covered by the system.
Additional information and background	▪ By enforcing EU standardized requirements within the restricted networks, future interoperability of the EU railway network is facilitated. In the future, the system may be expanded to larger regions such as entire railway networks, or across international borders. ▪ Within the geographic region specified in this requirement, the system should incorporate the main line (single and double track), depots, complex junction nodes, terminal stations, etc.

Requirement ID	**TE17_FRQ_012**
Requirement	System must include all types of railway traffic (defined at the point in time of release of this specification).
Category	Scope
Priority	Must
Main goal	Ensure that the system includes all types of railway traffic influencing the network.
Assumptions	The train types that need to be included into the system depend on train types operating in the input network.
Specifications	The system should especially include regional trains, high-speed trains, freight trains, main line trains, and suburban trains.
Additional information and background	▪ At a lower priority, other transport modes like tram lines and light rail may also be included. ▪ While, e.g., roads crossing train tracks might influence train traffic, these are not included in the system.

Requirement ID	**TE17_FRQ_013**

[1] We do not use the term Regional Network here as it may be misunderstood as regional Network (secondary line).

Requirement	The system must detect the specified conflicts.
Category	Scope
Priority	Must
Main goal	Ensure that the system can detect relevant conflict types that occur in the railway network.
Assumptions	Conflicts occurring in the railway network are not singular. In particular, they are classifiable as, e.g., one of the types listed below.
Specifications	The system should at least detect the following conflicts: ▪ Simultaneous track occupancy prediction (line and platform) ▪ Insufficient platform length risk ▪ Infrastructure restrictions are violated ▪ Spontaneous closure of tracks (including derived limitations like the omission of a planned overtaking) ▪ Headway conflict or crossing conflicts ▪ Specified transfer time between connecting trains is violated due to delay ▪ Transfer time of rolling stock is exceeded including turn-around times ▪ Extension of running time, violation of planned time
Additional information and background	▪ In the future all conflicts that affect the railway network should be included.

8.3.3 System Forecast and Conflict Detection

Requirement ID	**TE17_FRQ_014**
Requirement	A forecast of conflict detections, conflict resolution impacts, and train parameters must be provided as output of the system.
Category	Conflict Detection
Priority	Must
Main goal	Ensure that the system provides the intended type of forecast.
Assumptions	-
Specifications	Deviations should be forecasted using train movement predictions, train schedule, and active control decisions made by traffic controllers.
Additional information and background	-

Requirement ID	**TE17_FRQ_015**
Requirement	The forecast duration of conflict detections must be configurable.
Category	Forecast
Priority	Must
Main goal	Ensure that conflicts are detected far enough ahead of time.
Assumptions	The regional railway network is specified in TE17_FRQ_011.
Specifications	▪ The configuration may be locally configurable within the geographic scope defined in TE17_FRQ_011. ▪ The default value of the forecast duration should be the scheduled time required to travel the longest train line in the restricted railway network (maximal forecast).
Additional information and background	▪ The desired forecast duration may depend on the locality within the network: At a busy junction the situation may be very dynamic, and it might not be productive to detect conflicts and calculate solutions many hours in advance. ▪ A practical forecast duration needs to be developed by Operational Management. In a large network a forecast duration of multiple hours might not be appropriate.

Requirement ID	**TE17_FRQ_016**
Requirement	The conflict notice time must be configurable for each conflict type.
Category	Conflict Detection
Priority	Must
Main goal	Ensure that the decision-taker has sufficient time to assess and resolve a conflict.
Assumptions	Conflicts are detected as part of the forecast in TE17_FRQ_014.
Specifications	▪ If no notice time is set, the default notice time should be 10 Minutes or as soon as they are detected depending on the conflict type. ▪ The notice time will be set by Operational Management.
Additional information and background	There may be a tendency to configure short notice times to avoid conflict accumulation or to give Operations time to consider conflict resolutions. As detection might require several iterations, it might be possible to start with a pre-defined period that is shortened when approaching the end of the forecast window.

Requirement ID	TE17_FRQ_017
Requirement	The conflict notice times must be configurable locally for each conflict time.
Category	Conflict Detection
Priority	Must
Main goal	Ensure that the decision-taker has sufficient time to assess and resolve a conflict.
Assumptions	Conflicts are detected as part of the forecast in TE17_FRQ_014. Conflict notice times are set for each conflict type as a result of TE17_FRQ_16.
Specifications	The notice time for each conflict type is set centrally by Operational Management but can be reduced up to a pre-defined minimum time for a region by the dispatchers (train dispatcher and appropriate regional dispatcher).
Additional information and background	It may be desirable to have short notice times in network areas that are very dynamic, also to not overwhelm Operations.

8.3.4 System Solutions

Requirement ID	**TE17_FRQ_018**
Requirement	The conflict resolutions calculated by the system must lead to a conflict-free traffic flow.
Category	Calculation
Priority	Must
Main goal	Ensure that the solutions calculated by the system are conflict-free in the intended region and within the intended timeframe.
Assumptions	Solutions are conflict-free in a specific geographic region and within a specific time horizon – the scope of the geographic region and the time horizon are specified in TE17_FRQ_011 and TE17_FRQ_015 respectively.
Specifications	The system should calculate solutions that are conflict-free within the geographic region and within the entire forecast duration.
Additional information and background	▪ It would be nice for the area in which a solution is conflict-free to be configurable, also the time for which a solution is conflict-free. ▪ The calculation of the solution should be within the timeframe determined in TE17_FRQ_019. The larger the area in which a solution should be conflict-free and the longer the time, the more computation time may be required. ▪ There are situations in which a conflict-free resolution may not be found, e.g., deadlock conflicts. If no conflict-free solution can be found, then the conflict-free area and time could be re-parameterized with the expectation that upcoming conflicts will be solved in future system iterations. ▪ Similarly to the above point, sometimes solutions that are not conflict-free with regards to timetabling should be accepted in order to continue operations. The balance between recommending not conflict-free solutions or extending computation times to calculate a possible conflict-free solution should be researched.

Requirement ID	**TE17_FRQ_019**
Requirement	The system may not take more than 30 seconds to calculate solutions.
Category	Calculation
Priority	Must
Main goal	Ensure that the system's computation time stays within a timeframe such that the calculated solutions are still relevant to the current situation.
Assumptions	In some regions, the situation of the railway network is very dynamic (e.g., at busy junctions). Optimal solution are solutions that conform to the conflict-freeness requirement as specified in TE17_FRQ_018.
Specifications	▪ The calculation of optimal solutions should not take longer than 30 seconds. ▪ If a calculation has not finished within 30 seconds, it should be terminated. ▪ If a calculation is terminated a notification should be sent to Operational Management and the appropriate parties in Operations (i.e., train dispatcher and appropriate regional dispatcher).
Additional information and background	▪ A faster calculation time of 5 seconds would be preferred. ▪ For conflict detection, the system may take forecast calculations/ prognosis data for the network that have been calculated by other systems as input. ▪ The allowable calculation time depends on how urgently the solutions are required. Solutions may be needed very quickly when approaching busy junctions, as the situation would be very dynamic in that region. ▪ Due to the variance in computational complexity introduced by different parameterizations of the system, a configurable allowable computation time may be considered. ▪ It may be worthwhile to make the option of the system doing its own forecast calculations for conflict detection parameterizable. ▪ How the calculation sequences are defined and whether parallel calculations are useful needs to be determined during the development process.

Requirement ID	**TE17_FRQ_020**
Requirement	Conflicts must be detected, and solutions calculated, with every new train report, defined traffic management event, or after a configurable time interval.
Category	Calculation
Priority	Must
Main goal	Ensure that conflicts are detected and resolved frequently enough to keep the railway network operating according to the current standards.
Assumptions	New train reports are possibly obtained several times a second. In busy areas, the situation of the railway network may be very dynamic.
Specifications	▪ Next to the triggering of a calculation cycle with every new train report, there must be a way for Operations to communicate deviations in the network to trigger a calculation cycle manually. ▪ The forecast should be actualized following the acceptance of a conflict resolution.
Additional information and background	It may be desirable to distinguish the frequency of calculation cycles for the different logical functions of the system: 1. Present current situation, 2. Actualize forecast, 3. Detect conflicts, 4. Present solutions, and 5. Process the chosen solution in the plan. In particular, the system may be configured to only perform a conflict detection/ resolution run if there are deviations in the forecast.

Requirement ID	**TE17_FRQ_021**
Requirement	The system will only continue calculations for which the triggering event still exists. Furthermore, the system will not begin new calculations corresponding to triggering events that no longer exist.
Category	Calculation
Priority	Must
Main goal	Ensure that calculations corresponding to triggering events that no longer exist are aborted. This is to decrease the computational load.
Assumptions	-
Specifications	The system should be able to detect that a triggering event is invalid for ongoing calculations. In such a case the ongoing computation could be aborted since there would be no benefit in completing it.
Additional information and background	-

Requirement ID	TE17_FRQ_022
Requirement	The specified operations may be implemented for conflict resolution recommendations.
Category	Recommendations
Priority	Must
Main goal	Ensure that the system can include enough operational actions within recommendations to be able to calculate all dispatching solutions. To facilitate operational oversight of the system, we must specify allowable actions within a conflict resolution.
Assumptions	Operations that may be implemented to resolve conflicts are not singular (they are standardized), in the sense that they are classifiable as, e.g., one of the types listed below.
Specifications	The system should calculate solutions that include: ▪ Re-routing ▪ Early turnarounds ▪ Cancellation of a service (train or single stops) ▪ Addition of stops ▪ Order changes/ train priority changes ▪ Track and platform changes ▪ Travel time extension / reduction and adjusting operational speed ▪ Stopping time extension / reduction ▪ Stopping time creation / deletion These actions should only be included if they are allowed for the types of railway traffic in the network.
Additional information and background	▪ Another question is whether the system can enact these solutions independently, without or with supervision. This concerns the degree of automation of the system. ▪ Within the development of the system, other operational actions may be found to be essential and subsequently be permitted. ▪ In the future it is possible that it will be necessary to function under certain restrictions concerning allowable actions within the context of a system solution. Such restrictions may include: taking into account connecting passengers, maximal waiting times for battery operated trains, starting limits, and electrical limits.

Requirement ID	TE17_FRQ_023
Requirement	Multiple solutions must be calculated.
Category	Recommendations
Priority	Must
Main goal	Ensure that enough solutions are calculated to provide for multiple resolution options.
Assumptions	Decision-taker manually selects one of the multiple calculated solutions. Optimal solution are solutions that conform to the conflict-freeness requirement as specified in TE17_FRQ_018.
Specifications	▪ The calculated solutions should be optimal, unless otherwise specified. ▪ For each of the solutions it should be checked whether it is compliant to the real-time traffic situation.
Additional information and background	The number of solutions calculated depends on the desired degree of automation of the system. In an automatic system, only one solution (the “best”, see TE17_FRQ_024) should be calculated and enacted by the system. When the system is not automatic, the decision-taker is provided with multiple solutions and chooses one, if possible.

Requirement ID	TE17_FRQ_024
Requirement	Solutions shall be ranked according to the specified key performance indicators (KPIs).
Category	Recommendations
Priority	Must
Main goal	Ensure that the assessment of solutions is streamlined and according to the relevant criteria.
Assumptions	There are well-defined operational standards like punctuality thresholds that can be used to quantify the degree of disturbance caused in the network by the enaction of a specific solution. Optimal solution are solutions that conform to the conflict-freeness requirement as specified in TE17_FRQ_018.

Specifications	▪ The solutions calculated by the system should be ranked according to:
	  ▪ Delay time
	  ▪ Punctuality rate based on a configurable punctuality threshold
	  ▪ Pre-defined cost function
	  ▪ Passenger waiting times or other passenger comfort performance indicators
	  ▪ Time to return to standard timetable (if possible)
	  ▪ Reduction of train impact on other trains and operational stability of the network
	  ▪ Percentage of conflicts which require manual actions to be solved
	  ▪ Minimum degree of conflict-freeness (with respect to size of region and time in which the solution is conflict-free)
	▪ The influence of different KPIs on the ranking should be weighted according to an individual configuration. These configurations can also include a weighting of the KPIs based on the train type and train locality.
	▪ It is necessary to clearly outline how the various KPIs are measured or quantified.

Additional information and background	At a lower priority, also the power consumption could be used to rank solutions.

Requirement ID	**TE17_FRQ_025**
Requirement	Conflict detection, calculation of solutions, and ranking of the solutions must be explainable.
Category	Recommendations
Priority	Must
Main goal	Ensure that the detection and resolution of conflicts as well as ranking of solutions in the system is logical, and reliably accurate. The process should be explainable enough for possible future certification.
Assumptions	The detection of conflicts and calculation as well as ranking of solutions will involve smart components. Solutions are ranked according to the KPIs in TE17_FRQ_024.
Specifications	▪ The system should detect conflicts in a traceable way. ▪ The system should rank solutions with respect to the KPIs in a traceable way. ▪ Changes to the timetable must be explainable by the conflict resolutions taken and the system should provide transparency of the decision-making logic.
Additional information and background	▪ The explainability of the system may be a complicated issue if it involves learning algorithms. This is an issue with respect to accountability or might become an issue in the certification process. ▪ The explanation for the rankings should not be displayed to the train dispatcher or regional dispatcher as primary information. This might only be distracting and is not needed.

Requirement ID	**TE17_FRQ_026**
Requirement	The data for conflict detection and resolution must be stored at least for six months, where a longer storage-duration can be configured if needed.
Category	Recommendations
Priority	Must
Main goal	Ensure that the system stores all information on detected conflicts such that past situations can be analyzed. The stored information can also be used for possible future audits and certification.
Assumptions	The system detects conflicts and generates resolutions to these conflicts that should be archived.
Specifications	The following data should be stored: ▪ Location, time, and type of the primary conflict ▪ How the system itself was parameterized at the time of conflict detection and resolution ▪ Solutions that were calculated by the system ▪ Ranking of calculated solutions ▪ Selected solution ▪ Effect of selected solution on the network ▪ Position data following conflict, to allow for a comparison between the tool prediction and the reality ▪ If applicable, whether the solution was chosen by the user or automatically
Additional information and background	▪ The data should be stored within the system. ▪ A storage for feeding a typical replay-feature covering the items listed in the specifications field is also acceptable.

8.3.5 System Integration

Requirement ID	**TE17_FRQ_027**
Requirement	APIs must be provided for the specified input and output systems.
Category	Technical requirement
Priority	Must
Main goal	Ensure a better integration of the developed solution into existing IT infrastructures.
Assumptions	The system should be used by infrastructure managers resulting in a broad landscape of systems interfacing with the tool.
Specifications	If possible, the solution needs to provide an input interface for: ▪ Traffic Management System (TMS): timetable and actual times, train positions, GUI ▪ Advanced Protection System ▪ Signalling system ▪ Infrastructure maintenance or construction planning system for providing planned capacity restrictions ▪ Radio Block Centre ▪ Temporary speed restriction manager The solution needs to provide an output interface for: ▪ Traffic Management System ▪ A possibly self-implemented dashboard for displaying conflicts and conflict resolutions ▪ Customer information systems (also possible through TMS)
Additional information and background	▪ With further development of the solution, it can be fully integrated into an existing TMS. ▪ If the solution is integrated in the TMS this requirement is not applicable for the interfaces already provided/used by the TMS. ▪ The system output can also be transferred to crew management systems, rolling stock management systems, and signalling systems via the TMS.

Requirement ID	TE17_FRQ_028
Requirement	The specified external data must be included.
Category	Technical requirement
Priority	Must
Main goal	To detect conflict situations and resolve these situations external data needs to be integrated. A minimum set of data that the system needs to be able to process is defined in this requirement.
Assumptions	There are external conditions, e.g., from RU or IM, for which data are available that will affect the railway network.
Specifications	The system should be able to process the following types of data: ▪ Real-time train positions and mechanical conditions of trains ▪ Operational plan ▪ Infrastructure constraints (e.g., line sections not available, capacity plan)
Additional information and background	With further development of the solution, further information can be included such as ▪ Data on weather and weather forecast ▪ Data from other IM/ RUs ▪ Real-time mobility demand information from a mobility information management system

8.3.6 User Interaction

Requirement ID	**TE17_FRQ_029**
Requirement	The conflicts should be displayed in the specified way.
Category	Graphical representation
Priority	Must
Main goal	To ensure that the conflicts detected by the system are communicated to the user in an easily understandable way.
Assumptions	The system provides information on conflicts and recommendations that can be visualized.
Specifications	The following visualizations need to be provided by the system: ▪ List of conflicts (ordered, e.g., according to projected conflict-time) ▪ Time-distance-diagram in which conflicts are highlighted (e.g., via an icon)
Additional information and background	▪ In a general level version, the tool can be integrated into TMS and the time-distance-diagrams of the TMS can be used to visualize the conflicts. ▪ The required types of visualizations might change during the implementation phase. ▪ Lack of clarity and difficulties in understanding the conflicts or their suggested resolutions might lead in a user rejection of the tool. ▪ The types of visualizations have to be refined after feedback from end-users in demonstrations in WP 18.

Requirement ID	**TE17_FRQ_030**
Requirement	The conflict resolutions must be displayed in the specified way.
Category	Graphical representation
Priority	Must
Main goal	To ensure that the user can easily select an appropriate conflict resolution for a detected conflict.
Assumptions	The system provides information on conflicts and recommendations that can be visualized.
Specifications	The following visualizations need to be provided by the system: ▪ For each conflict, the calculated solutions are displayed in a list with the highest ranked conflict resolution (according to the KPIs in TE17_FRQ_024) on top. ▪ The solutions are represented as a sequence of operational actions that must be taken.
Additional information and background	This requirement is not applicable, if the resolution process is fully automated.

Requirement ID	**TE17_FRQ_031**
Requirement	The conflict resolutions have to be displayed in the specified way in the general level system.
Category	Graphical representation
Priority	Must
Main goal	To ensure that the selection process for conflict resolutions is as easy as possible for the user.
Assumptions	The system provides information on conflicts and recommendations that can be visualized.
Specifications	▪ All of the visualizations already mentioned in TE17_FRQ_030 must be included. ▪ Visualizations of proposed conflict resolutions should be available as time-distance-diagrams.
Additional information and background	There may be the option available in the system to overlay the time-distance-diagrams of the various suggestion conflict resolutions.

Requirement ID	**TE17_FRQ_032**
Requirement	A user of the system should always be able to view a list of the current system parameterizations.
Category	Graphical representation
Priority	Must
Main goal	User knowledge of system parameterizations may be necessary to ensure optimal usage of the system.
Assumptions	System parameterizations will result, amongst others, from forecast duration (see TE17_FRQ_015), the notice time (see TE17_FRQ_016 and TE17_FRQ_017), parameters on conflict-freeness (see TE17_FRQ_018).
Specifications	All parameters that can be set by the Operational Management and the user can be viewed in the GUI.
Additional information and background	-

Requirement ID	**TE17_FRQ_033**
Requirement	Conflict notifications sent by the system to operations should conform to the following specifications.
Category	Ergonomics
Priority	Must
Main goal	Since too much information decreases the level of ergonomics only the relevant information for a first assessment of the conflict should be displayed.
Assumptions	When a conflict is detected, notifications are sent respecting the parameterized notice times (see TE17_FRQ_016 and TE17_FRQ_017).
Specifications	The user should get the following information without any action from the user required: ▪ Indicator that a conflict exists ▪ Time and location of the conflict ▪ List of trains involved in the conflict ▪ Conflict presentation in a time-distance-diagram ▪ List of highest conflict resolutions, ranked by the KPIs in TE17_FRQ_024 Any additional information should require additional action from the user.
Additional information and background	▪ The final decision on which information is displayed should be discussed with the users. ▪ Only critical information should be shown in a first notification.

Requirement ID	TE17_FRQ_034
Requirement	The interaction of the user with the tool should performed via mouse in the specified way.
Category	Ergonomics
Priority	Must
Main goal	It should be guaranteed that the user can interact with the system like the way in which they interact with the other systems used in daily operations.
Assumptions	-
Specifications	The operation of the tool should be mainly via mouse in the following way: Selection of an action via mouse-click and confirming the decision with a confirmation button or pop-up window.
Additional information and background	▪ An additional approach could be to integrate interaction via keyboard shortcuts into the process. ▪ For optimizing ergonomics, experts should be involved in the specifications of further requirements such that the interface is easy to use. ▪ In the development process, near-future technologies enabling, e.g., finger or hand steering can be evaluated to substitute interactions via mouse.

Requirement ID	TE17_FRQ_035
Requirement	The user should be able to configure what information is displayed.
Category	Usability
Priority	Must
Main goal	To increase user acceptance, the user should be able to configure the system to his needs.
Assumptions	In the developed GUI different layers of visualizations can be implemented.
Specifications	The system GUI should contain different layers with varying information that can be displayed on demand by the user.
Additional information and background	Throughout the course of implementation and in discussions with the users, it will be determined if some information is compulsory in the GUI. A list of such compulsory elements should be developed, and it should not be possible for these to be configured away by users.

8.4 Non-Functional Requirements for TE 17

To ensure that the system performs the required functionalities with appropriate quality in later operation and is also properly scalable, the following non-functional requirements are defined for TE 17.

8.4.1 System

Requirement ID	**TE17_NFRQ_001**
Requirement	The system needs to enable *cross-border connected operation* in the specified way without being limited to a specific number of connected processes and systems wherever possible.
Category	Cross Border Operation
Priority	Must
Main goal	Ensure that the system can be used in *cross-border connected operation*.
Assumptions	The term *cross-border connected operation* indicates the option to "connect" different TMSs across borders in a logical way but does not imply cross-border operating TMS-systems.
Specifications	The system must: ▪ Provide real-time operational information like state, handover-times, predictions, etc. ▪ Offer a standards-based interface and data structure ▪ Ensure harmonized (standardized) processes wherever possible
Additional information and background	-

Requirement ID	**TE17_NFRQ_002**
Requirement	Any exchange of data and/or commands between different TMSs must use the (at time of writing of this requirement) specified standards.
Category	Cross Border Operation
Priority	Must
Main goal	Ensure that the communication between TMSs complies with the current standards.
Assumptions	This requirement extends TE17_NFRQ_001.
Specifications	The system must be able to use the standards TAF/TAP TSI.
Additional information and background	-

Requirement ID	**TE17_NFRQ_003**
Requirement	Any exchange of data and/or commands between different TMSs must use the (at time of implementation) standardized structures and interfaces for this application (based on RailML, resp. its successor X2RAIL4/CDM, Eulynx SCI-OP, TMS2ext).
Category	Cross Border Operation
Priority	Must
Main goal	Ensure that the communication between TMSs complies with future standards.
Assumptions	This requirement extends TE17_NFRQ_001 and TE17_NFRQ_002.
Specifications	The according standards will be set/ finalized within the ERJU by the System Pillar.
Additional information and background	-

Requirement ID	**TE17_NFRQ_004**
Requirement	The maximal delay of an event from occurrence to showing-up in the live data for cross-border exchange is in a specified time window.
Category	Cross Border Operation
Priority	Must
Main goal	To ensure the timely relaying of real-time data within the context of handover at borders.
Assumptions	-
Specifications	The time window should be no longer than 1.5 Minutes.
Additional information and background	▪ The current requirement should include the Integration Layer developed in the Shift2Rail context (IN2RAIL, X2RAIL-2 and X2RAIL-4). ▪ It is acknowledged that requirements of this nature are difficult to enforce on other IMs.

Requirement ID	**TE17_NFRQ_005**
Requirement	The number of trains that can be simultaneously handled by the conflict detection and resolution function must cover a large enough operating area to be useful.
Category	Number of Trains Considered
Priority	Must
Main goal	To ensure that the conflict detection and resolution system can handle enough trains to be usable in operations.
Assumptions	Since network segmentation may be required for this requirement, as a prerequisite, an approach to interlink network segments including fall-back procedures needs to be developed.
Specifications	Ideally the solution is built-up of scalable/combinable modules to cover the varying sizes of operating areas.
Additional information and background	The number of trains depends on the network.

Requirement ID	**TE17_NFRQ_006**
Requirement	The conflict detection and resolution function must cover at least 50 trains.
Category	Number of Trains Considered
Priority	Must
Main goal	To ensure that a demonstrator of the confliction detection and resolution system can handle enough trains to be eligible for further development.
Assumptions	-
Specifications	-
Additional information and background	This requirement is applicable for the demonstrator level system.

Requirement ID	**TE17_NFRQ_007**
Requirement	The system must ensure a mode and architecture to manage at least 100 conflicts simultaneously.
Category	Number of Trains Considered
Priority	Must
Main goal	To ensure that the confliction detection and resolution system can handle enough trains to be usable in operations.
Assumptions	This requirement extends TE17_NFRQ_005.
Specifications	-
Additional information and background	This requirement is applicable for the general level system.

Requirement ID	NFRQ_008
Requirement	The system must ensure a suitable mode and architecture of extensibility that enables a growth to more than 1000 trains without resulting in extended reaction times.
Category	Number of Trains Considered
Priority	Must
Main goal	To ensure that the confliction detection and resolution system can be extended to be used in operations within suitable large networks.
Assumptions	This requirement extends TE17_NFRQ_005 and TE17_NFRQ_007.
Specifications	-
Additional information and background	This requirement is applicable for the general level system.

8.4.2 Scalability

Requirement ID	TE17_NFRQ_009
Requirement	The system must be able to be integrated into existing TMS via the specified interfaces
Category	Integrability
Priority	Must
Main goal	To ensure the integration of the new algorithm into the TMS systems.
Assumptions	-
Specifications	The new system must be built as a module that is deeply integrated into the TMS (using base data and state data, etc.) using the SCI-OP interface.
Additional information and background	-

Requirement ID	TE17_NFRQ_010
Requirement	The system must be able to be integrated into existing APS via the specified interfaces.
Category	Integrability
Priority	Must
Main goal	To ensure the new system is connected to the APS.
Assumptions	-
Specifications	The new system must be built as a module that is connected to the APS using the SCI-CMD interface.
Additional information and background	▪ The demonstrators can deviate from this requirement (as the relevant standards are not yet finalized), but they should be developed as close as possible to the draft of the standards available. ▪ When the system is integrated into a TMS the corresponding TMS interface can be used.

8.4.3 Performance

Requirement ID	TE17_NFRQ_011
Requirement	The system must achieve a specified availability rate.
Category	Availability
Priority	Must
Main goal	To ensure that the system meets the level of availability required for use in operations.
Assumptions	-
Specifications	The system needs to achieve an availability rate of 99,9% where planned maintenance downtimes are not included.
Additional information and background	▪ This requirement is applicable for a general level system with TRL 8 or higher. ▪ It is important to distinguish between the detection of conflicts (more availability required) and conflict resolution (can be processed by manual rescheduling).

Requirement ID	**TE17_NFRQ_012**
Requirement	The system must be resilient to failure.
Category	Availability
Priority	Nice-to-have with high priority
Main goal	To ensure that operations are not interrupted by system failure.
Assumptions	-
Specifications	The system must be set-up in a redundant architecture.
Additional information and background	This requirement also includes the compliance with cybersecurity guidelines formulated in TE17_NFRQ_019 to address cybersecurity risks.

Requirement ID	**TE17_NFRQ_013**
Requirement	In the case of a downtime of the recommendation engine the specified procedures will be followed.
Category	Availability
Priority	Nice-to-have with high priority
Main goal	To ensure that if the recommendation engine fails, there are procedures in place for a degraded mode (which still allows for use of the conflict detection system).
Assumptions	-
Specifications	In the case of a downtime of the recommendation engine: ▪ Conflict detection should continue. ▪ Manual mode: No recommendations will be proposed to the dispatchers. ▪ Automatic mode: No recommendations will be made operational. ▪ Detected conflicts should be addressed manually. ▪ Degraded mode procedures must be implemented in the system and in interfaces.
Additional information and background	Safety functionalities should be working constantly.

Requirement ID	**TE17_NFRQ_014**
Requirement	The detection time (time from root cause to detection of a conflict) of conflicts should be used as a KPI for system benchmarking for conflicts where the time of the root cause is determinable by the algorithm.
Category	KPIs for Benchmarking
Priority	Must
Main goal	To ensure that the conflict detection system is fast enough to be used in operations.
Assumptions	The time of the occurrence of the root cause need to be determinable by the system.
Specifications	The detection time should have a threshold above which error notifications are sent.
Additional information and background	The issue of calculation-timeout is relevant.

Requirement ID	**TE17_NFRQ_015**
Requirement	The calculation time from the detection of a conflict to the suggestion of at least one resolution should be used as a KPI for system benchmarking.
Category	KPIs for Benchmarking
Priority	Must
Main goal	To ensure that the conflict resolution system is fast enough to be used in operations.
Assumptions	-
Specifications	This calculation time should also be used as a KPI for benchmarking.
Additional information and background	The calculation duration for conflict resolution may depend on the type of conflict and number of trains.

Requirement ID	TE17_NFRQ_016
Requirement	The maintainability of the system must be used as a KPI for benchmarking.
Category	KPIs for Benchmarking
Priority	Nice-to-have with high priority
Main goal	To ensure that software malfunctions may be easily fixed.
Assumptions	Maintainability KPI will monitor the ease of changes in the code to repair software malfunctions. Also, the ease with which operational changes may be implemented and how flexible the code is to changes during development.
Specifications	For a pre-defined measure of maintainability, the system should be able to be evaluated. These measures are based on statistical data such as: ▪ Down times ▪ Failure solving times
Additional information and background	▪ For this KPI, a quantitative measure needs to be developed. ▪ This KPI can only be evaluated after a long operation time to be reliable. ▪ Since it is only a “Nice-to-have” requirement, demonstrators do not need to fulfil this requirement.

Requirement ID	TE17_NFRQ_017
Requirement	The quality of recommendations should be used as a KPI for benchmarking.
Category	KPIs for Benchmarking
Priority	Must
Main goal	To ensure that the conflict resolutions suggested by the system are of a reliable quality which enables the support of operations.
Assumptions	-
Specifications	▪ The quality of resolutions should be measured either via acceptance rate or via a "conflict effects comparison" (e.g., delay minutes) with a benchmark period representing standard operations in the absence of the system. ▪ A threshold quality of solutions should be implemented, below which the system sends error notifications. ▪ This threshold is to be determined.
Additional information and background	▪ The calculation duration should be considered when adjusting the quality threshold. ▪ With respect to the acceptance rate of recommendations, this should be compiled local at the different operational points and if it is particularly low at a point then this should be addressed.

8.4.4 Regulations and Security

Requirement ID	TE17_NFRQ_018
Requirement	The system must be auditable by providing a tamper-proof log of the specified data.
Category	Auditability
Priority	Must
Main goal	To allow for system audits and prove non-discrimination of RUs in conflict resolutions.
Assumptions	See also TE17_FRQ_025 and TE17_FRQ_026.
Specifications	For post-analysis and to prove the non-discrimination of RUs in the algorithm, the following data should be stored: ▪ Conflicts ▪ Proposed resolutions ▪ Metadata about the process
Additional information and background	This requirement does not make existing log-requirements (IT-Security) obsolete!

Requirement ID	TE17_NFRQ_019
Requirement	The system must comply with cybersecurity guidelines.
Category	Compliance
Priority	Must
Main goal	To ensure that the system conforms with robust cybersecurity guidelines.
Assumptions	-
Specifications	The requirements concerning cybersecurity must be derived by specialists in this field.
Additional information and background	-

Requirement ID	TE17_NFRQ_020
Requirement	The system must provide the needed functionalities and procedures required for compliance with the General Data Protection Regulation (GDPR) of the EU, also with any regional regulations concerning data protection.
Category	Compliance
Priority	Must
Main goal	To ensure that the system complies with the relevant Personal Data Protection guidelines.
Assumptions	-
Specifications	Special emphasis should be placed on the management of “who-did-what” logs.
Additional information and background	This requirement will result in functionalities and procedures to ensure general compliance with GDPR and the development of a deletion concept, also measures for data-anonymization (based on the specific requests of official authorities).

Requirement ID	TE17_NFRQ_021
Requirement	The system must provide the necessary functionalities and proofs that are required for compliance with EU AI Regulations that are either expected or already instituted at the time of implementation.
Category	Compliance
Priority	Must
Main goal	To ensure that the system complies with EU AI Regulations and may be used for train operations within the EU.
Assumptions	-
Specifications	-
Additional information and background	At the time of writing of this requirement, a set of EU AI Regulations are expected, but they are still being finalized.

8.5 Operational Requirements

The implementation of the new TMS with respect to TE 17 needs to fulfil the following operational requirements (which are valid for the solution as a whole), reflecting the legal and organizational environment the system is placed in.

8.5.1 Compliance

Requirement ID	**TE17_ORQ_001**
Requirement	The system must comply with all relevant national/ EU-wide regulations, specifically those specified below.
Category	Regulation
Priority	Must
Main goal	To ensure that the system may be used within the intended operating areas in the EU.
Assumptions	▪ National regulations are deducted from European regulations: they can tighten the European regulations, but not overrule them. (I.e., a feature not allowed by European regulations cannot be allowed by national regulations.) ▪ The procedures to check the adherence to regulations stays unchanged (e.g., certification).
Specifications	Existing and expected regulations that should be complied with include: ▪ TSI (CCS) ▪ EN 50126 – 50129 (CENELEC) ▪ Network and Security Act ▪ Additional general EU-regulations on AI
Additional information and background	▪ The rules that must be adhered to in this technical area not only originate in the field of railway regulation, but also come from AI (see also TE17_NFRQ_017) and data regulations (see also TE17_NFRQ_016). ▪ We remark that there is a circular reference here to the ERJU – as the regulations of the ERJU that must be adhered to are also created in this initiative.

Requirement ID	**TE17_ORQ_002**
Requirement	The system must comply with all relevant company regulations.
Category	Regulation
Priority	Must
Main goal	To ensure that the system may be used by IM and RU for railway operations.
Assumptions	Internal company regulations are not static (but must evolve and adapt in response to changing realities) and, therefore, the specific rules entailed by this requirement are not set in stone.
Specifications	The system must comply with: ▪ Generic operational rules (internal to each company) ▪ National Railway Act Companies have the possibility to trigger adaptions of their company's internal regulations based on the progress and insights of this program.
Additional information and background	▪ The rules that must be adhered to in this technical area not only originate in the field of railway regulation, but also come from AI (see also TE17_NFRQ_017) and data regulations (see also TE17_NFRQ_016). ▪ We remark that there is a circular reference here to the ERJU -as the regulations of the ERJU that must be adhered to are also created in this initiative.

8.5.2 Automation

Requirement ID	**TE17_ORQ_003**
Requirement	The levels of automation for this system will be defined as specified below.
Category	Automation
Priority	Must
Main goal	To ensure that the technological concepts and usages of the new TMS correspond to the accepted degrees of automation set by the European railways.
Assumptions	This requirement reflects the gradual approach taken towards the introduction of AI features: Starting with a semi-automatic system, which after successfully running gets more and more integrated into the loop (moving towards automatic operation). Assuming that TE17_ORQ_001 and TE17_ORQ_002 allow for it and that sufficient experience and trust exist within a company, a fully automatic system may be aspirational for the future.
Specifications	We distinguish the following allowed levels of automation: ▪ **semi-automatic:** human needs to select and approve an action (final acceptance). ▪ **automatic**: highest-ranking option is implemented automatically, but with time-lag to allow for manual veto. ▪ **fully automatic:** no human action required. Highest-ranking solution implemented automatically with no time-lag. System still enables overview and supervision. For TE 17, the system needs to provide an architecture to support at least a semi-automatic process.
Additional information and background	▪ Acceptance and trust in the automatic service should be built gradually, making sure to involve the operators. First, offline tests could be used. Then, manual validation of the proposed solution can be necessary. It is important to focus on the explainability of the solutions (see also TE17_FRQ_025) and to be able to evaluate the quality of the solution (see also TE17_NFRQ_022). ▪ Some of the above requirements may eliminate the option of fully automatic operations (e.g., TE17_NFRQ_017 and TE17_ORQ_001 might require that AI may not function without human supervision). It is unclear how to handle this: Possibly running through the various stages of development

	and automation (thereby gaining trust in the system) will be sufficient to alleviate concerns.

Requirement ID	**TE17_ORQ_004**
Requirement	The system must be defined/built in such a way that it can handle the paradigm triggered by the ETCS Level specified in this requirement.
Category	Other (Future-Proofing)
Priority	Must
Main goal	To ensure that the developed system will be appropriate for the level of ETCS prevalent in the network at the time of system deployment.
Assumptions	Within the implementation timeframe, in addition to the existing ETCS L2 tracks, we assume that the first L3 implementations will need appropriate functionalities in the system.
Specifications	The system needs to be able to handle the paradigm triggered by ETCS Level 3 Moving Block.
Additional information and background	-

8.6 Requirement disambiguation: Demonstrator level and general level system

In this document we deliver a full set of requirements for demonstrators of TE 17, where the demonstrators developed in subsequent parts of WP 17 are of TRL 4. We also give a set of requirements for a general level system with respect to TE 17 (TRL 8/9), a full set of such requirements is still dynamic and will evolve between the time of release of this report and deployment of a new TMS integrating TE 17. The requirements are as follows:

Requirements for demonstrator level of TE 17:

- **Functional requirements:** All of the functional requirements listed in Section 8.3, except for TE17_FRQ_007, TE17_FRQ_010, TE17_FRQ_017, and TE17_FRQ_031. In this TE17_FRQ_031 would be nice to have for a demonstrator.
- **Non-functional requirements:** Demonstrators must comply with TE17_NFRQ_006, TE17_NFRQ _014, TE17_NFRQ _015, TE17_NFRQ _17, and TE17_NFRQ_018. A demonstrator should have the potential to satisfy system integration as specified in TE17_NFRQ_009 and TE17_NFRQ_010, but full integration of a demonstrator is not necessary. Demonstrators may deviate from TE17_NFRQ_018, but it should be stated in documentation for the demonstrator exactly where it deviates and how.

- **Operational requirements:** Demonstrators must comply with TE17_ORQ_003 and TE17_ORQ_004. Demonstrators may deviate from TE17_ORQ_001 and TE17_ORQ_002, but any deviations must be documented.

Preliminary requirements for a general level system with respect to TE 17:

- **Functional requirements:** All of the functional requirements listed in Section 8.3.
- **Non-functional requirements:** All of the non-functional requirements listed in Section 8.4, with the exception of TE17_NFRQ_006. We, furthermore, remark that TE17_NFRQ_019 has been inserted as a placeholder for a set of cybersecurity requirements that are outside of the scope of this report and must be specified in consultation with cybersecurity experts.
- **Operational requirements:** All of the operational requirements listed in Section 8.5.

9. Benchmarking Criteria

One of the deliverables associated with Task 17.1 is the development of benchmarking criterion for demonstrators in decision support for planning and timetable optimization. Establishing a standardized procedure to determine how suitable a demonstrator is, is an essential part of this WP. It may be used as a measurement schema for conducting rigorous, transparent, and replicable testing and comparing both the algorithms and the resolutions generated by the method. In this context we define benchmarking criterion as a set of reference points against which the performance and reliability of demonstrators may be compared. The testing and comparison of different methods can be performed with a testbed and benchmarking methodology developed in Task 7.2.

9.1 Scenario Characterization

Conflict Detection and Resolution algorithms are generic pieces of software that will be applied over specific networks. In order ensure the accuracy of the comparison, it is important to correctly define that comparison. For this purpose, scenarios are developed that depict conflict situations in a simulation. Different scenarios will lead to completely different results. Therefore, to properly benchmark, it is important to first define the different types of representative scenarios. This section intends to define those parameters that define, model, or characterize the various representative scenarios. These representative scenarios are categorized based on the characteristics of the track infrastructure layout in which the benchmarking will be applied.

Track infrastructure layouts that might appear similar may, in fact, produce very different results when applying conflict detection and resolution algorithms, depending on the parameters that actually characterize the track layouts.

Once representative track layouts have been defined, based on characterizations in terms of predetermined parameters, it will be possible to decide which representative track layout may be optimal for certain specific applications/purposes. Below we have provided a preliminary list of parameters that must be part of any track layout characterization. The availability of data (in terms of frequency of update, persistence, accuracy, etc.) may affect the appropriate characterization of track layouts. In all cases, the baseline data (either infrastructure, rolling stock attributes and timetable) of the simulation model must always be exactly the same.

The list is as follows:

- Complexity of the network/area to be covered. Different levels can be defined based on characteristics such as:
  - Total number of routes
  - Incompatible routes
  - Most optimal routes (less run-time) ranking
  - Number of vehicles operating in the area
  - Number of junctions and types of junctions:
    1. Single Crossover
    2. Double Crossover
    3. Track Crossing
    4. Slip Switch

5. Lapped Turnouts

- Dimensions of the area to be covered. This includes the consideration of:
  - Distance travelled by each train
  - Percentage (%) of track usage.
- Type of railway application:
  - High Speed
  - Commuter
  - Main Line
  - Metro
  - Light Rail
- Time horizon (what is the future time horizon in which the algorithm will restrict the rescheduling)
- Stopping time at stations
- Transfer time
- Turn-around time
- Trains coupling/Decoupling time
- Headway
- Train(s) characteristics (e.g., maximum speed, deceleration, acceleration)
- Trains availability
- Drivers' availability
- Signalling System:
  - Fixed Block
  - Moving Block
- Grade of automation in the train network:
  - GoA 0 – Line of Sight Operations
  - GoA 1 – Non-Automated Train Operation
  - GoA 2 – Semi Automated Train Operation
  - GoA 3 – Driverless Train Operation (DTO)
  - GoA 4 – Unattended Train Operation (UTO)

9.2 Benchmarking Parameters

Once the scenario in which the algorithms are executed is well-defined for comparing the performance of the different algorithms, indicators for the benchmarking need to be defined.

The intention of the below list is to provide the reader with all indicators that are necessary for the benchmarking or at least may influence it, even if may not be measured in the ration.

After a preliminary analysis, the following parameters have been identified:

- Total number of detected conflicts
- Number of detected conflicts per type of conflict type (for a list of conflict types see the functional requirement chapter)

- Total number of resolved conflicts
- Number of resolved conflicts per type of conflict (for a list of conflict types see the functional requirement chapter)
- Number of actions taken to solve conflicts per type of action (for a list of all possible actions that the system should provide see the functional requirement chapter)
- In semi-automatic mode, number of recommendations accepted by dispatcher
- Conflict detection time
- Conflict resolution time
- Percentage of punctuality achieved (entrance-exit model)
- Number of affected trains:
  - Trains are delayed by more than X minutes (acceptable although disturbing)
  - Trains are delayed by more than Y minutes (non-acceptable)
- Passengers/ trains that can be moved (i.e., capacity) considering:
  - Priority Stations
  - Time of the day prioritization
- Trains' Power consumption
- Cost:
  - Staff
  - Kilometers travelled per train
  - Refunds for delays
  - etc.

9.3 Benchmarking Criteria

The definition of the benchmarking criteria depends in particular on the local conditions and individual networks. This is because the benchmarking criteria for the algorithm strongly depends on the application purpose, which differ locally. Even if it is the same algorithm, with possibly locally different configurations the prioritization of the different benchmarking criteria may differ. It may, in particular, be the case that for a certain application/purpose the best performing algorithm was not specifically developed for that application/purpose. For example, an algorithm may have been designed for use in medium-complex networks, but also operate well at terminal stations. For weighting and prioritization of the benchmarking criteria, it is recommended to take into consideration both the characteristics of the track layout and any pre-existing restrictions, as well as the application/purpose for which an algorithm has been designed. In other words, given a railway network, a set of trains, a set of passing/stopping times at each relevant point in the network, the position and speed of each train at time t0, find a set of non-dominated deadlock-free schedules such that each train enters the network at its release time, the given rolling stock constraints are respected, the constraints due to the enforced (passengers) transfer connections are respected, all potential train conflicts in the network are solved, no train departs from a relevant point before its minimum scheduled departure time, trains arrive at their relevant points with the smallest possible consecutive delay and the selected transfer connections return the highest possible connection value (Corman et al., 2010).

To provide a complete benchmarking for algorithms as applied to a fully parameterized (in the sense of Section 9.1) representative scenario, the algorithms should be applied (all taking the same input data) to the scenario and then their performance scored according to the parameters in Section 9.2. This information should then be clearly and completely communicated in a table.

10. Conclusions

The present document constitutes the deliverable of Task 17.1 "*Requirements Specification for Automated Decisions and Decision Support for Traffic Management optimisation*" of WP 17 in the ERJU FA1 (MOTIONAL).

The objective of this report is to provide a complete and coordinated list of requirements for demonstrators related to the technical capabilities that are to be developed under WP 17. These capabilities are addressing the technical enablers TE 16 "Automation of very short-term train control decisions" as well as TE 17 "Real-time conflict detection & resolution for main line and optimisation".

Within this context it was expected that this deliverable develops and defines a set of European standard requirements for traffic management optimization meant for decision support and, whenever possible, automated decision making. Additionally, the definition of benchmarking criteria as a basis for comparability of different algorithms is provided.

The technical basis for the formulation of the Europe- and industry-wide requirements specification delivered in this report was the systematic collection and subsequent analysis and consolidation of the demands of stakeholders (infrastructure managers, railway undertakings and suppliers). The creation of this report followed a classical requirement engineering framework: repeated sequences of iterative "information gathering" and writing stages were separated by review phases. For the execution of this workflow, the partners participating in the work package were split into three groups:

- **Author Group:** responsible for the creation of questionnaires for gathering technical information as well as opinions from stakeholders, followed by the analysis and consolidation of these responses into a standardized requirements specification.
- **Expert Group:** the main source of technical information with respect to the requirements. In particular, this group provided input into the requirements specification by completing the questionnaires developed by the Author Group.
- **Review Group:** examined the iterative versions of the requirements specification developed by the Author Group and, if necessary, inserted new perspectives.

We remark that there is a nontrivial intersection between the Author Group and the Expert Group, all members of the Author Group also being experts in fields relevant to the creation of this report. The Review Group was disjoint from both the Author Group and the Expert Group.

The current document contains the deliverable that was developed using the workflow described above: a consolidated and detailed specification of functional, non-functional, and operational requirements for the functionalities of real-time conflict identification, decision support, and automated/semi-automated conflict resolution with a view towards technical capabilities covering different aspects of decision support and decision automation on a demonstrator level. The specified requirements are allocated to the different technical enablers associated with WP 17 (TE 16 and TE 17). It is also indicated requirements apply only on the demonstrator level or also on a general level (the general level was only defined and described where needed to set the future

setting and environment).

The requirements that are delivered in this report should be taken as an applicable base for the planned implementation of demonstrators within this FA as well as a foundation of European standard requirements. Hence, we assume that the deliverable has achieved the goals set for Task 17.1 of WP 17.

We are aware that during the planning and implementation of the demonstrators for TE 16 and TE 17 (in later stages of WP 17) more discussions will have to be had concerning allowable cutbacks and limitations of these requirements within the demonstrator-scope. We also expect that with the implementation of demonstrators some of the requirements will have to be discussed on a more detailed level and resulting realizations/ feedback should be incorporated into the next version of this deliverable. To make sure this feedback cycle is observed, an according task (update of specification with learnings and insights from the demonstrator) must be planned in WP 18.

Taking the requirements delivered in this report as a base, our recommendation is to move into the demonstrator phase of WP 17 and 18 and to plan a feedback cycle with which to enhance the current deliverable with the expected realizations made during implementation. The resulting enriched list of requirements should be taken as input for the envisioned European Standard requirements.

11. References

Corman, F., D'Ariano, A., Pacciarelli, D., Pranzo, M. – Bi-objective conflict detection and resolution in railway traffic management – *Transportation Research Part C: Emerging Technologies*, 20 (1): 79-94, 2010.

12. Appendices

12.1 Requirement questionnaire first round

Category		Subject	Question
functional requirements			
	Role information and Stakeholders	Roles	What roles will work with the system?
		Responsibilities	What are the responsibilities of each of the roles? (Please use separate lines for different roles.)
		Interaction	What input to the system is required from the individual roles? (Please use separate lines for different roles)
		Notification recipients	Who should receive notifications?
		Stakeholders	What stakeholders should the system interface with?
	Decision	Decision taker	Who is responsible for taking the decision on which recommendation to execute (influencing running trains)?
		Varying decision taker	For what type of recommendations does the decision maker vary?
	Scope	Geographical Scope	Which part of the network must be covered?
		Train Network Scope	Which type of trains must the system cover?
		Conflicts	Which kind of conflicts are in scope?
		Number of conflicts	How many conflicts should the system be able to solve in a minute?
		Range Type	What unit would be suitable to measure the required range in which the system's solutions are conflict-free?
		Range	For how large regions should the system's solutions be conflict-free?
		Forecast	What type of forecast does the system provide?
		Forecast duration	How far in the future should conflicts be detectable?
		Notice time	recommendation and to resolve the conflict (e.g., is it sufficient to receive a conflict warning 2
		Calculation duration	How long may the system take to calculate solutions?
		Calculation cycles	How often and at what temporal intervals are solutions of the system calculated?
	Recommendations	Operational actions	What kind of conflict resolution actions is the system allowed to take?
		Number of recommendations	Should the system provide several solutions?
		Type of key performance indicators (KPIs) for prioritization	What type of key performance indicators key performance indicators (KPIs) should be used to rank the solutions?
		Prioritization of recommendations	Are the solutions to be ranked according to the above mentioned key performance indicators (KPIs)?
		Explainability of conflict detection	What information should be provided to explain a conflict detection?
		Explainability of recommendations	What information should be provided to explain the derivation of a recommendation?
	Technical requirements	Multi User Management	What is the number of users that can influence the train traffic at the same time?
		Input Systems	Which systems, with application programming interface (API), provide input to the traffic management system (TMS)?
		Output Systems	Which systems, with application programming interface (API), receive data from the traffic management system (TMS)?
		External data	What kind of external data should be included?
	User interaction	Graphical representation	What kind of information should be included in the graphical representation?
non-functional requirements			
	Regulations and security	Compliance	Are there any regulations the system need to comply with?
		Auditability	Does the system need to be audited when in operation?
	Operations	Availability	What influence does a system downtime have and what is an acceptable system downtime?
	Scalability	Integrability	Should the system be integrated into another system or is it stand alone? What kind of system should it be integrated into?
	Quality	Key performance indicators (KPIs)	Should any other key performance indicators (KPIs) than those for conflict detection and recommendations be considered and evaluated?
	System	Cross border operation	Is the system planned to operate across international borders?
		Cross border operation	Are there special requirements to the system when working across international borders?
		Number of conflicts	What is the maximum number of trains observed with the system?
operational requirements			
	Operational regulations	National / EU-wide Regulations	What national / EU-wide regulations apply to the system?
		Company regulations	What are operational regulations in your company that are derived from the above mentioned regulations applicable to the system?
		Automatization	What processes cannot be automated and where does a human need to decide / trigger an action?
	Other operational requirements	Other operational requirements	What are other operational requirements for the system?

12.2 Requirement questionnaire second round

Type	Category	Subject	Current Requirement	Question Background/ Reason for Question	Question	D/ FV
functional requirements						
	Role information and Stakeholders	Roles		One issue that we identified in the responses on the previous questionnaire is that there are no standardized terms for the various roles. In particular, we want to make sure that everyone means the same thing when they say "train dispatcher" and "regional dispatcher".	List the responsibilities of the "train dispatcher" and the "regional dispatcher". If these are not the same, please emphasize what the differences are in these two lists of responsibilities.	Both
		Roles	**Current roles and their description:** **Train dispatcher** and **Regional dispatcher**: Users of the system. Accept / reject recommendations. The train dispatcher and regional dispatcher differ in which decisions they have to make. (This is, e.g., specified to some degree in the questions labeled "Varying decision taker".) **Operational Management**: In charge of strategic decisions on how to operate the system (e.g., configuration of tolerances). **IT Organization**: Technical system owner. In charge of system maintenance and technical operations.	This is a general question asking if we have missed any integral roles in the current requirement. Another issue that came up on the first questionnaire is that we need to agree on the degree to which we refine operational roles (e.g., do we include the role "Conflict Agent" or "train dispatcher" and "regional dispatcher"?). The full list of suggested roles was: "train dispatcher", "regional dispatcher", "Operational Management", "IT Organization", "Operational Plan Manager", and "Conflict Agent". Below is a schematic in which all of the suggested roles are categorized and ordered with respect to refinement (e.g., "train dispatcher" is a refinement of "Conflict Agent"). The most "unrefined" version of a specific role has been underlined, and refinements are specified. **The requirements that have been taken into the catalogue are in Bold.** Conflict Agent: **train dispatcher**, **regional dispatcher** **Operational Management**: Operational Plan Manager	Are there any other roles that should be included? Please include the responsibilities of any new roles with respect to the system and also if they provide input to the system. Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response. (Current roles are: train dispatcher - User of system, accepts/ denies recommendations-, regional dispatcher -User of system, accepts/ denies recommendations-, Operational Management -in charge of strategic decisions-. and IT Is the degree of refinement of roles that we have chosen the appropriate one? (Please see the hierarchy of roles at the bottom of the "Question Background" column: In the current version of the requirements catalogue, we have chosen to refine "Conflict Agent" as "train dispatcher" and "regional dispatcher"; in contrast, we have chosen to forego the refinement "Operational Plan Manager" of "Operational Management".) Do you agree with these choices? Should further parties be added under, e.g., "Conflict Agent"? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Roles				Both
		Notification recipients	**FRQ_002** **Train dispatcher:** Should receive all conflict notifications. **Regional dispatcher**: Should receive all relevant conflict notifications for their region. **IT organization:** Should receive technical notifications (e.g., runtime errors, system errors, system overload, failed plausibility checks, etc.). **Conflict notifications should include** when/ where a conflict is projected to occur and what kind of conflict it is. Furthermore, the system should provide solutions ranked according to KPIs. **If the system is down** all three roles should be informed.	In the current requirement we require that "relevant" notifications are sent to the regional dispatchers. Here we are clarifying what is meant by "relevant".	Given your definition of regional dispatcher (as you defined it in your response to the first question above), should the regional dispatcher only receive conflict notifications for their and neighboring regions? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Notification recipients		The conflicts mentioned in the question were given as responses in the first questionnaire. It was unclear to us if these conflicts are within the scope of the system. E.g., signaling equipment failure might not be predictable at hand of train simulations.	Is it necessary to receive notifications of track-side equipment errors/ failures and rolling stock equipment errors/ failures? If yes, who should receive these notifications? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Notification recipients		In the current requirement, the only IT notifications received by the train dispatcher and regional dispatchers are system downtimes. Should they also be informed if, e.g., the system has failed a plausibility check? Or, e.g., if there has been a runtime error? The point of this question is to clarify.	Which IT notifications (e.g., hardware errors/ failures, software errors/ failures, and system overload) should be sent to which roles? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Stakeholders	**FRQ_003** The system should interface with the following stakeholders: Train control, Train operation, and Operational communication.	The additional stakeholders mentioned in this question were given as responses in the previous questionnaire. In the two questions to the right **we are distinguishing between** : 1) **The prototype system** (stakeholders listed here will be given a "Must" be interfaced with priority), and 2) A **integrated future version of the system** (stakeholders listed here will be given a "Nice to" be interfaced with priority).	Which of the following stakeholders *must* be interfaced with by a *prototype* system: Customer information systems, staffing, rolling stock management, emergency services, RU transport controller, signaler, dispatcher of adjacent network, vehicle monitoring systems, manager of yards and event logger? Please explain why these stakeholders should be interfaced with. For which of the following stakeholders *would it be nice* if a *future integrated version* of the system interfaced with them: Customer information systems, staffing, rolling stock management, emergency services, RU transport controller, signaler, dispatcher of adjacent network, vehicle monitoring systems, manager of yards, and event logger? Please explain why these stakeholders should be interfaced with.	Demonstrator
		Stakeholders				Final version
	Decision	Varying decision taker	**FRQ_004** **The system is flexible to varying decision-takers depending on** region and what kind of action is required by the decision (e.g., order change or re-routing of trains). **Train dispatchers may take decisions concerning** re-routing or early turnaround recommendations. **Regional train dispatchers may take decisions concerning** platform change or order change.	If the Railway Undertaking (RU) has accepted a system recommendation, how should the Infrastructure Management (IM) be informed? In particular, how automated should this communication process be?	For the purposes of decision-taking, are there requirements on the automation of the communication process between the Railway Undertaking (RU) and the Infrastructure Manager (IM)? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Varying decision taker		If a conflict is projected to occur in Region A and the "best" calculated solution requires a general re-routing and platform change in Region B, should the acceptance of a solution be a collaborative process involving the regional dispatchers in Regions A and B and the train dispatcher (3 total decision-takers)?	Should the selection of solutions be a collaborative process between the train dispatcher and regional dispatchers? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response. (Please see description of scenario in "Question Background".)	Both
		Varying decision taker		If a conflict is projected to occur in Region A and the highest ranked solution requires a general re-routing and platform change in Region B, what should the decision-flow be?	If the selection of a solution should be a collaborative process, is there a decision-making hierarchy? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response. (Please see description of scenario	Both
	Scope	Conflicts	**FRQ_008** **The system should detect the following conflicts**: Simultaneous track occupancy (line and platform), insufficient platform length, infrastructure restrictions are violated, closure of track sections/ stations, headway conflict or expiration of movement authority, specified transfer time between connecting trains is violated due to delay, and transfer time of rolling stock is exceeded.	These conflicts were suggested as responses in the previous questionnaire, but were not included because we were not entirely sure what is meant (there are multiple conflict types that these terms could be referring to).	Should "possession" and "isolation" conflicts be detected by the system? If yes, please specify what you mean by these conflicts. Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both

Typ	Category / Scope	Subject	Current Requirement	Question Background/ Reason for Question	Question	D/ FY
		Range Type		A recommendation may be conflict-free in Region A (spatial) for the next hour (temporal).	Should the range in which a solution is conflict-free be measured spatially or temporally or be measured in both ways; e.g., by parametrizing which measure should be used depending on the situation? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Range Type	**FRQ_012** The system should calculate solutions that are conflict-free within the geographic region and within the entire forecast duration.	This was suggested as a unit to measure the conflict-free range in the previous questionnaire.	Should we use Real/ Virtual TVD to measure the conflict-free range?	Both
		Range		If the system is unable to calculate a completely conflict-free solution within the allotted computational time, maybe one would instead then desire to calculate solutions that are only conflict-free within a certain spatial region and within a certain future time window (e.g., seek a solution that is conflict-free in Region A for the next 2 hours)? **Remark:** Both the region and time in which a solution should be conflict-free may depend heavily on the area in the network (busy or not, single or double track, etc.).	Are there situations in which the solutions calculated by the system do not have to be entirely conflict-free (i.e., conflict free in the whole network)? If yes, should the desired region and time of conflict-freeness be parameterizable? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Forecast duration		This question is included to further specify the current requirement.	Should the default value for the parameterizable forecast duration be the time required to travel the longest trainline, or should it be 60 minutes? Or, should both default settings be possible? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Forecast duration	**FRQ_010** **The forecast time is configurable** and **flexible to locality** within the system. **The default value of the forecast duration** should be the time required to travel the longest trainline in the regional railway network.	In this question our aim is to further clarify how the regional forecast duration is configured. In particular, configuring the regional notice time *might be* the responsibility of the regional manager: The default notice time might be coarsely set by the operational management (e.g., at 1 hour) and then further refined by the regional manager (e.g., at 15 minutes). It may be the case that the regional manager is only allowed to decrease the notice time set by the train dispatcher -if the regional manager would like to increase the notice time, then they would have to communicate with the train dispatcher. (Please give us your version of such a requirement as	Who should be responsible for the configuration of the regional notice time? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Forecast duration		We see the **system as having two particular uses: 1) Dispatching of current train traffic (short-term)**, and 2) **Planning of near-time future train traffic (long-term)**. This question aims to determine the time threshold at which we transition from 1) -> 2); i.e., where we use forecasted data instead of real-time data. An example answer may be, "A forecast duration of <15 minutes would be considered use 1) and anything >15 minutes would be considered use 2)." (Please give us your version of such	What is the threshold in terms of forecast duration at which the tool transitions from being used for the (almost) real-time detection / resolution of conflicts to being used for future train scheduling (operational planning)? (Please see "Question Background" for a more in-depth explanation of this question.)	Both
		Forecast duration		This is a continuation of the previous question. An example answer may be, "A reasonable forecast duration for planning is 3 days. The forecast duration used for planning the train schedule does not need to be regionally configured." (Please give us your version of such a requirement as the answer to this question.)	For a tool that should be used for the operational planning (i.e., using forecasted data), what would be a reasonable forecast duration? Should this also be regionally parameterizable? (If you are unsure what is meant here, please see "Question Background".)	Both
		Notice time		In this question we are referring to the situation in which one would like a shorter notice time because there is a very dynamic section of track, where the situation (and the conflicts) are changing	If the duration of the forecast is set at 3 hours, are there situations in which the system should wait until, e.g., 30 minutes before the conflict to send notifications? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement	Both
		Notice time		This question is included to further specify the current requirement.	Should default notice time be 10 minutes or immediately after detection? Or should both default settings be available? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Notice time		Consider the scenario in which a conflict is in Region A where the regional notice time is set to 5 minutes, but the "best" solution includes a re-routing which requires notice of at least 2 hours. What should the notice time be? (Should, e.g., the maximum of the two notice times be taken? In this case, 2 hours.)	How should the configurations of notice time with respect to "region" and "operations included in 'best' solution" (e.g., does the "best" solution involve a re-routing, an order change, etc.) interact? (Please see "Question Background" for scenario.)	Both
		Notice time	**FRQ_011** **The notice time is configurable** and **flexible to locality within the system and the types of actions that are required by solutions.** If no notice time is set, the **default notice time should be** 10 minutes or as soon as they are detected.	In this question our aim is to further clarify how the notice time is configured. An example answer may be, "The regional dispatcher of Region A would be able to manually set a notice time which applies in Region A". (Please give us your version of such a requirement as the answer to this question.)	Who is responsible for the configuration of the notice time with respect to "region"? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Notice time		In this question our aim is to further clarify how the notice time is configured. An example answer may be, "The train dispatcher would manually enter into the system that the notice time for a re-routing is, e.g., 2 hours. Configuring the notice time for an order change is the responsibility of the regional dispatcher.".	Who should be responsible for the configuration of the notice time with respect to "operations included in 'best' solution" (e.g., does the "best" solution involve a re-routing, an order change, etc.)? Does this depend on the particular operation (e.g., does a different person configure the notice time for an order change or a re-routing)? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your	Both
		Notice time		Recall that we distinguish between the **two uses of the system: 1) Dispatching of current train traffic using real-time data (short-term), and 2) Planning of future train operation using forecasted date (long-term)**. (**Note:** The previous questions regarding "Notice time" should have been answered for use 1).) This question aims to determine what the notice time of conflicts should be for the purposes of use 2), and if this notice time should be configurable.	For a long-term conflict detection/ resolution tool that is used for planning future train operations, what should be the default notice time for conflicts detected within the process of planning of the network. Should this notice time be regionally configurable? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Calculation duration		Recall that we distinguish between the **two uses of the system: 1) Dispatching of current train traffic using real-time data (short-term), and 2) Planning of future train operation using forecasted date (long-term**). We think that this distinction might be one reason for the large variation in responses to desired calculation duration in the first questionnaire. This question aims to clarify.	For a system used for conflict detection/ resolution at-hand of the real-time traffic situation (i.e., use 1 in question background)), should the calculation time be approximately 5 seconds or approximately a minute? What about for a system used for near-time train operation planning (i.e., use 2 in question background))? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Calculation duration		Another possible reason for the large variation in responses to "calculation duration" in the last questionnaire is that it may not have been clear what the system should compute. In particular, if the system has calculate the train simulations itself or if these are already calculated and simply taken as input. In the first scenario (train simulations calculated by system), the computational performance of the system would be lower (and the calculation time	For conflict detection / resolution should the system take existing train simulations as input or calculate these itself? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Calculation duration	**FRQ_013** The system shall not take more than 5 seconds to calculate solutions.	This question is a continuation of the question above.	Is there any other data (aside from train simulations) that the system takes as input? E.g., machine learning models. Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Calculation duration		We do not, e.g., want the system to get stuck in an infinite loop.	Is there a time threshold after which a calculation should be terminated (even if no solutions have been recommended)? If yes, what is that threshold? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your	Both
		Calculation duration		This question is a continuation of the question above.	If the calculation times-out, who should be notified and what should the notification look like? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both

Typ	Category	Subject	Current Requirement	Question Background/ Reason for Question	Question	D/ FV
	Scope	Calculation duration		While the above questions should have been answered for a system used for live train traffic control, there may be different requirements for a long-term conflict detection/ resolution tool that is used in the actual planning of the network. Since the solutions are much less urgent, a "long-term" tool used for planning of the network may have a longer allowable calculation duration.	For a long-term conflict detection/ resolution tool that is used in the actual planning of the network, what would be an acceptable calculation duration? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Calculation cycles		If, e.g., the forecast actualization occurs more often than conflict detection, this would save computational time. However, it might be desired that every time the system initiates a computational cycle (i.e., current situation -> conflict resolution -> updating of current situation), the full cycle is run through. In this case the calculation cycles of the different logical functions would be the same. In this question our aim is to clarify if different functions of the system should have different calculation cycles.	Should we distinguish between the different logical functions of the system (e.g., between: 1. Present current situation, 2. Actualize forecast, 3. Detect conflicts, 4. Present solutions, and 5. Process the chosen solution in the plan)? In particular, should the calculation cycles of these different logical functions be different? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Calculation cycles	**FRQ_014** Conflicts shall be detected, and solutions calculated with every new train report or after a configurable time interval.	If the computation time is 5 seconds and there are 3 new train reports per second, then the system would be calculating 15 different scenarios in parallel. This question aims to clarify if this is intended.	Should the system finish one detection/ resolution cycle before starting another? I.e., sequential/ queue handling or parallel handling. Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Calculation cycles		While the above questions should have been answered for a system used for live train traffic control, there may be different requirements for a long-term conflict detection/ resolution tool that is used in the actual planning of the network. For the a "long-term" tool used for planning of future train operations, possibly fewer calculation cycles would be acceptable.	For a long-term conflict detection/ resolution tool that is used in the actual planning of future train operations using forecasted data, what would be acceptable calculation cycles? Should this be locally configurable? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
	Recommendations	Operational actions	**FRQ_015** **The system should calculate solutions that include:** Re-routing, early turnarounds, order changes/ train priority changes, track and platform changes, travel time extension / reduction and adjusting operational speed, stopping time extension / reduction.	Our aim in this question is to make sure that the system has all the operations available to it in order to calculate conflict-free solutions.	Are there any other operational actions that may be included in solutions? If yes, and there is a difference between the operations required for a demonstrator vs. a final version, please indicate this and mark the new operations accordingly. (Currently have: Re-routing, early turnarounds, order changes/ train priority changes, track and platform changes, travel time extension / reduction and adjusting operational speed, stopping time extension / reduction.)	Both
		Operational actions		There are already technological developments underway, which would restrict the operations allowable in solutions provided by the system. E.g., if a train is running entirely on a battery, it may not be able to wait for 2 hours while situations in the rest of the network are resolved. Any requirements obtained from this question will be listed as "Nice to have", but not be compulsory.	Are there any foreseeable constraints that may in the future be placed on operations enacted by solutions? If yes, please describe why the constraints may arise. (Please see explanation in "Question Background" column. The requirements obtained from this question will be listed as "Nice to have" in the requirements catalogue.)	Final version
		KPIs for recommendation priorization	**FRQ_017** **The solutions calculated by the system should be ranked according to:** delay time, punctuality rate based on a configurable punctuality threshold, pre-defined cost function, passenger comfort, reduction of train impact on other trains and operational stability of the network, and percentage of conflicts with manual actions. **The influence of different key performance indicators (KPIs) on the ranking should be weighted** according to an individual configuration. These configurations can also include a weighting of the KPIs based on the train type and train locality.	This questions is to make sure that the ranking of the solutions contains all of the necessary information to optimize the railway network performance.	Are there any other key performance indicators (KPIs) that should be included? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response. (Currently have: delay time, punctuality rate based on a configurable punctuality threshold, pre-defined cost function, passenger comfort, reduction of train impact on other trains and operational stability of the network, and percentage of conflicts with manual actions.)	Both
		KPIs for recommendation priorization		This question contains a suggestion for a further KPI that may be used for the ranking of solutions.	If some of the multiple solutions calculated by the system cannot be entirely conflict-free, but are rather only conflict-free in a specific spatial and temporal region, should the degree of conflict-freeness be a KPI? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Data storage	**FRQ_019** **The following data should be archived for every conflict for at least 6 months:** Location, time, and type of the primary conflict; how the system itself was parameterized at the time of conflict detection and resolution; solutions that were calculated by the system; ranking of calculated solutions; selected solution; and effect of selected solution on the network.	Our aim here is to make sure that any data required in the future (e.g., for future certification purposes, or for an internal system review), is available.	Are there any other pieces of data that should be stored? If yes and there is a difference between the data that should be stored for a prototype vs. a future integrated system, please indicate this and mark the new data accordingly. (Currently have: Location, time, and type of the primary conflict; how the system itself was parameterized at the time of conflict detection and resolution; solutions that were calculated by the system; ranking of calculated solutions; selected solution; and effect of selected solution on the network.)	Both
	Technical requirements	Integration	**FRQ_020** **The solution needs to provide an input interface for:** Traffic Management System (timetable and actual times, train positions), signaling system, Radio Block Center, and Temporary Speed Restriction Manager. **The solution needs to provide an output interface for:** Traffic Management System, a possibly self-implemented dashboard for displaying conflicts and conflict resolutions, customer information systems, and crew management and rolling stock management systems **The accepted conflict resolutions should be directed to** the existing signaling system.	Our aim in this question is to further specify the current requirement.	What APIs need to be provided to interface with input and output systems? Are there any requirements on a final integrated system that could be dropped for a prototype version? (Current input systems: Traffic Management System -timetable and actual times, train positions-, signaling system, Radio Block Center, and Temporary Speed Restriction Manager. Current output systems: Traffic Management System, a possibly self-implemented dashboard for displaying conflicts and conflict resolutions, customer information systems, and crew management and rolling stock management systems.)	Both
	User interaction	Graphical representation		In this question our aim it to specify how a conflict should be indicated in the GUI (e.g., possibly via a mesh representation or time-distance diagram (ZWL)).	How should conflicts be represented in the GUI? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Graphical representation	**The future forecast, projected conflicts, and ranked solutions shall be displayed in a separate GUI.** These should be **represented in terms of a mesh representation.**	This question is included to further specify the current requirement.	What information about a conflict should be shown in the GUI? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Graphical representation		The aim of this question is to determine if solutions should be displayed in a visual way (e.g., via a mesh representation or time-distance diagram, ZWL) or possibly as a list of operations (e.g., the system tells the dispatcher: Train A performs route change, Train B changes platform, etc.).	How should solutions be represented in the GUI? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
		Graphical representation		This is a continuation of the previous question.	How should the ranking of solutions appear in the GUI? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
	User Experience	Ergonomics	-	Currently we have no requirements on user experience and ergonomics of the system. With these questions further requirements on this topic should be generated.	Should the operation of the tool be mainly via mouse or should the User also be able to make entries with a keyboard (e.g. use keyboard shortcuts)?	Demonstrator
		Ergonomics	-	Currently we have no requirements on user experience and ergonomics of the system. With these questions further requirements on this topic should be generated.	How should the User accept a recommended solution (e.g., double-click on it)?	Demonstrator
		Ergonomics	-	Currently we have no requirements on user experience and ergonomics of the system. With these questions further requirements on this topic should be generated.	When a conflict is detected, what information should be immediately displayed to the User? What information should be available for the User after further action to access (e.g., an additional "click")? Please keep in mind that too much information decreases the level of ergonomics and specify for a demonstrator and final version. Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both

User Experience	Usability	-	Currently we have no requirements on user experience and ergonomics of the system. With these questions further requirements on this topic should be generated.	Should the User be able to configure what and how the information is displayed, e.g. by hiding certain visualizations? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
	Usability	-	Currently we have no requirements on user experience and ergonomics of the system. With these questions further requirements on this topic should be generated.	Is there a point at which the system would give so many notifications that it becomes a hinderance in the daily operations, rather than a help? Can you quantify the amount of notifications for this? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
	Usability	-	Currently we have no requirements on user experience and ergonomics of the system. With these questions further requirements on this topic should be generated.	With respect to user interface (not algorithmic), are there reasons that a User might reject the tool? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
	Usability	-	Currently we have no requirements on user experience and ergonomics of the system. With these questions further requirements on this topic should be generated.	Do you have any specific further ideas on how to avoid information overload or attention fatigue for the User? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
x **non-functional requirements**					
Operations	Availability	**NFR_008, NFR_009, NFR_010** **The system has to achieve an availability > 99,995%** (ÖBB)/ 99,9% (others). Planned maintenance downtimes are not included. **The system should exist in a redundant architecture.** **In case of a downtime** (of the recommendation engine) no recommendations will be proposed to the dispatchers (manual mode) nor made operational (automatic mode) is possible. These procedures have to be implemented in the system & interfaces.	Our goal in this question is to further specify the current requirement.	In case of a system downtime, what are the requirements for a degraded mode? In particular, what functionalities should one be able to turn-off? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
Quality	KPIs for system benchmarks		The goal of this question is to introduce "quality of recommendations" as an indicator of the quality of the system and to determine how this should be measured. We want to make sure that the demonstrators are of a sufficient quality to proceed with the development of an integrated final system.	Should quality of recommendations be a KPI for comparison of recommendations? If yes, how should it be measured (e.g., by acceptance rate and/or effects like delay-minutes)?	Demonstrator
	KPIs for system benchmarks			Is there a certain minimal "quality of recommendations" (i.e., recommendation-trust-level of the engine)? If yes, what should happen if this threshold is not achieved?	Demonstrator
	KPIs for system benchmarks	**NFR_016, NFR_017, NFR_018, NFR_019** **The quality of the system shall be measured in terms of:** Quality of solutions, the calculation time from detection of a conflict to a solution proposal, and maintainability. *There is discussion required to solidify this requirement.* **Note:** It is important that a prototype system scores highly according to these KPIs to make it feasible that the prototype may be expanded to become an actual live system.	Our aim here is to determine if there is a certain "quality threshold" under which the system should, e.g., be taken down.		
	KPIs for system benchmarks		The goal of this question is to introduce "maintainability" of the system as an indicator of the quality of the system and to determine how this should be measured. We want to make sure that the demonstrators are of a sufficient quality to proceed with the development of an integrated final system.	Should the maintainability of the system be a KPI for system benchmarking? If yes, how should this be measured?	Demonstrator
	KPIs for system benchmarks		The goal of this question is to introduce "average time from existence of a conflict to detection" as an indicator of the quality of the system and to obtain feedback from the experts. We want to make sure that the demonstrators are of a sufficient quality to proceed with the development of an integrated final system.	Should the average time from existence of a conflict (root cause of conflict in train simulation) to detection of the conflict by the system be a KPI for system benchmarking?	Demonstrator
	KPIs for system benchmarks		The goal of this question is to introduce "average computational time required to provide three solution" as an indicator of the quality of the system and to obtain feedback from the experts. We want to make sure that the demonstrators are of a sufficient quality to proceed with the development of an integrated final system.	Should the average computational time required to provide three solutions (possibly some which are suboptimal) be a KPI for system benchmarking?	Demonstrator
System	Cross border operation	**NFR_001, NFR_002, NFR_003** **The system needs to enable cross border connected operation in the following way without being limited to a specific number of connected processes and systems:** Provide real-time operational information like state, handover-times, predictions, etc. ; offer a standards-based interface and data structure; and ensure harmonized (standardized) processes. **Any exchange of data and/or commands between different TMS must** use the already existing standards (TAF/TAP TSI) as well as upcoming defined and standardized structures and interfaces for this application (based on RailML	The aim in this question is to further specify the current requirement.	What is the maximal delay (in minutes) of an event from occurrence to showing up in the live data for cross-border exchange? Please make sure to differentiate between a demonstrator requirement vs. a final version requirement in your response.	Both
x **operational**					
Operational regulations	Automatization	-	The aim of this question is facilitate possible future semi-automatic or fully automatic use of the system.	Towards semi-automatic or fully-automatic service, how could "trust in the system" be built?	Final version
	ETCS	-	This requirement will ensure that the system is compatible with the ETCS level that is likely to be used when the demonstrator goes	In 5 years, what will approximately be the level of ETCS for which the system needs to be compatible with?	Demonstrator