RCA

Reference CCS Architecture

An initiative of the ERTMS users group and the EULYNX consortium

Solution Concept: MAP

Preliminary Issue

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1 Introduction

1.1 Release information

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1.3 Purpose of the document

“Plan Execution” (PE), “Advanced Protection System” (APS) and “Map Data Management” are core subsystems inside RCA which in turn are generating an architecture description (business and operational requirements, and interface specifications) to be used as a **standard reference tender specification** for enabling of further specification steps and specific implementations. All three together called “**A.P.M.**” in this document: “**A**dvanced trackside protection, **P**lan execution and **M**ap Data management (MAP)”.

This document contains the solution concept focused on the MAP part which covers the whole process (high-level) from the preparation until the activation of Map Data within the RCA architecture (see chapter 1.5 Scope).

In the first step the business targets defined in the A.P.M. business strategy and targets document [7] have been evaluated regarding which of them are applicable for MAP. Afterwards MAP specific business objectives have been derived from all relevant business targets and defined in the A.P.M. objectives document [8]

This document details each objective by describing the current problems, the proposed improvements, and the derived requirements. Based on the identified requirements the overall MAP conceptual approach is derived, which describes one possible solution as a high-level process including basic functions and involved RCA systems. All allocations are preliminary on conceptual level and the decisions will be challenged as part of the following formal development process.

It is to be noted, that the different stages of the overall MAP process *are analysed with different level of detail depending on the current focus of the RCA working groups*. While the engineering and validation of data is not in the focus yet, the publication of Map Data for the configuration of the trackside systems is already in development and being detailed (e.g. by the RCA System Capability SysC87). In addition, the publication of Map Data to the On-Board Systems is the initial focus of the Digital Map cluster, which already provided documents like the Digital Map Concept [3], System Definition [12] or several conceptual Evaluation Documents [2], [9].

This document is the overall umbrella over the MAP initiatives inside RCA with different states of development. Therefore, this document can be considered as an extension of the already existing Digital Map Concept [3], which has been published as common working base for the Digital Map Cluster.

1.4 Disclaimer

- Digital Map as cross-cutting topic requires coordination with RCA for Trackside CCS Domain, OCORA for On-Board CCS Domain and other Cross-Cutting Domains like Lineside CCS Assets, Traffic Management, Track Worker Safety, etc.
- This concept is based on the RCA candidate architecture and on derived assumptions regarding the functionalities and capabilities that are expected for the architectural target of RCA.
- In general, Digital Map does not define its own Subsystem(s), rather Digital Map functionalities will be allocated to several RCA subsystems. Therefore, Digital Map uses "DM Trackside" and "DM On-Board" as functional clusters (not systems) to describe the Digital Map functionalities.

Besides the target system RCA, the Digital Map context also considers the legacy architecture, which is based on the existing ERTMS/ETCS along with the introduced game changers of independent On-Board Vehicle Localisation component and Virtual Balise.

1.5 Scope

MAP is a cross cutting component in the RCA CCS architecture:

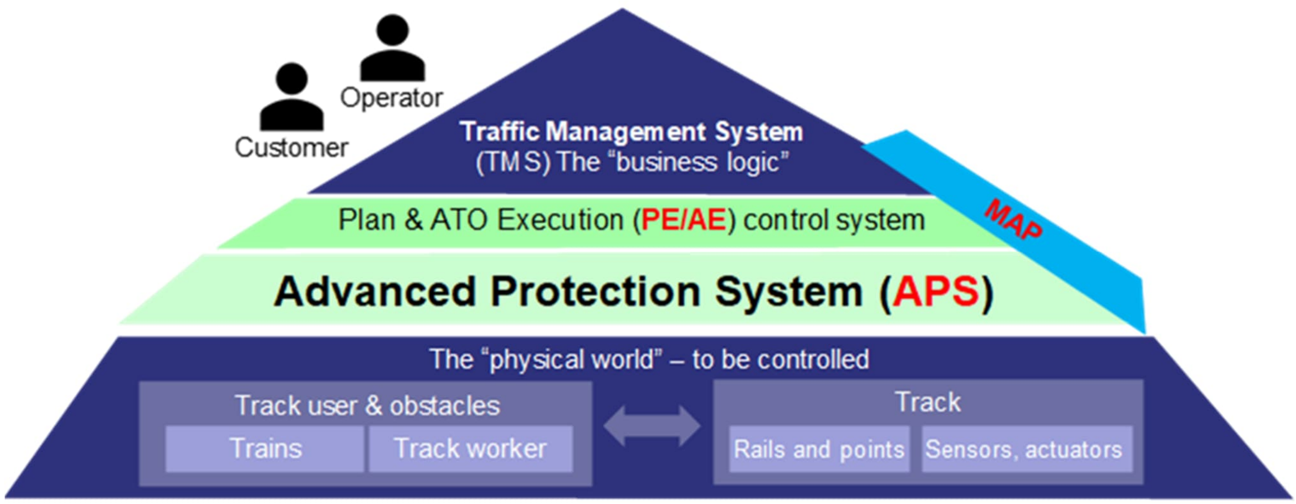

Figure 1 MAP in context of the railway production

The main goal of MAP is to provide reliable, validated topology and topography data, also referred to as Map Data, for all operational RCA subsystems, including safety-related components. Another important goal is to control the distribution of the Map Data from a single source to the trackside subsystems and the On-Board.

1.6 Use of This Document

The MAP concept documentation shall be used as a general description that helps to understand the basic intentions behind MAP. It will be used for communication and onboarding events, for discussions about product development strategies, or to describe the business expectations for feasibility studies or for the design of prototype projects and pilot lines.

Please consider the referenced documents for deeper understanding of the business targets and objectives referenced in this document. The leading “**@-symbol**” indicates an objective and the leading “**$-symbol**” tags a system requirement. Each @objective will be addressed with one or multiple system requirements, later referred to as $system requirement. All $system requirements are listed at the end of the document to give an overview of all MAP main requirements.

1.7 Target Group

The target group for this document are asset managers, product managers, system architects, designer of operational processes, system engineers and industry representatives.

1.8 Related Documents

The following documents provide related information:

[1] RCA System Definition [RCA.Doc.35] - published with BL0R2
[2] RCA Digital Map - Evaluation Publish Onboard Map Approaches [RCA.Doc.56] - published with BL0R3
[3] RCA Digital Map Concept [RCA.Doc.46] - published with BL0R2
[4] OCORA System Architecture, v1.05 [OCORA-TWS01-030]
[5] RCA Terms and Abstract Concepts [RCA.Doc.14] - published with BL0R4
[6] Realization of RCA Goals [RCA.Doc.48] - published with BL0R2
[7] 01 A.P.M. Business Targets and Strategy [RCA.Doc.50] - published with BL0R3
[8] 02 A.P.M. Objectives [RCA.Doc.53] - published with BL0R3
[9] RCA Digital Map Evaluation Reference Model [RCA.Doc.57] - published with BL0R3
[10] MAP Object Catalogue [RCA.Doc.69] – published with BL0R4
[11] RCA Capella Model (Architecture) - Capability SysC87 “Activate Map Data” - published with BL0R3
[12] RCA Digital Map System Definition [RCA.Doc.59] - published with BL0R4
[13] RCA Digital Map Preliminary Hazard Analysis [RCA.Doc.58] - published with BL0R4
[14] RCA Digital Map Business Case [RCA.Doc.55] - published with BL0R3
[15] RCA SMI Concept [RCA.Doc.74] – published with BL1R0

1.9 Terms and Abbreviations

For terms and definitions refer to the general glossary [5]. In addition, some specific terms for MAP are temporally introduced here as proposals (marked below). Please note, that the final definitions of the proposed terms will be in the overall glossary.

1. Digital Map / MAP - *from [5]:*

   Digital Map is a set of functions providing track and trackside infrastructure information in the form of structured Map Data, including quality criteria for the data. In addition, it also ensures map management functions like map versioning, download of Map Data.

   Extended Scope:

   Digital Map also ensures functions associated with the life cycle of the Map Data such as, generation, validation, compiling, and update of Map Data in the trackside and On-Board consuming systems.

2. Infrastructure Manager Data (IM Data) - *proposal*:

   Data from Infrastructure Manager (IM) specific digital sources required for engineering of RCA systems, such as:

   - Track layout (nominal geometry of the respective construction phase)
   - Objects (points, signals, train detection elements, etc.)
   - Properties (speeds, gradients, etc.)
   - Structures (platform, tunnel, etc.)
   - Logical data such as trackside train detection sections (if still available)

3. Acquisition Data - *proposal*:

   Acquisition Data follows the Engineering Data Structure and represents the part of Engineering Data that can be captured on the track for the purpose of comparison in the validation function.

4. Engineering Data - *from [5]:*

   The Engineering Data is created based on Infrastructure Manager Data (IM Data). Typically, the data are not adapted to cope with specific views demanded by each consumer. The Engineering Data contains all the base data (i.e. track topology and topography) for deriving the Map Data during the compile process. Besides providing base data for Map Data generation, the Engineering Data should also cover the needs for configuration of systems (e.g. parameter data). The Engineering Data must fulfil engineering rules, that are influenced by requirements of Map Data and they must meet the same quality attributes (e.g. correct formats, complete datasets) as the map data.

   Engineering Data contains only the updated resulting data (i.e. no several variants/versions of the same track) that is needed for the next provisioning and operation at a certain point of time in the consuming systems.

5. Map Data - *from [5]:*

   Map Data is provided to the consuming systems. During the operation, the Map Data is used to support system specific functions, e.g. for support with On-Board localisation, generating ETCS movement authorities or other specific use cases.

   The Map Data includes a build-up set of edges along with associated nodes (e.g. points, buffer stops), the relevant infrastructure characteristics (e.g. curve radius and gradients), and location information (e.g. specific reference points, balises). The Map Data remain unchanged during operation phase until the next provisioning of Map Data.

The so-called Map Data from the Digital Map is based on the existing MAP Object Catalog [RCA.Doc.69]

6. Configuration Data – *from [15]:*

   Configuration data is the data distributed between the RCA Subsystem Device and Configuration Management (DCM) and other RCA SubSys via SMI. Configuration data is split into two categories: Railway configuration data and System configuration data.

   - Railway Configuration Data
     - Map Data
     - Railway Specific Parameters
   - System Configuration Data
     - Software Data
     - Security Parameters
     - Communication Parameters

7. Safety-related Map Data *- from [3]:*

   Safety-related Map Data refers to the data which are utilised by system functions, which have a pre-defined safety classification i.e., from SIL1 up to SIL4. These data for SIL functions, when imprecise (out of tolerance) or incorrect might lead to a safety-related failure resp. feared event in the system.

   Note: the term "safety-related Map Data" is used to avoid the often used, but misleading term "SIL-data", since the data itself does not have any SIL according EN 50126-2:2017"

8. Reliable (Map) Data *- from [3]:*

   Reliable (Map) Data refers to a typical characteristic of data which satisfies the qualities of being trustworthy/lower probability of incorrect information/lower fault rate of the information, current (not obsolete), complete, and accurate.
   Reliable data is not only about *safety-related Map Data*, but also *non-safety-related* Map Data that still needs to fulfil certain criteria for a specific function of consumer/system.

9. On-Board Map (Data) – *proposal*:

   Part of the Map Data that is transmitted to the On-Board systems, i.e. for the purpose of localisation enhancement.

Note:
The relationship between the different data is shown in Figure 5 High-level process PREP in chapter 4.4.

2 MAP Objectives

2.1 MAP specific objectives

The following table identifies, groups, and lists all the MAP specific objectives, that have been defined and assigned to the various business targets in the A.P.M. objectives document [8].

Each objective is described in more detail in chapter 3.2 Requirement Analysis, a link to the relevant subchapter is available in the description column.

Table 1 Derived MAP objectives from business targets

ID	Objective	Category	Description
MO01	@Provide Map Data versions for testing without impact on operation	Life Cycle Management and Updateability	The Map Data shall be provided prepared and pre-loaded for testing purposes. This process shall not have an impact on the activated Map Data version during operation. See chapter 3.2.1 for this objective.
MO02	@Efficient PREP processes and tools with highest economical grade of automation	Standardisation, Automatisation and Integration	The data preparation process for the Map Data shall be automated as far as economically reasonable by a reliable toolchain. See chapter 3.2.2 for this objective.
MO03	@Efficient distribution of Map Data to On-Board Systems	Life Cycle Management and Updateability	In order to increase the potential benefit from reliable Map Data for the On-Board systems the data shall be provided to On-Board systems as well. See chapter 3.2.3 for this objective.
MO04	@Efficient distribution of Map Data to Trackside Systems	Life Cycle Management and Updateability	The Map Data shall be synchronised to all consuming trackside systems using an automated update process. See chapter 3.2.4 for this objective.
MO05	@Minimise engineering efforts	Standardisation, Automatisation and Integration	Reduce the engineering to the Map Data and minimise remaining configuration parameters and less engineering effort by increasing the generic/standardised operational rules. See chapter 3.2.5 for this objective.
MO06	@Flexible distribution of Map Data to On-Board systems for different railway	Standardisation, Automatisation and Integration	Allow update of On-Board Map Data for different situations in an optimal way. See chapter 3.2.6 for this objective.

ID	Objective	Category	Description
	operations (mainline, high-speed, regional, urban railways)		
MO07	@Define standard interface for Engineering Data according RCA specifics	Standardisation, Automatisation and Integration	Define standard interfaces to external engineering tools/processes for the Engineering Data to be implemented/used by the IM specific systems. See chapter 3.2.7 for this objective.
MO08	@Provide reliable Map Data reflecting the actual topology	Safety Strategy	The PREP toolchain must deliver reliable and trusted Map Data: updated, accurate, complete. Validation rules shall ensure, that the defined constraints are fulfilled for the input Engineering Data. See chapter 3.2.8 for this objective.
MO09	@Ensure security by design for all MAP systems and data flows according to RCA	Security Strategy	Follow the overall “security by design” guideline, i.e., authentication, traceability, identify/access management. See chapter 3.2.9 for this objective.
MO10	@Ensure modularity and adaptability for MAP systems and interfaces	Standardisation, Automatisation and Integration Life Cycle Management and Updateability Safety Strategy RAM Strategy	Dependency reduction between components in general from a functional and safety level point of view. See chapter 3.2.10 for this objective.
MO11	@Define standard interfaces for distribution of Map Data to Trackside and On-Board systems	Standardisation, Automatisation and Integration	Provide Map Data required for the consuming RCA subsystems according to their needs. See chapter 3.2.11 for this objective.
MO12	@Provide Map Data for enhanced localisation with reduced number of physical balises	Standardisation, Automatisation and Integration	The initial focus of MAP providing Map Data to the vehicles shall be the improvement of localisation by an On-Board Map. See chapter 3.2.12 for this objective.
MO13	@Frequently provide Map Data to ensure safety and high-cadence asset modification	Life Cycle Management and Updateability	Map Data shall be provided whenever it is required to immediate reflect changes in the topology or asset configuration. See chapter 3.2.13 for this objective.

ID	Objective	Category	Description
MO14	@Avoid the need for end-to-end-testing from APS to trackside assets	Safety Strategy	Decouple testing of subsystems and minimise end-to-end-testing by sufficient processes and system designs. See chapter 3.2.14 for this objective.
MO15	@Support localisation by On-Board Map in any operational mode	Life Cycle Management and Updateability	Independently provide Map Data via dedicated channels and do not rely on other systems such as ETCS or ATO for map provisioning. See chapter 3.2.15 for this objective.
MO16	@Allow partial Map Data update	Life Cycle Management and Updateability	In order to support incremental improvements or modifications, the update process for Map Data shall allow partial updates. See chapter 3.2.16 for this objective.
MO17	@Support interoperability for provisioning of On-Board Map Data	Standardisation, Automatisation and Integration	Support seamless cross-border traffic and avoid implementation variants, which increase the complexity in standardisation and cross-border map management. See chapter 3.2.17 for this objective.
MO18	@Support scalable and robust architecture	Migration Strategy Robustness	Provide scalable system architecture to be used in a modular way depending on local needs. See chapter 0 for this objective.
MO19	@Integrate legacy systems into On-Board Map Data publishing	Migration Strategy	Allow integration of On-Board Map in existing legacy architectures as well. See chapter 0 for this objective.
MO20	@Handle internal failures and degraded modes efficiently	Robustness, Standardisation, Automatisation and Integration	Detect and react to failures during data preparation and publishing to guarantee high availability and fast recovery. See chapter 0 for this objective.
MO21	@Provide diagnostic data about system behavior for monitoring	RAM Strategy	Collect RAMSS relevant diagnostic data about the system behavior and provide this data to external monitoring or diagnostic systems. See chapter 0 for this objective.

ID	Objective	Category	Description
MO22	@Integrate legacy systems into Trackside Map Data publishing	Migration Strategy	Potentially integrate existing trackside systems in Map Data distribution flow (generic standard interface). See chapter 0 for this objective.
MO23	@Harmonised GUI ensuring high usability	Usability	Provide state of the art usability for GUI operations (incl. comfort functions such SSO). See chapter 0 for this objective.

2.2 A.P.M. objectives

The following table lists all A.P.M. related objectives defined in the A.P.M. objectives document [8] and their allocation to one or more corresponding MAP specific objective:

Table 2 A.P.M. objectives and their allocation to MAP objectives

A.P.M. Objective	Category	MAP Objective
A.P.M.@ Accompanying standardisation to reduce system compatibility testing between On-Board and trackside	Life Cycle Management and Updateability, Standardisation, Automatisation and Integration	@MO01 @MO11
A.P.M.@All building blocks shall utilise an identical MAP data reference, provided by each MAP data version in order to prevent interpretation efforts	Standardisation, Automatisation and Integration	@MO11
A.P.M.@Allow different system layouts from decentralised to highly centralised safe computing with virtualisation and container technologies, n-modular redundancy, fast disaster recovery, multi-tenant and multi-company cloud structures	Migration Strategy Robustness	@MO18
A.P.M.@Allow integration of GUI for all APM systems, which allows a cross-system overview and quick change between operated systems	Usability	@MO23
A.P.M.@Allow large area of control segment sizes to reduce the amount of transitions to neighboring legacy systems in order reduce integration efforts	Life Cycle Management and Updateability Standardisation, Automatisation and Integration	@MO02 @MO04 @MO05
A.P.M.@Apply a generic safety approach in encapsulating smallest possible safety relevant functions in building blocks that allow a separate safety assurance	Safety Strategy	@MO10
A.P.M.@Architecture design reduces the functional and non-functional dependencies between the SubSys and thus reduces the functional and non-functional requirements (especially RAMS) for the individual SubSys.	RAM Strategy	@MO10
A.P.M.@Asset management must support the demand for high-cadence asset modification	Life Cycle Management and Updateability	@MO13 @MO16
A.P.M.@Avoid temporary investments (e.g. avoid temporary interfaces between old and new interlockings by	Standardisation, Automatisation and Integration	@MO02 @MO11

A.P.M. Objective	Category	MAP Objective
supporting technically the efficient and stable replacement of full lines by just relacing safety logic but not the OC)		
A.P.M.@Avoid unnecessary authorisation by building trusted clusters	Security Strategy	@MO09
A.P.M.@Build a modular system architecture that supports different lifecycles	Life Cycle Management and Updateability	@MO10
A.P.M.@Consider open interfaces to integrate as much formats as possible	Standardisation, Automatisation and Integration	@MO07
A.P.M.@Demonstrably successful best practices in software development for highly available systems should be applied	Robustness	@MO18
A.P.M.@Deployment of the system must be possible in various configurations but all of them need to fulfil basic requirements	Standardisation, Automatisation and Integration	@MO06 @MO10
A.P.M.@Design a modular system architecture with small as possible amount of safety relevant components	Safety Strategy	@MO10
A.P.M.@Enable changes, adaptations and extensions throughout the life cycle of the building blocks	Life Cycle Management and Updateability	@MO10
A.P.M.@Encapsulate minimal viable functionalities in building blocks to enable an individual configuration of the building blocks and simple interfaces	Standardisation, Automatisation and Integration	@MO10
A.P.M.@Ensure security by design for all SubSys and data flows according to RCA	Security Strategy	@MO09
A.P.M.@Ensure synchronised state between GUI of all APM systems	Usability	@MO23
A.P.M.@Exchangeability between building blocks must be present wherever non-overlapping technology lifecycle profiles are present	Life Cycle Management and Updateability	@MO10
A.P.M.@Handle internal failures and degraded modes efficiently	Robustness	@MO20

A.P.M. Objective	Category	MAP Objective
A.P.M.@Implement ATO GoA2 or GoA3-4	Standardisation, Automatisation and Integration	@MO02 @MO07 @MO11
A.P.M.@Integrate upwards compatibility by design	Standardisation, Automatisation and Integration	@MO10
A.P.M.@Malfunctioning of system components shall not lead to a shutdown of the system	Robustness	@MO20
A.P.M.@Overlapping technology lifecycle profiles must be respected by the system design	Life Cycle Management and Updateability	@MO10
A.P.M.@Provide data about system behaviour about RAMS and capacity usage to other systems	RAM Strategy	@MO21
A.P.M.@Provide scalable system architecture to be used in a modular way depending on local needs	Migration Strategy	@MO18
A.P.M.@Provide state of the art usability for GUI operations (incl. comfort functions such SSO)	Usability	@MO23
A.P.M.@Reduce complex and manually triggered or processed process and replace or reengineer with automated processes	Standardisation, Automatisation and Integration	@MO02 @MO05
A.P.M.@Reduce maintenance efforts by maximally reducing dependencies between building blocks	RAM Strategy	@MO10
A.P.M.@Reduce the number of individual systems, components, field elements sharing non-standardised interfaces	Migration Strategy Robustness	@MO18
A.P.M.@several modes for degraded operation ensuring a high-level of safety and a high-level of operational system must be implemented by design	Robustness	@MO20
A.P.M.@Standardise all main CCS processes, functionalities and interfaces	Standardisation, Automatisation and Integration	@MO02 @MO07 @MO11
A.P.M.@Support a broad applicability to different railways and in various types of traffic and operational processes	Standardisation, Automatisation and Integration	@MO06

A.P.M. Objective	Category	MAP Objective
A.P.M.@Support fast module replacement	Standardisation, Automatisation and Integration	@MO10
A.P.M.@Support of self/remote diagnostics	RAM Strategy	@MO21
A.P.M.@Support the integration with state-of-the-art identity and access management service	Security Strategy	@MO09
A.P.M.@The overall system should be as robust as possible against version changes and missing information	Robustness	@MO20
A.P.M.@Use interfaces with automatic adaptions and internal intelligence for interfacing different versions of building blocks without the need of upgrade existing building blocks based on change in interface	Standardisation, Automatisation and Integration	@MO20
A.P.M.@Use secure standard protocols	Security Strategy	@MO09
A.P.M.@Use standardised processes and systems	Standardisation, Automatisation and Integration	@MO02 @MO05 @MO07

2.3 Exclusions

To further refine the scope of MAP the following objectives are explicitly excluded from MAP:

Table 3 Exclusions for MAP

Exclusion	Rationale
Variants of same topological situation (e.g. for long-term planning)	• limit complexity • Variant for engineering should be decided before it is loaded into the systems, even for the long-term planning of TMS
Management and organisation of rollout/adaption projects	• National specific processes and responsibilities • Not standardisable or limited benefits from standardisation
IM specific approval of tool-supported processes, which are based on the RCA generic tools, processes and subsystems *Note: while the actual approval process is not part of RCA/MAP, the development of generic RCA tools, processes, subsystems shall deliver sufficient input for national-specific approvals*	• National specific processes and responsibilities

Exclusion	Rationale
Long term data persistency and management procedures	• National specific processes and responsibilities
Synchronisation of engineering from different trades	• National specific processes and responsibilities
(Master) Data Management for engineering and asset management	• National specific processes and responsibilities
Standardisation of Engineering tools	• National specific processes and responsibilities
Specific guidelines for creation of Engineering Data	• National specific processes and responsibilities • MAP considers generic rules only
Adaption and digitisation of planning and validation procedures	• National specific processes and responsibilities
Acquisition of infrastructure, such as topology and element data	• National specific processes and responsibilities • Not standardisable or limited benefits from standardisation • IM specific availability of digital infrastructure data with sufficient quality
Data Governance procedures	• National specific processes and responsibilities • Not standardisable or limited benefits from standardisation
Change Management for IM specific integration of tools, processes,…	• National specific processes and responsibilities
Integration of conventional trackside systems (e.g., RBC) into online data management	• While the Map Data can be shared with legacy systems according to MO22 (@Integrate legacy systems into Trackside Map Data publishing) the full integration into the Map Data flow is not planned. • Reason: today these process are covered by supplier specific processes, tools, interfaces, which should not be changed.

3 MAP Requirements

3.1 High-level MAP process

This chapter covers all the business objectives listed in Table 1 and describes the problems of today's situation, the proposed improvements to solve the mentioned problems and the resulting $system requirements for each @objective.

The requirements are bound to a specific phase of an overall high level MAP process, which is defined as shown in Figure 2.

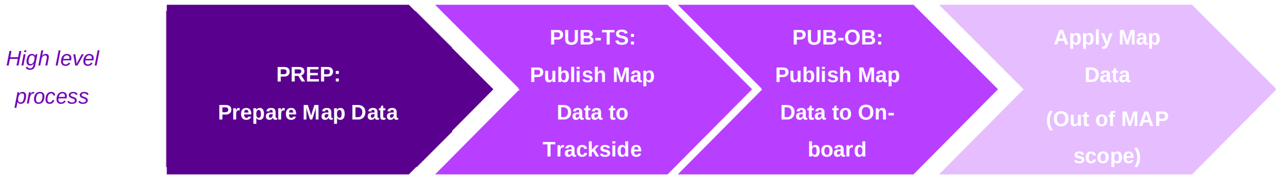

Figure 2 High level process of MAP

Based on the high-level MAP process the requirements of this chapter are allocated to the following hierarchy of tags:

- #**MAP**: all MAP related phases and systems are involved.
  - #**PREP**: Systems/functions for the engineering and generation of Map Data are involved, divided into:
    - #**PREP-1**: system functions for the first part of MAP PREP process (PREP1), which contains the actual creation and aggregation of Engineering Data, which serves as input for Map Data.
    - #**PREP-2:** system functions for the second part of MAP PREP process (PREP2), which contains the validation and compilation of Map Data into the data structures for the consuming systems.
  - #**PUB**. System functions for the distribution and activation of Map Data in the consuming systems,
    divided into:
    - #**PUB-TS**: system functions that are required to implement the publishing of Map Data to the trackside consumers
    - #**PUB-OB**: system functions that are required to implement the publishing of Map Data to the On-Board consumers (i.e., for the enhancement of localisation systems on the vehicle)

Some requirements cannot be solved within the scope of MAP and require the involvement of other trackside or On-Board actors. Hence, the following additional requirement tags are defined for the later export of requirements:

- #**TRACKSIDE** (e.g., APS, PE, …): all systems of the trackside domain, that consume Map Data
- #**ONBOARD** (e.g. systems that deal with vehicle locator functionaliy or vehicle supervisor functionaliy): all systems of the On-Board domain, that consume Map Data

3.2 Requirement Analysis

3.2.1 MO01 - @Provide Map Data versions for testing without impact on operation

3.2.1.1 Problem description

- Today the grade of automation supporting the change of CCS installations is low as safe integration test creates large efforts when changing assets
- Validation procedures typically are based on end-to-end-tests between centralised systems and de-centralised assets.
- There is no overall strategy for switching between operational configurations and the test of new configurations within the CCS domain.
- Remaining test or check activities, which needs to be done in the operating system, require a preview of the next Map Data version. The operation of the system should not be affected by test or check activities.

3.2.1.2 Improvement

- Be able to prepare, provide, manage/handle multiple versions (at least: active version & next version) for the Map Data and be able to distinguish between versions for test only and for operation.
- A pre-loading mechanism should be offered which allows the distribution of next Map Data update (hours, weeks, months) before it is put into operation. The operational subsystem functions are not aware of the loaded Map Data until its activation.
- Test/Check functions should be able to access this preloaded data, e.g., successful binding between Object Controller (OC) and Fixed Object Transactor (FOT).

3.2.1.3 Requirements

RQ-MO01-1 $The #PREP-1 shall be able to manage different versions of Map Data (incl. preliminary test/check versions) and ensure its maintainability and updatability.

RQ-MO01-2 $The #PREP-2 shall provide Map Data before it is put into operation for testing purposes.

RQ-MO01-3 $The #PUB-TS shall provide the next version of Map Data before it is required for operation.

RQ-MO01-4 $The #TRACKSIDE shall pre-load the data for testing/check activities.

RQ-MO01-5 $The #TRACKSIDE shall confirm the successfully accomplished Map Data distribution and loading process (incl. required checks and error management).

3.2.2 MO02 - @Efficient PREP processes and tools with highest economical grade of automation

3.2.2.1 Problem description

- Today CCS projects need several years of manual planning, design, detailed engineering, data preparation, configuration, and testing/validation.
- The skill requirements and the complexity are high (especially for ERTMS projects), i.e. because of complex optimisation challenges and safety rules.
- The technical possibility of larger control areas compared to conventional interlockings, or RBCs comes also with increased requirements for the data creation, validation, and management procedures. Otherwise, the complexity of projects with even larger control areas cannot be handled and is a barrier for the rollout processes (high project risks).
- Data transformation in consuming systems shall be avoided
- Time-consuming and repeated data entry in the current engineering process, due to different tools, media and paper-based information transfer

3.2.2.2 Improvement

- Automate the engineering by applying generic engineering and validation rules on the imported Engineering Data. This is the enabler for the rollout of new architectures with usually very limited human resources and even increased control areas (compared to today's implementations).
- The standardisation of trackside systems lead to generic engineering rules during system design. These rules are the base for automatisation of engineering and validation activities and for an efficient engineering process.
- The Map Data will be provided directly in the format as required by the consuming systems.
- Paper-driven processes will be replaced by digital toolchains as far as possible.
- *Note: As a side effect of the new architecture it is assumed, that the engineering efforts will be reduced due to the reduction of trackside assests and because of CCS functional and operational standardisation.*

3.2.2.3 Requirements

RQ-MO02-1 $The #PREP-1 shall create the design of the layout of still existing trackside CCS assets (like balises) from the physical track layout with the max. economical grade of automation.

RQ-MO02-2 $The #PREP-2 shall automate the validation of Map Data based on generic rules (structure, consistency, relations, ...).

RQ-MO02-3 $The #PREP-2 shall automate the compilation of Map Data to transform the Engineering Data into Map Data as required by the consuming systems, so additional data transformations by the consuming systems are avoided.

RQ-MO02-4 $The #PREP-1 shall not define engineering constraints which will lead to unnecessary restrictions in the Trackside and On-Board systems (e.g. location of segment borders).

RQ-MO02-5 $The #TRACKSIDE shall develop generic engineering rules during standardisation process, which allow an efficient automation of PREP processes (i.e. abstract concepts instead of supplier specific solutions). This includes cross-system compatible and consistent data structures for the configuration of the systems (Map Data).

RQ-MO02-6 $The #PREP-1 shall introduce a fully digitised Engineering- and Map-Data flow.

3.2.3 MO03 - @Efficient distribution of Map Data to On-Board Systems

3.2.3.1 Problem description

- The On-Board Systems today only have very limited access to safe Map Data (basically it's only the information which is contained in a Movement Authority).
- However, many On-Board applications (i.e. Localisation, Perception,…) would benefit from a MAP service, which allows additional Map Data to be transmitted independently of a Movement Authority.
- As the amount of Map Data increases with each On-Board application (e.g., ATO GoA4 with perception system) the bandwidth for data transmission between trackside and On-Board is limited (especially for existing systems and communication channels that transmit data between Trackside and On-Board).

3.2.3.2 Improvement

- Introduce a MAP service for On-Board systems, which is able to provide Map Data on a sepatate channel and indenpendant from the transmission of a Movement Authority.
- First On-Board consumer shall be the localisation system (as per ETCS-CR 1368), further potential On-Board customers will benefit from a scalable MAP service, i.e., the perception systems for ATO GoA4 operations or passenger information systems.
- Enhance transmission capabilities by using an additional or sufficiently capable channel between trackside and On-Board like FRMCS but also public radio as an additional channel.
- Provide maximum amount of efficiency by e.g. caching strategies, demand-based downloads etc.
- While the initial scope of this is the enhancement of localisation (map is used as a sensor) further use cases must be considered (e.g., ATO GoA4/Perception, Passenger Information Systems)

3.2.3.3 Requirements

RQ-MO03-1 $The #PUB-OB shall provide Map Data for localisation and future On-Board applications such as ATO/Perception.

RQ-MO03-2 $The #PUB-OB shall offer a dedicated or sufficiently capable channel for Map Data, which is able to transmit the required data volume.

RQ-MO03-3 $The #PUB-OB shall provide Map Data for each connected vehicle within its area of operation/control.

RQ-MO03-4 $The #PUB-OB shall maintain Map Data safety over the whole life cycle of the vehicle (e.g. shut down train, start of mission, national or international handover procedures between two areas of control, handling degraded modes like "connection lost between trackside and On-Board", …).

RQ-MO03-5 $The #PUB-OB shall minimise the transmitted data volume, i.e., avoid redundant transfers by safe cache, avoid downloading of Map Data areas that are not required during operation.

RQ-MO03-6 $The #PUB-OB shall be able to use public radio to transmit the Map Data until FRMCS will be available.

3.2.4 MO04 - @Efficient distribution of Map Data to Trackside Systems

3.2.4.1 Problem description

- Today, configuration data (here referred to as “Map Data”) as result of the engineering/preparation process is delivered via proprietary, supplier-specific processes, tools and interfaces.
- Each set of configuration data (TMS, Interlocking, ETCS, …) is delivered separately due to the lack of standards and an overall data management process.
- Overlapping information in the systems might lead to inconsistencies since there is no fully digitised process or tool chain available yet.
- New systems such as ATO even increase the amount of Map Data to be provided to the Trackside systems.
- Supporting incremental improvements will result in an increased update frequency of the Map Data.
- Engineering rules for the different systems are not harmonised, this leads to further inconsistencies which cannot be checked and detected by data preparation due to the lack of standardised interfaces

3.2.4.2 Improvement

- Accelerate Map Data distribution and reduce efforts by an overall trackside update process for Map Data.
- Avoid inconsistencies and minimise potentials for errors/faults by single source of Map Data and harmonised update process
- A new version of Map Data shall be activated if all consumers successfully loaded the data, also following an automated activation process.

3.2.4.3 Requirements

RQ-MO04-1 $The #PUB-TS shall introduce a fully digitised Map Data flow.

RQ-MO04-2 $The #PUB-TS shall offer the highest grade of automatisation for the distribution of Map Data.

RQ-MO04-3 $The #PUB-TS shall always have a single reliable source of Map Data as provided by #PREP.

RQ-MO04-4 $The #PUB-TS shall allow a distribution and activation of next Map Data version for all consuming systems.

RQ-MO04-5 $The #PUB-TS shall provide feedback loops for coordination and issue solving by external actors.

RQ-MO04-6 $The #PUB-TS shall have a minimal impact on operation (i.e., solve potential issues during pre-loading phase, decision for activation by TMS, ...).

3.2.5 MO05 - @Minimise engineering efforts

3.2.5.1 Problem description

- The sum of CCS life cycle cost (design and planning, construction investment, maintenance, operators technological fixed costs, technology driven skill assurance costs, system operations cost, etc.) correlates in first place to the number of physical trackside assets and in second place to the grade of process automation for planning, construction, maintenance, etc.
- The pure purchase price of single asset components is normally not a significant cost driver, but the overall effort to plan, check, install, wire up and test every component causes it to be very expensive overall.
- The obsolescence of legacy system requires increasing modernisation efforts, which contrast with very limited personal resources and too long project durations
- Today the interlockings are based on a mainly static configuration/functional behavior which has to be planned, engineered, checked, installed and tested in advance before it is put into operation. For each incremental change of configuration (regardless how small it might be) the complete procedure has to be executed again which is time-consuming and costly.
- Maximum instead of sufficient requirements regarding Map Data/Engineering Data leads to high costs and significant project delays. The rollout of new technologies/architectures takes too long.

3.2.5.2 Improvement

- Avoid static configurations but enable dynamic runtime functions within Trackside and On-Board systems.
- Reduce the engineering to the Map Data and minimise remaining configuration parameters.
- Less engineering effort by increasing the generic/standardised operational rules (reduce need of IM specific rules)
- Avoid physical trackside assets as much as reasonable possible
- Ensure economical and technical feasible engineering rules by overall impact analysis, which is based on the actual relation between provided Map Data and intended functionality and considers the RAMSS effects for each requirement
- The accuracy of the data should take into account the life cycle of the track maintenance works. The guarantee of the accuracy should not imply an excessive and costly track maintenance work (mainly during regular track maintenance works).

3.2.5.3 Requirements

RQ-MO05-1 $The #TRACKSIDE and #ONBOARD shall minimise the need for physical trackside assets.

RQ-MO05-2 $The #TRACKSIDE shall minimise the need for configuration data, which should basically consist of the Map Data and a very limited set of application specific parameter data (for this goal the interaction with On-Board must be considered as well).

RQ-MO05-3 $The #TRACKSIDE and #ONBOARD shall replace complex fixed configurations by dynamical functional capabilities as far as possible (find the best balance between complexity and required data).

RQ-MO05-4 $The #MAP and #TRACKSIDE and #ONBOARD shall consider technical feasibility as well as economic efficiency for the configuration of the systems during system design (e.g. avoid very restrictive accuracy requirements (e.g. <10cm) for position data due to higher costs and project durations). The decision process shall be supported by a continuous impact analysis, which directly links the parts and quality criteria of Map Data to the relevant functionality of the consuming systems (e.g. MAP quality framework).

RQ-MO05-5 $The #PREP-1 shall focus the engineering capabilities to only those assets and configuration parameters which remain as required input for #TRACKSIDE. This involves the generation of specific, abstract concepts which are required for the RCA safety logic.

RQ-MO05-6 $The #MAP and #TRACKSIDE and #ONBOARD should take into account the overall life cycle of the Map Data (including the maintenance phases) for defining the accuracy of the data. The guarantee of the accuracy should not imply an excessive and costly track maintenance work.

3.2.6 MO06 - @Flexible distribution of Map Data to On-Board systems for different railway operations (mainline, highspeed, regional, urban railways)

3.2.6.1 Problem description

- Different modes of railway operation require specific modes of data transmission for Map Data to the vehicles. This is not easy to implement with legacy systems.
    - Operations like urban railways benefit from preloading of complete networks of Map Data since the area of operation is very limited.
    - Operations like main line benefit from incremental downloads of Map Data along the actual route, since the area of operation can be long very flexible.

3.2.6.2 Improvement

Allow download of On-Board Map Data for different situations in an optimal way (e.g., preloading complete urban network vs. incremental loading on highspeed line).

3.2.6.3 Requirements

RQ-MO06-1 $The #PUB-OB shall allow complete or incremental provisioning methods – fitting to the needs of different network sizes (small regional networks up to whole countries).

3.2.7 MO07 - @Define standard interface for Engineering Data according RCA specifics

3.2.7.1 Problem description

- Today, the engineering process is usually highly regulated by the IMs resulting in the problem that no common engineering process or generic tool support currently exists.
- Also, the processes are very different between IMs regarding value-chain, apportionment, and synchronisation of trades (signaling, electrification, alignment, …) - so that the Engineering Data are generated at different times with different contents.
- The optimisation of engineering processes by digitised toolchains with high grade of automation still is an IM specific challenge. To overcome this problem, standards which define a common and IM & supplier independent Engineering Data interface are already in development and at least some IMs/suppliers intend to use this standardised interface (e.g., EULYNX PREP, railML) for the implementation of legacy systems (such as interlocking, ETCS, TMS...).

3.2.7.2 Improvement

- Define a standard interface for the Engineering Data, which contains the required information for generating Map Data of all consuming systems and allows the integration into IM or supplier specific tool chains or databases.
- Define the interface for Engineering Data based on standardised interfaces (e.g., EULYNX Data-Prep, railML) which are already used (or planned to be used) by existing systems/tools to reduce the overall integration effort.
- Take advantage of new architectures regarding generic engineering rules/principles and data to reduce the many variants of existing engineering processes to an abstracted, more harmonised engineering process.
- In contrast to legacy architectures, new architectures with highly standardised systems/interfaces and a set of generic functions and engineering rules/principles also offer an additional potential for harmonised engineering core processes.
- Support the configuration resp. parametrisation of the subsequent RCA subsystems in the engineering process (excluding software/firmware management and software/firmware version management)

3.2.7.3 Requirements

RQ-MO07-1 $The #PREP-1 shall define a structured, semantically consistent, and comprehensive Engineering Data model covering all the input information required for generating Map Data of the consuming systems.

RQ-MO07-2 $The #PREP-1 shall define an interface for the Engineering Data which will be used by the different IMs and vendors to import or process Engineering Data.

RQ-MO07-3 $The #PREP-1 shall re-use existing Engineering Data model standards (i.e. EULYNX PREP, railML) to ensure compatibility across vendor solutions or infrastructure managers and reduce integration efforts.

RQ-MO07-4 $The #PREP-1 shall allow the generalisation of IM/supplier specific engineering processes based on the standardisation and abstract concepts of the consuming systems (e.g. APS).

RQ-MO07-5 $The #PREP shall support the parametrisation of OCs and FOTs in the engineering process.

3.2.8 MO08 - @Provide reliable Map Data reflecting the actual topology

3.2.8.1 Problem description

- Errors in Map Data cause systematic effects for potentially safety-related functions of systems relying on this Map Data as essential part of their configuration.
- Therefore, the PREP toolchain must deliver reliable Map Data: updated, accurate, complete.
- Today the reliability of Engineering Data (or Map Data) is usually proven by manual processes or functional tests (e.g. test runs on the actual infrastructure). Both produce high efforts and limits the possibility for complete checks.

3.2.8.2 Improvement

- PREP should be the single source of Map Data which is distributed to all the consuming systems that rely on it.
- Avoid testing of topological/topographical Map Data (e.g., such as Movement Authority length vs. actual position of signal) by reliable (complete, updated and sufficiently accurate) input data for Map Data compilation.
- Based on generic engineering rules developed during standardisation of trackside systems a highly automated validation procedure should prove the correctness of Map Data.
- Besides rule checks, the comparison against Acquisition Data of the actual infrastructure could be implemented in a standardised way (scope of standardised to be defined).
- The validation must consider and integrate the results of external validation routines and procedures (e.g. validation of Static Speed Profile, which is the result of complex IM specific processes and can hardly be solved in standardised environment)
- The standardisation of PREP process and tools must deliver the base for safety acceptance/assessment (i.e., sufficient deliverables for tool validation/certification).

3.2.8.3 Requirements

RQ-MO08-1 $The #PREP must be the single reliable source of Map Data, which is distributed to all the consuming systems.

RQ-MO08-2 $The #PREP-2 must maintain the state of already validated (i.e. by external processes) parts of Engineering Data or Map Data.

RQ-MO08-3 $The #PREP-2 should ensure the consistency of the Map Data with the actual infrastructure situation (complete, accurate/correct, current) by automated comparison between Map/Engineering Data and Acquisition Data.

RQ-MO08-4 $The #PREP-2 must validate the Map Data against proving rules which are derived from the generic engineering rules of the consuming systems.

RQ-MO08-5 $The #PREP and #PUB-TS shall develop the deliveries for the acceptance of automated tools to minimise manual activities during data generation, validation, transformation/compiling, storing and further distribution.

RQ-MO08-6 $The #MAP shall ensure the integrity of Map Data over the whole data flow from the engineering up to the provision to the Trackside and On-Board systems.

RQ-MO08-7 $The #PREP shall maintain safety requirements of the data over the whole life cycle of the system engineering.

RQ-MO08-8 The #MAP shall apply a generic approach to ensure that data used by safety application are trusted.

3.2.9 MO09 - @Ensure security by design for all MAP systems and data flows according to RCA

3.2.9.1 Problem description

- The stepwise modernising of the rail system leads to a wider usage of IT-based parts in the system and together with the need of data exchange between the different components. Both require an appropriate mitigation strategy for assuring security.
- The implementation of relevant software (safety- and non-safety) on standard products and data transmission in complex networks requires a security philosophy to be state-of-the-art. This must be considered from the beginning of the design.
- In general, unintentional manipulations of Map Data must be excluded for the complete process and life cycle.
- integrating security aspects into legacy systems is a very complex task and can be hardyachieved.

3.2.9.2 Improvement

- An appropriate mitigation strategy for assuring security shall be applied based on the principles of TS 50701.
- Security is an integral part of the system design (“security by design”) and is relevant for all processing and transmission of Map Data.

3.2.9.3 Requirements

RQ-MO09-1 $The #MAP shall be implemented based on “security by design”.

RQ-MO09-2 $The #MAP shall implement multi-level security zones.

RQ-MO09-3 $The #MAP shall implement security monitoring functions.

RQ-MO09-4 $The #MAP shall use a central identity, access and key management.

RQ-MO09-5 $The #MAP shall ensure providing Map Data in a secure way to the consuming systems avoiding undetected / unintended manipulations.

3.2.10 MO10 - @Ensure modularity and adaptability for MAP systems and interfaces

3.2.10.1 Problem description

- New services like the orchestrated distribution of Map Data might lead to an increased dependency between the systems, which would harm the modularity of the overall architecture.
- The modification of the MAP systems/services might impact other systems though changes of the interfaces and/or functionalities.
- The Map Data generation or publish process might affect the grade of freedom for applying RCA as a modular system.
- *Note: the specific needs of the consuming subsystems regarding Map Data content must be still addressed.*

3.2.10.2 Improvement

- The MAP systems/services should be integrated as independent functional blocks with minimum number of dependencies to other systems, i.e., do not mix safe and non-safe functions and do not mix functional blocks with different purposes.
- The MAP systems/services should work for different configurations of RCA systems/consumers

3.2.10.3 Requirements

RQ-MO10-1 $The #MAP shall enable modularity of a single framework in order to facilitate migration strategies allowing different configurations, which can be independently created, modified, replaced or exchanged with other modules or between different systems (i.e., by minimum number of dependencies to other systems).

RQ-MO10-2 $The #MAP processes, tools, system functions and interfaces shall be extendable and scalable for future needs.

RQ-MO10-3 $The #MAP shall allow future updates of components and extensions of Map Data at low costs and in an independent way (by avoiding impact on other systems).

RQ-MO10-4 $The #MAP shall encapsulate minimum viable functions in suitable building blocks.

RQ-MO10-5 $The #MAP shall apply a generic safety approach by encapsulating smallest possible safety relevant functions in its own building blocks that allow a separate safety assurance (e.g. separate engineering and validation functions).

3.2.11 MO11 - @Define standard interfaces for distribution of Map Data to Trackside and On-Board systems

3.2.11.1 Problem description

- Different configuration/Map Data interfaces for different systems lead to the problem, that it will become harder to decouple the different types of life cycles between the consuming systems and the MAP systems. In addition, there will be a high integration effort.
- Without standard interfaces it is also not possible to reduce the dependencies between the different components and to react to technical obsolescence without changing the components instead of a simple exchange from the standard interface perspective.
- Today, for legacy systems each set of Engineering Data/Map Data (TMS, Interlocking, ETCS, ...) is distributed separately due to the lack of standards and an overall data management process.

3.2.11.2 Improvement

- Standardise interfaces for Map Data distribution (provisioning).
- Standardise the data model so that Trackside (and On-Board) consumers will use the same Map Data references

3.2.11.3 Requirements

RQ-MO11-1 $The #PREP-2 shall use standardised interfaces to PUB-TS.

RQ-MO11-2 $The #PUB-TS shall use standardised interfaces for Map Data provision and management.

RQ-MO11-3 $The #PUB-OB shall use standardised interfaces for Map Data update and management.

RQ-MO11-4 $The #MAP shall ensure that the characteristics/parameters/quality aspects are reusable irrespective of consuming systems.

RQ-MO11-5 $The #TRACKSIDE shall be based on the overall, common definition of Map Data (incl. domain knowledge for “topology”) to ensure that all building blocks use an identical Map Data reference and to avoid interpretation errors.

3.2.12 MO12 - @Provide Map Data for enhanced localisation with reduced number of physical balises

3.2.12.1 Problem description

- ETCS, ATO and further systems require a sufficiently performant localisation with an assured safety level.
- To achieve the sufficient level of localisation performance, many physical balises are required as reference points for odometry today. These physical balises cause high efforts spent over the whole life cycle (planning, mounting, validation, maintaining, ...).
- Localisation could take advantage of Map Matching approach, so the map is seen as a fault-free sensor. However, the safety-related Map Data available On-Board basically consists of Movement Authority data only and is very limited. Basically, it is one-dimensional graph with balises as nodes including some gradient (and other) information. While this data is sufficient for the supervision of ETCS, further use cases – such as improved localisation – require more data about track axis or trackside elements.

3.2.12.2 Improvement

- Provide Map Data (also referred to as “On-Board Map”) from trackside to On-Board, which describes the track axis and relevant elements (e.g. tunnels) with a sufficient level of detail and quality. The provided Map Data must be reliable (i.e. complete, accurate, up to date) and the integrity must be maintained.
- In addition, On-Board Map can support the further reduction of balises by concepts like virtual balise, hence, the physical balises could be at least partially replaced by virtual balises (if economically reasonable).
- Reduce the number of required ETCS balises by a significant factor by using precise On-Board localisation of trains

3.2.12.3 Requirements

RQ-MO12-1 $The #PUB-OB shall provide Map Data for improved localisation (map as sensor).

RQ-MO12-2 $The #PUB-OB shall provide Map Data for virtualisation of balises: To enable this function, the balise telegrams according to the engineering needs to be provided as part of Map Data including a virtual position of the balise.

RQ-MO12-3 $The #PUB-OB shall maintain the integrity of the Map Data provided to the vehicle (On-Board Map).

RQ-MO12-4 $The #PUB-TS shall provide the Map Data for On-Board applications (On-Board Map) to the trackside system responsible for PUB-OB process.

RQ-MO12-5 $The #PREP shall generate Map Data for On-Board applications (On-Board Map), such as localisation, which is reliable (i.e. complete, accurate, up to date).

3.2.13 MO13 - @Frequently provide Map Data to ensure safety and high-cadence asset modification

3.2.13.1 Problem description

- Modern signal controlled warning and (temporary) supervision systems, which avoid negative operational impacts around the construction area, partially require updated Engineering Data including temporary information of construction phases.
- The processes of today cannot deliver Engineering/Map Data with a sufficient frequency to support all the changes during construction phases or during rollouts of large segments.

3.2.13.2 Improvement

- Be able to manage and handle two versions of Map Data (active and next) for the topology and support fast switching between these two configurations.
- Be able to manage rollouts of large segments
- Map Data should consider changes of construction phases.
- The delivery of Map Data updates should be accelerated to follow the construction process and avoid unnecessary track closures or operational impacts.
- Quick Map Data updates for enabling the usage of securing systems instead of manual procedures (Map Data should be provided for warning systems (or local supervision systems)).

3.2.13.3 Requirements

RQ-MO13-1 $The #PREP shall support construction phases (versioning, process times, ...).

RQ-MO13-2 $The #PREP shall not be limited to a specific segment size or a maximum number of assets.

RQ-MO13-3 $The #PREP and #PUB-TS shall provide Map Data for all trackside interfaced systems (incl. warning systems).

RQ-MO13-4 $The #MAP shall allow quick data updates (short-term adjustments) considering temporary states of construction phases.

RQ-MO13-5 $The #PUB-TS shall be capable to process and provide the Map Data coming from PREP for the specific segment size (Area of Control).

3.2.14 MO14 - @Avoid the need for end-to-end-testing from APS to trackside assets

3.2.14.1 Problem description

- Today, there are still too many validation procedures that require end-to-end-tests between centralised systems and decentralised assets which cannot be automated through lab-tests.
- This coupled approach takes a lot of time, produces high efforts, and usually takes place at very late project phases (project risks) and impacts normal operation as no normal train movements are allowed during the tests.

3.2.14.2 Improvement

- Decouple testing procedures of OCs and assets from the centralised systems.
- Avoid end-to-end-testing from FOT to trackside assets by safe binding information in OC and FOT configuration:
  - Onsite tests for OC/Trackside Asset without need for APS/FOT
  - Ensure safety during first handshake procedure between APS/FOT with OC (without additional onsite testing).

3.2.14.3 Requirements

RQ-MO14-1 $The #PREP shall provide a stable and reliable ID-management for Map Data with cross-system consistency, i.e., in order to allow an efficient safe binding procedure between FOT and OCs.

RQ-MO14-2 $The #PREP shall provide Map Data with all information (protection data), that is required by Trackside to confirm the safe binding to OC/trackside assets.

RQ-MO14-3 $The #PUB-TS shall maintain the integrity of the Map Data.

RQ-MO14-4 $The #TRACKSIDE shall provide a binding function which confirms that the connected OC fits to the FOT configuration (part of provided Map Data) in a safe way.

3.2.15 MO15 - @Support localisation by On-Board Map in any operational mode

3.2.15.1 Problem description

- The existing reliable "Map Data" on the vehicle is the trackside transmitted Movement Authority (MA), which is not only very limited regarding information but also only available during specific ETCS modes like Full Supervision or On Sight.
- Due to the lack of trust-worthy position information the Start of Mission procedure usually requires movements in Staff Responsible mode until the first balise.

3.2.15.2 Improvement

- Independent from the ETCS communication channel, the On-Board system should be able to use On-Board Map Data.
- The Map Data provisioning should be also possible without the need for ATO, since this system is not necessarily available in any local or operational situation (and also not considered “safety-related”).
- The initial localisation in Start of Mission procedure shall be supported and accelerated by On-Board Map Data.

3.2.15.3 Requirements

RQ-MO15-1 $The #PUB-OB shall provide Map Data independent from the ETCS communication (with or without movement authority).

RQ-MO15-2 $The #PUB-OB shall ensure that relevant Map Data updates in the trackside systems are communicated to the vehicles.

RQ-MO15-3 $The #PUB-OB shall ensure that no vehicle operates with outdated Map Data.

RQ-MO15-4 $The #PUB-OB shall ensure that Map Data is not used if a potential change of Map Data could be missed (e.g. no connec-tion between trackside and On-Board).

RQ-MO15-5 $The #PUB-OB shall provide Map Data for the localisation during Start of Mission process.

RQ-MO15-6 $The #PUB-OB shall allow an operation which can use messages from other RCA systems (such as Journey Profile) as supporting trigger, but not necessarily rely on it.

3.2.16 MO16 - @Allow partial Map Data update

3.2.16.1 Problem description

- For the trackside systems of today, many kinds of changes lead to an unavailability of large areas and have an impact on areas that are larger than the update area itself. Therefore, the changes cause a lot of costs and has an impact on the operation.
- Incremental functional improvements are blocked by complex update procedure, i.e., if configuration data must be adapted accordingly.
- Local construction works with changed topology or element positions require update procedures, that might affect the operation in a larger area than just the area of construction of the concerned interlocking or RBC

3.2.16.2 Improvement

- To support incremental improvements or modifications the update process for Map Data shall allow partial updates, which reduces the impact to the changing area. This objective becomes even more important in case of growing Areas of Control.
- To minimise the impact, this improvement must be applied to all trackside systems.
- The systems must be supported by a sufficient Map Data update process (e.g., provide delta between active and next Map Data version, define sufficient anchor points to define "parts" that can be modified independently).

3.2.16.3 Requirements

RQ-MO16-1 $The #PREP shall provide a stable and reliable ID-management for Map Data, which ensures robustness for unmodified areas.

RQ-MO16-2 $The #PREP and #PUB-TS must provide information about the actual changes (diff), such as deletion, insertion, replacements of specific elements, edges or other parts of the Map Data.

RQ-MO16-3 $The #PREP must define sufficient anchor points to cut the Map Data into parts, that can be changed independently/autonomously. The definition of anchor points must consider the constraints of all trackside systems, that consume the Map Data as configuration.

RQ-MO16-4 $The #PREP and #PUB-TS must provide a versioning system, that is compatible with partial Map Data updates.

RQ-MO16-5 $The #TRACKSIDE shall provide the functionality of partial updates of configuration, also referred to as Map Data.

RQ-MO16-6 $The #PREP and #PUB-TS must provide a versioning system that shall ensure the management of the different versions in a safe way.

3.2.17 MO17 - @Support interoperability for provisioning of On-Board Map Data

3.2.17.1 Problem description

Local/national solutions to provide Map Data from trackside to On-Board systems won't work for international traffic and increase the LCC.

3.2.17.2 Improvement

- Ensure standardised development for On-Board Map Data provisioning.
  - Standard interface MAP Trackside System (i.e., MOT) ↔ MAP On-Board System (i.e. VL).
  - Standard On-Board interface, i.e. MAP On-Board System ↔ Vehicle On-Board System.
- Allow seamless cross-border traffic by robust handover procedure
- Avoid implementation variants, which increase the complexity in standardisation and cross-border map management.

3.2.17.3 Requirements

RQ-MO17-1 $The #PUB-OB shall rely on interfaces and functions that are part of standardisation (e.g., RCA/OCORA, System Pillar, EULYNX, ERTMS, TSI...) only.

RQ-MO17-2 $The #ONBOARD shall be based on standardised Map Data requirements regarding content, structure, accuracy, etc.

RQ-MO17-3 $The #PUB-OB shall support a seamless cross border traffic (between two IMs) by sufficiently robust handover procedures (e.g. overlapping control areas of trackside Map System).

RQ-MO17-4 $The #PUB-OB shall avoid any variants in standardisation which increase the complexity for map management and application during operation.

RQ-MO17-5 $The #PUB-TS shall provide a standardised interface to #PUB-OB.

3.2.18 MO18 - @Support scalable and robust architecture

3.2.18.1 Problem description

- Current CCS systems are usually built as a monolithic system with very limited possibilities to change the behavior or the system layout.
- If the system is not designed to support scalability, redundancy or high availability, a single failure might lead to an unavailability of the complete system.
- Subsequent changes to the architecture of a system to increase robustness are usually not possible or only possible with great effort.

3.2.18.2 Improvement

- Support different system layouts from decentralised to highly centralised.
- Provide scalable system architecture to be used in a modular way depending on local needs.
- Support virtualisation and container technologies.
- Support modular redundancy and fast disaster recovery.
- Enable a multi-tenant and multi-company usage.

3.2.18.3 Requirements

RQ-MO18-1 $The #PUB-TS shall support asynchronous loading and synchronous activation of Map Data Versions to support centralised as well as decentralised trackside system platforms solutions.

RQ-MO18-2 $The #MAP shall offer fast recovery times to avoid processual or operational delays.

RQ-MO18-3 $The #PREP shall ensure multi-tenant operation by defining different user groups and separating the data for each group.

RQ-MO18-4 $The #MAP shall support an automated and remote-controllable deployment concerning the MAP functionality.

3.2.19 MO19 - @Integrate legacy systems into On-Board Map Data publishing

3.2.19.1 Problem description

- The migration phase needs to handle mixed architectures consisting of legacy and new systems
- On-Board Map services should be possible to implement before the systems of RCA/System Pillar are rolled out, since the improvement of localisation by Map Data is a generic request also for the supervision of train movements by the ETCS implementations of today.

3.2.19.2 Improvement

- The service for distributing On-Board Map (Map Data for On-Board systems) data should be integrable into legacy architectures as well with minimal impact on existing CCS trackside and On-Board systems.

3.2.19.3 Requirements

RQ-MO19-1 $The #PUB-OB shall be integratable with legacy architectures (i.e., no other RCA systems should be essentially required except for MAP systems), which offers a wider range of application and different migration scenarios.

3.2.20 MO20 - @Handle internal failures and degraded modes efficiently

3.2.20.1 Problem description

- An error in one system or component that is not recognised or dealt with can lead to an unexpected failure in another system or component.
- Faulty data that is not detected or detected too late leads to feared events in subsequent systems.
- Errors often lead to a failure of a system or component and thus reduce availability or in the worst case have safety-critical impacts.

3.2.20.2 Improvement

- Errors occurring within MAP do not affect subsequent RCA systems.
- Validation of input and output data to detect data errors before they are processed in MAP and before they are transmitted to subsequent RCA subsystems
- Monitoring of data transmission and acknowledgement by the processing systems.
- Compensate missing capabilities by a reduced form of interaction.

3.2.20.3 Requirements

RQ-MO20-1 $The #PREP shall avoid publishing Map Data that is not successfully validated to exclude operational impacts and safety hazards.

RQ-MO20-2 $The #PUB-TS and #PUB-OB shall provide feedback regarding errors during Map Data distribution and activation.

RQ-MO20-3 $A failure in the #PUB-TS and #PUB-OB process shall not lead to operational degraded modes.

RQ-MO20-4 $The #ONBOARD shall allow the operation in a degraded situation even without available Map Data (e.g. with potentially reduced performance in localisation).

RQ-MO20-5 $The #ONBOARD shall report potential deviations between provided Map Data and data provided by sensors on the vehicle.

3.2.21 MO21 - @Provide diagnostic data about system behavior for monitoring

3.2.21.1 Problem description

- The status or availability of a system is difficult to assess without monitoring and diagnostic data.
- A change in the system's behavior can only be detected if the diagnostic data is not only provided at runtime but is also stored for a longer period of time for comparative analysis and reporting.
- Pure runtime monitoring allows an error to be determined after it occurs, but it does not allow it to be detected at an early stage.
- Legacy systems do not focus on monitoring yet and therefore are not able to provide diagnostic data.

3.2.21.2 Improvement

- Collect RAMSS relevant diagnostic data about the system behavior
- Provide the collected data to monitoring systems
- Support of self/remote diagnostics
- Enable a predictive maintenance to improve the availability of the system

3.2.21.3 Requirements

RQ-MO21-1 $The #MAP shall monitor the processing of its functions by collecting information about the processing states and results (based on the definition of RAMSS related parameters).

RQ-MO21-2 $The #MAP shall store the monitoring and diagnostic data for later reports and analysis.

RQ-MO21-3 $The #MAP shall provide the monitoring and diagnostic data over a defined monitoring and diagnostic interface.

3.2.22 MO22 - @Integrate legacy systems into Trackside Map Data publishing

3.2.22.1 Problem description

The RCA migration strategy to come from todays legay systems to the new target architecture will involve existing systems, which need to be integrated. And even in the target architecture, there still might be legacy neighbouring systems. These systems, such as a conventional RBC, require their own Map Data for configuration as well, though in a different, supplier specific and proprietary structure with different interfaces and which is not compatible to the Map Data.

3.2.22.2 Improvement

- Allow integration of legacy systems into the trackside Map Data management by generic Map Data interface.
- Suppliers of existing systems (such as RBC) can use the validated Map Data for transformation and configuration.

Note: The online integration of legacy systems into the complete Map Data update process is not taken into account due to non-standardised configuration interface.

3.2.22.3 Requirements

RQ-MO22-1 $The #PUB-TS shall be integratable with legacy architectures (i.e., no other RCA systems should be essentially required except for MAP systems), which offers a wider range of application and different migration scenarios.

3.2.23 MO23 - @Harmonised GUI ensuring high usability

3.2.23.1 Problem description

- If each system develops its own GUI, this usually results in different concepts, interfaces and operating philosophies that are not coordinated with each other.
- A later integration due to e.g. an integrated operational concept of separate and independent GUIs is hard to achieve if this was not foreseen at the development of the products before.
- Separate and independent GUIs cannot be used across functions and systems. An operational scenario, that affects several systems, for example, cannot be handled consistently.
- Without a central user and rights management system, users must log on to each GUI separately, which leads to a high administrative effort on the one hand and to reduced acceptance among users on the other.
- Separated GUI concepts and developments lead to high grade of fragmentation and redundant implementations, which is unacceptable especially in the context of safety-related operations

3.2.23.2 Improvement

- Design one GUI which covers all intendend systems and that supports various configurations
- Provide a state-of-the-art usability for GUI operations which includes comfort functions such as Single-Sign-On (SSO)
- Allow the integration of GUI for all A.P.M. systems, which enables a cross-system overview and a quick change between operated systems
- Ensure a synchronised state between the GUI of all A.P.M. systems

3.2.23.3 Requirements

RQ-MO23-1 $The #MAP shall support a cross-system GUI by offering a harmonised interface which can be integrated into a superordinated GUI (I.e. generic Workbench) .

RQ-MO23-2 $The #MAP shall support a cross-system Single-Sign-On (SSO).

RQ-MO23-3 $The #MAP should allow that they are operable or controllable from a superordinated GUI.

RQ-MO23-4 $The #MAP should be able to feedback their current status to enable system-wide synchronisation.

3.3 Conclusion and next steps

After the identification of the requirements for the different MAP phases or system groups the following activities are required:

- #PREP including #PREP-1 and #PREP-2 phases: develop MAP PREP detail concept, which sketches the overall data generation process and defines the scope of standardisation for this phase of Map Data. This concept can be found in chapter 4 Solution Concept MAP – PREP phase.
- #PUB-TS: develop MAP PUB-TS detail concept, which summarises the developed processes and concepts for the distribution, loading and activation of Map Data of the trackside consumers. This concept can be found in chapter 5 Solution Concept MAP – PUB-TS phase.
- #PUB-OB: develop MAP PUB-OB detail concept, which summarises and refers to the results of the RCA Digital Map cluster, which is focused on the Map Data provisioning to the On-Board systems. The overall solution concept incl. references to Digital Map cluster deliveries can be found in chapter 6 Solution Concept MAP – PUB-OB phase.
- #TRACKSIDE: the identified requirements must be exported to the design processes of the trackside related subsystems (e.g. APS and PE). The list of relevant requirements can be found in chapter 8.1 Exported requirements for Trackside.
- #ONBOARD: the identified requirements must be exported to the design processed of the On-Board related subsystems (e.g. OCORA). The list of relevant requirements can be found in chapter 8.2 Exported requirements for On-Board.

4 Solution Concept MAP – PREP phase

The chapter is based on the overarching MAP requirements analysed in chapter 3.2 and is valid for all business objectives assigned to the **PREP** phase. In general, the overall #PREP functionality is responsible for the engineering until the generation of Map Data, divided into:

A) **#PREP-1**: system functions for the first part of MAP PREP process (PREP1), which contains the actual creation and aggregation of Engineering Data, which serves as input for Map Data.

B) #**PREP-2:** system functions for the second part of MAP PREP process (PREP2), which contains the validation and compilation of Map Data into the data structures as required by the consuming systems.

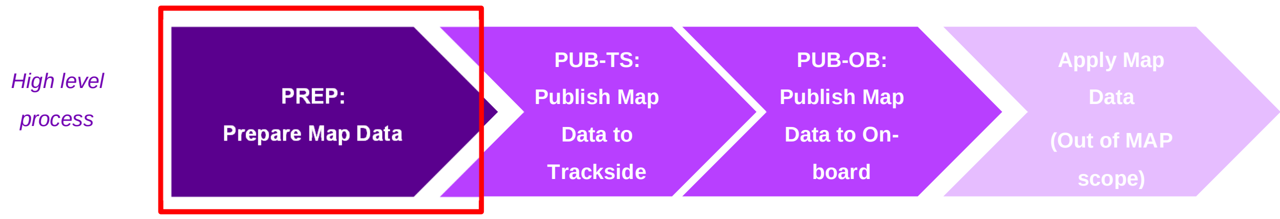

Figure 3 PREP in the high-level process of MAP

4.1 PREP References

The data model that is recommended to define the RCA data objects and attributes is evaluated in detail in the evaluation document RCA Digital Map Evaluation Reference Model [9].

A basic topology model for the track layout and for the positioning of objects in the track is defined in the Topology Domain of the RCA Terms and Abstract Concepts [5].

The MAP Object Catalogue [10] [10]defines and describes the Object Model that will be used by MAP cluster to provide reliable and validated topology and topography data in the form of Map Data for all operational RCA / OCORA subsystems and the Planning System.

4.2 PREP Terms

The following terms are used in this chapter:

- Infrastructure Manager Data (IM Data)
- Acquisition Data
- Engineering Data
- Map Data

For the definition of these terms, see chapter 1.9 Terms and Abbreviations.

4.3 PREP in the RCA context

PREP functions in the currently defined logical architecture of RCA are covered by the subsystems EDP and Topo4, located in the Generic Function Layer (marked with the solid red square).

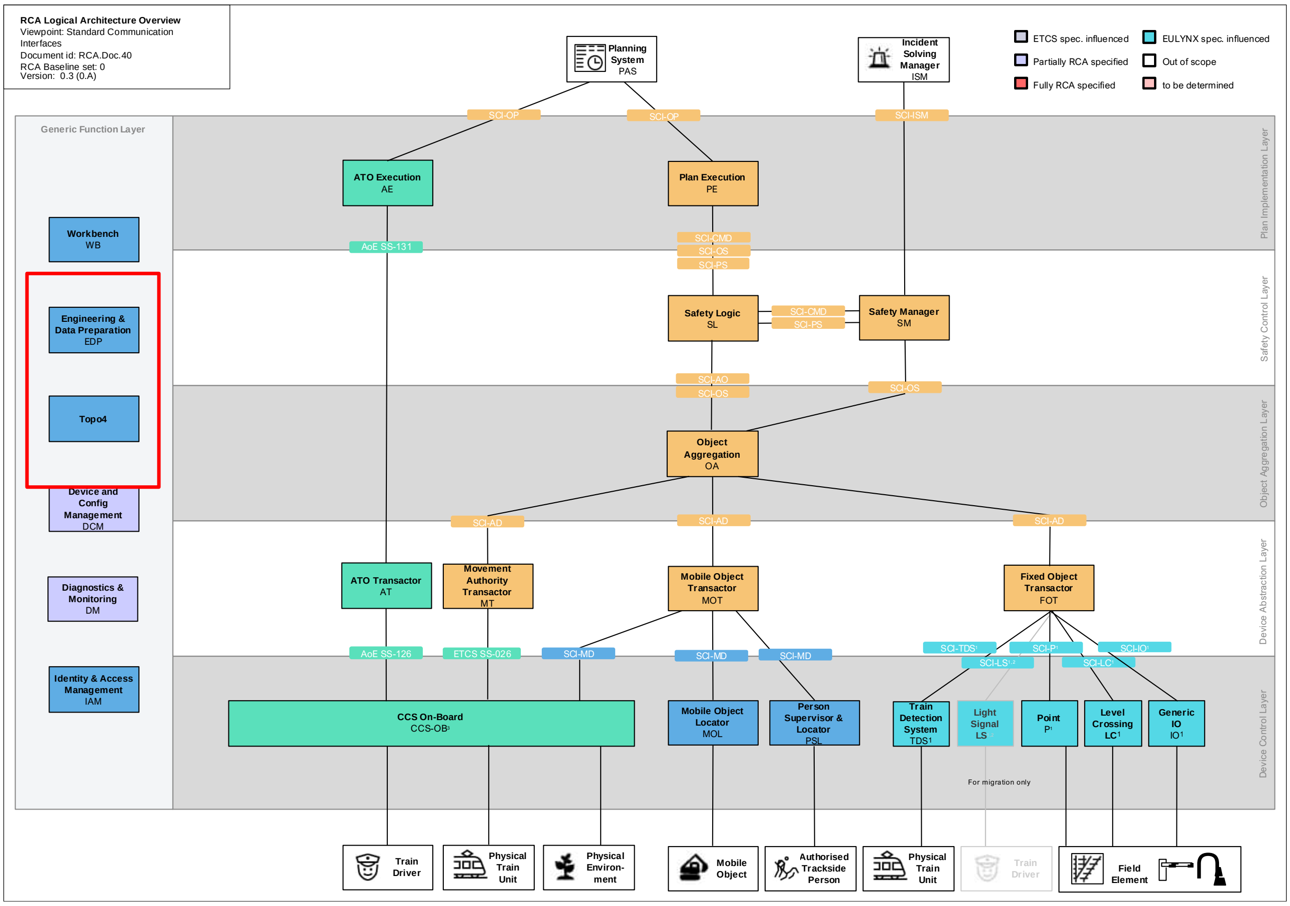

Figure 4 PREP in the RCA Logical Architecture

4.4 High-level PREP Process

The following illustration gives an overview of the definition of the high-level processes and how they are related to the PREP phases by MAP. In addition, the data flow during the phases is shown (data term see chapter 1.9).

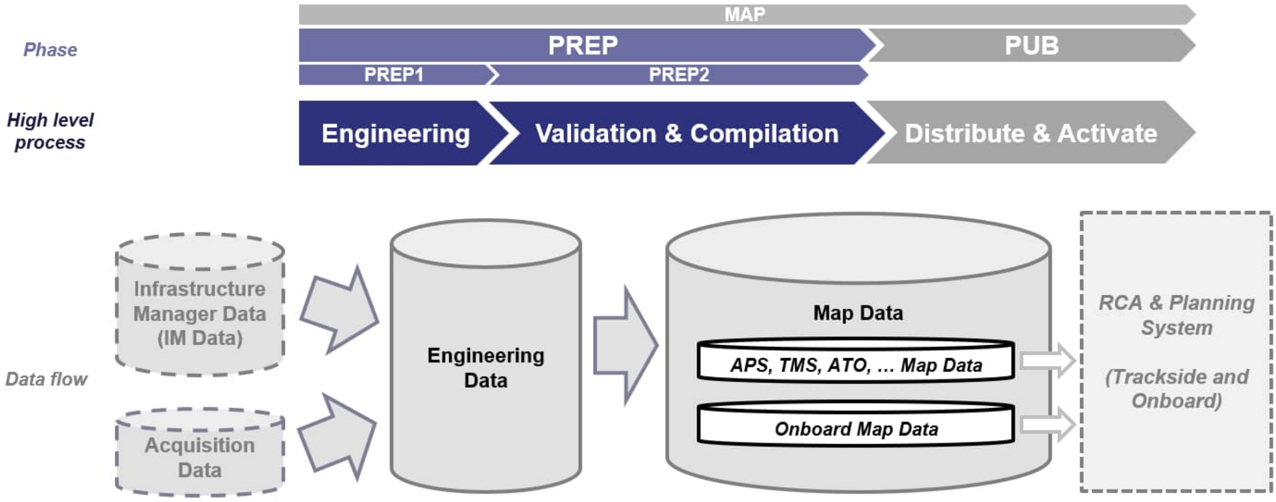

Figure 5 High-level process PREP

The two main PREP phases of Figure 5 (Engineering and Validation & Compilation) are roughly explained including the aimed scope of standardisation. The process is more detailed by the function definition of chapter 4.5.

4.4.1 Engineering (#PREP1)

The Engineering Data is created based on Infrastructure Manager Data (IM Data). The engineering follows an Engineering Process and Guideline, which is based (amongst others) on the generic design rules for Map Data. The design rules for map data are on the one hand generic rules specified by MAP (e.g. the representation of the topology) and on the other hand rules derived from the requirements of the RCA (and OCORA) subsystems, the required data objects/elements and their attributes, the required accuracy of element positions, generic consistency rules, minimum or maximum distances between objects (in general the required level of trust). According to the goal of RCA, to define a generic system architecture to overcome the national specifics of todays (legacy) systems, the design rules should not be specific to the IMs as much as possible. Any specific items in order to consider national and specific operative environments should be configurable data which is part of the design rules (e.g. national safety rules and pattern, parameter of trak assets).

A general standardisation of the overall engineering process seems to be not feasible, only a standardised Engineering Data interface including inherited constraints, rules, etc. of Engineering Data. This still can provide the basis for a shared core of an engineering tool, that works across several IMs at least for the generic part.

A standardisation for an acquisition process is also not recommended, to enable IMs to reuse their existing tools and methods or own development strategies to solve the problem of acquiring updated infrastructure data (including potential outsourcing of the task). However, the interface of “Engineering Data” could be used to standardise the expected input of acquisitions to compare it against data from the engineering.

4.4.2 Validation & Compilation (#PREP2)

The imported infrastructure manager data, which originates from the IM-specific inventories, is compared on the one hand against acquisition data (a subset of the engineering data, also imported from the IM-specific inventories) and on the other hand validated against a defined set of engineering and validation rules. Potential issues could be detected and the feedback of the comparison and the validation is returned to the IM specific system. In case of successful validation, the Engineering Data is compiled to Map Data. The Map Data is then ready for the distribution to the RCA and Planning System for both trackside and On-Board components.

The standardisation of the validation process is recommended since the qualification of data in a very efficient way is a cross-IM challenge. Especially the formal proving of Engineering Data against engineering rules is considered for standardisation, while the comparison of Acquisition Data and Engineering Data is considered optional for standardisation. Therefore, the comparision function can be skipped for IM's that already have an established process for the data acquisiton, so they can themselves provide the Engineering Data that are consistent with the outside world in terms of completeness. In this case, the Acquisition Data is also not required.

The standardisation of the compilation process is highly recommended since this step is a new aspect of IM process chain and must be done in the same way for each IM applying the RCA.

4.5 Functions

The following chapter defines the functions that must be realised by the PREP related subsystems to enable the sketched process for engineering, validating and compiling Map Data. For each function there is a link to the requirements which will be fulfilled and a link to the specific high-level process as shown in Figure 5 High-level process PREP.

4.5.1 Import and aggregate Infrastructure Manager Data

High-level process: Engineering

4.5.1.1 Allocated requirements

Based on the list of all requirements allocated to PREP the following requirements are identified as relevant in this functional context:

Table 4 Allocated requirements for import of infrastructure manager data

ID	Requirement
RQ-MO02-6	$The #PREP-1 shall introduce a fully digitised Engineering- and Map-Data flow.
RQ-MO07-1	$The #PREP-1 shall define a structured, semantically consistent, and comprehensive Engineering Data model covering all the input information required for generating Map Data of the consuming systems.
RQ-MO07-2	$The #PREP-1 shall define an interface for the Engineering Data which will be used by the different IMs and vendors to import or process Engineering Data.
RQ-MO07-3	$The #PREP-1 shall re-use existing Engineering Data model standards (i.e. EULYNX PREP, railML) to ensure compatibility across vendor solutions or infrastructure managers and reduce integration efforts.
RQ-MO07-4	$The #PREP-1 shall allow the generalisation of IM/supplier specific engineering processes based on the standardisation and abstract concepts of the consuming systems (e.g. APS).
RQ-MO13-2	$The #PREP shall not be limited to a specific segment size or a maximum number of assets.

ID	Requirement
RQ-MO02-6	$The #PREP-1 shall introduce a fully digitised Engineering- and Map-Data flow.
RQ-MO18-3	$The #PREP shall ensure multi-tenant operation by defining different user groups and separating the data for each group.

4.5.1.2 Conceptual approach

Import of the Infrastructure Manager data from digital sources (the sources are IM specific inventories/databases, that are assumed to be machine-readable), e.g.

- Track layout (nominal geometry of the respective construction phase)
- Objects (points, signals, trackside train detection elements, etc.)
- Properties (speeds, gradients, etc.)
- Civil work structures (platform, tunnel, etc.)
- Logical data such as train detection sections (if still available)

The area for which the Infrastructure Manager Data has to be imported should be configurable (specific locations up to big areas)

In general, a complex GUI for the manual aggregation of topology data is not foreseen in the standardised tool environment. Required data from non-digital sources like signaling plans or plans of other trades are considered to be digitised and aggregated to the Infrastructure Manager Data in the IM repository before the import. However basic adjustments and data modifications shall be possible.

The Infrastructure Manager Data should contain the information, whether it's validated or non-validated data. In case of non-validated data, the import of the acquisition data is mandatory in order to be able to validate the imported Engineering Data by comparing it to the acquisition data.

As of the provision of the engineering data, control mechanisms for integrity protection must be provided. Propose an acceptable set of measures that can even be used be the IMs to sufficiently mitigate the risk of manipulation beginning with the import of the Engineering Data.

4.5.2 Manage construction phases and data versions

High-level process: Engineering

4.5.2.1 Allocated requirements

Based on the list of all requirements allocated to PREP the following requirements are identified as relevant in this functional context:

Table 5 Allocated requirements for Manage construction phases

ID	Requirement
RQ-MO01-1	$The #PREP-1 shall be able to manage different versions of Map Data (incl. preliminary test/check versions) and ensure its maintainability and updatability.
RQ-MO13-1	$The #PREP shall support construction phases (versioning, process times, …).
RQ-MO16-1	$The #PREP shall provide a stable and reliable ID-management for Map Data, which ensures robustness for unmodified areas.

RQ-MO16-4	$The #PREP and #PUB-TS must provide a versioning system, that is compatible with partial Map Data updates.
RQ-MO16-6	$The #PREP and #PUB-TS must provide a versioning system that shall ensure the management of the different versions in a safe way.
RQ-MO13-4	$The #MAP shall allow quick data updates (short-term adjustments) considering temporary states of construction phases.

4.5.2.2 Conceptual approach

The consumers that rely on Map Data need a trustworthy representation of the actual topology. Thus, temporary construction states (e.g., a transitional construction phase) and construction objects (e.g., a construction turnout) are also relevant for the Map Data to be distributed to the recipient systems. The provisional construction responsibilities/elements are usually handled as part of a (large-scale) project.

The basis for safe operation is that it shall be guaranteed without uncertainty that the topology known to the subsystems and used by them to control the railway traffic always corresponds to the real topology outside.

Since PREP is the source of the topology data for the consumers, it must therefore be ensured that they work with the same data that was engineered and validated in PREP. At the same time, it must also be always comprehensible, which data status is currently valid and being used in operation. In the event of changes to the topology due to an adaptation of the project planning, the differences between the version currently in operation and the new version must be clearly recognisable.

In order to be able to guarantee this required traceability, the Map Data (with its objects and attributes) shall be versioned and a suitable numbering scheme shall be used to make it possible to identify the type of change, e.g. whether it is a new project, a modification or a bug fix. In addition to the versioning at object level, the Map Data, that will be provided due a change has to be packaged as a release. One release combines all affected objects compared to the previous release. A release is identified by a release version number and it has to be distributed to all subsystems, that consume Map Data to ensure, that every subsystem uses the same Map Data release.

When providing the data to a consumer, in addition to the version number, it must also be marked per element whether it has changed, newly created or deleted, i.e. it must be recognisable for the consumer whether an object / object version has been new, changed or deleted since the last import.

Additionally, the version information needs an attribute to state whether the version is released for testing only or also for operation.

4.5.3 Rule-based (automated) data engineering

High-level process: Engineering

4.5.3.1 Allocated requirements

Based on the list of all requirements allocated to PREP the following requirements are identified as relevant in this functional context:

Table 6 Allocated requirements for Rule-based (automated) data engineering

ID	Requirement
RQ-MO02-1	$The #PREP-1 shall create the design of the layout of still existing trackside CCS assets (like balises) from the physical track layout with the max. economical grade of automation.

RQ-MO02-4	$The #PREP-1 shall not define engineering constraints which will lead to unnecessary restrictions in the Trackside and On-Board systems (e.g. location of segment borders).
RQ-MO02-6	$The #PREP-1 shall introduce a fully digitised Engineering- and Map-Data flow.
RQ-MO05-5	$The #PREP-1 shall focus the engineering capabilities to only those assets and configuration parameters which remain as required input for TRACKSIDE. This involves the generation of specific, abstract concepts which are required for the RCA safety logic.
RQ-MO05-6	$The #MAP and #TRACKSIDE and #ONBOARD should take into account the overall life cycle of the Map Data (including the maintenance phases) for defining the accuracy of the data. The guarantee of the accuracy should not imply an excessive and costly track maintenance work.
RQ-MO07-5	$The #PREP shall support the parametrisation of OCs and FOTs in the engineering process.
RQ-MO08-6	$The #MAP shall ensure the integrity of Map Data over the whole data flow from the engineering up to the provision to the Trackside and On-Board systems.
RQ-MO08-7	$The #PREP shall maintain safety requirements of the data over the whole life cycle of the system engineering.
RQ-MO08-8	The #MAP shall apply a generic approach to ensure that data used by safety application are trusted.
RQ-MO18-3	$The #PREP shall ensure multi-tenant operation by defining different user groups and separating the data for each group.

4.5.3.2 Conceptual approach

The project engineering is about the engineering of the topological properties and the engineering and parametrisation of the trackside assets according to the equipment strategy. Each part of the produced Engineering Data is described with the properties relevant for the consumers using generic engineering rules. The generic engineering ruleset is an integral development part of the RCA systems and including interfaced systems that rely on the resulting Map Data. Hence, the Engineering Data is minimised by system design approaches that take into account the engineering effort as optimisation criteria from the very beginning.

At the end of the engineering process all Engineering Data as required for later generation of Map Data (incl. system specific parameter, like OC configuration) is provided. The content of Map Data is elaborated by the MAP Object Catalogue as defined in [10].

Generic planning artefacts can be derived and exported from the Engineering Data as required by the process. According to the requirements the process shall provide the highest technical and economical grade of automation.

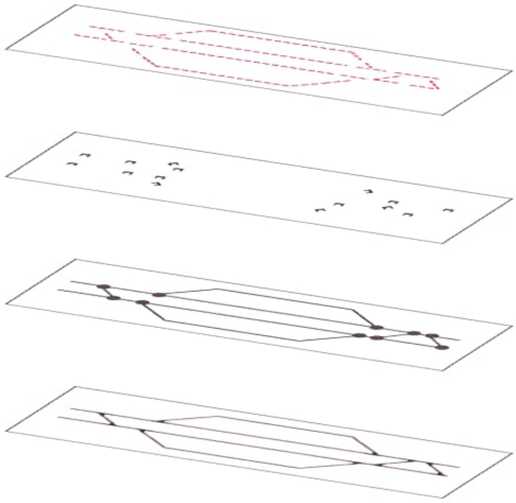

Figure 6: Layering concept with basic topology, point objects and linear objects

While a standardised toolset can deliver a core functionality for the generic rules and base for Map Data it is assumed that national/IM specific extensions, which are outside of the scope of PREP, are required to cover the complete engineering process (e.g. IM specific artifacts or complex/asset specific set of OC configuration data, hardware engineering and cable planning).

4.5.4 Comparison of Acquisition Data with Engineering Data

High-level process: Validation

4.5.4.1 Allocated requirements

Based on the list of all requirements allocated to PREP the following requirements are identified as relevant in this functional context:

Table 7 Allocated requirements for Comparison of acquired data with Engineering Data

ID	Requirement
RQ-MO08-2	$The #PREP-2 must maintain the state of already validated (i.e. by external processes) parts of Engineering Data or Map Data.
RQ-MO08-3	$The #PREP-2 should ensure the consistency of the Map Data with the actual infrastructure situation (complete, accurate/correct, current) by automated comparison between Map/Engineering Data and Acquisition Data.
RQ-MO08-1	$The #PREP must be the single reliable source of Map Data, which is distributed to all the consuming systems.
RQ-MO08-5	$The #PREP and #PUB-TS shall develop the deliveries for the acceptance of automated tools to minimise manual activities during data generation, validation, transformation/compiling, storing and further distribution.

4.5.4.2 Conceptual approach

The system compares the imported Acquisition Data with the imported Engineering Data and identifies relevant deviations, that are out of expected tolerance (e.g., missing edge or element, element position deviation out of tolerance, …). In this way, the approval of the implementation is checked to be consistent with the reality.

This function is only required if the imported Engineering Data is not marked as already compared to Acquistion Data.

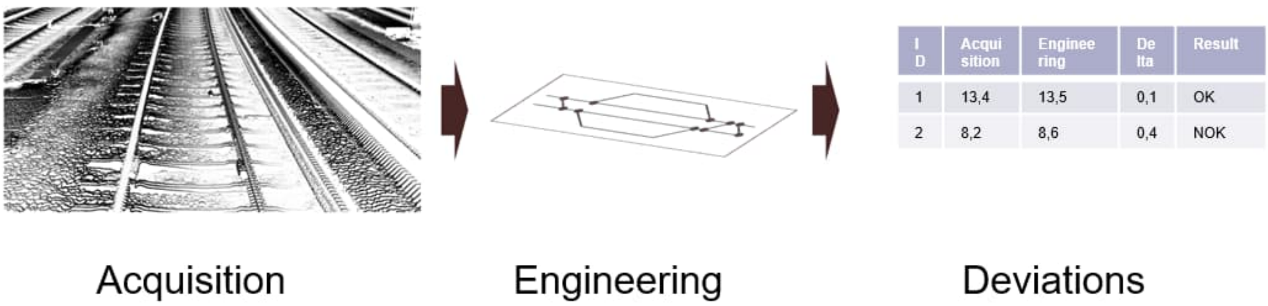

Figure 7: Comparison of Acquisition Data and Engineering Data

4.5.5 Rule Checks

High-level process: Validation

4.5.5.1 System requirements

Based on the list of all requirements allocated to PREP the following requirements are identified as relevant in this functional context:

Table 8 Allocated requirements for Rule Checks

ID	Requirement
RQ-MO01-2	$The #PREP-2 shall provide Map Data before it is put into operation for testing purposes.
RQ-MO02-2	$The #PREP-2 shall automate the validation of Map Data based on generic rules (structure, consistency, relations, …).
RQ-MO08-4	$The #PREP-2 must validate the Map Data against proving rules which are derived from the generic engineering rules of the consuming systems.
RQ-MO20-1	$The #PREP shall avoid publishing Map Data that is not successfully validated to exclude operational impacts and safety hazards.

4.5.5.2 Conceptual approach

The system checks the Engineering Data against defined rules, which are based on generic engineering rules, structural definitions, consistency conditions and quality attributes. The generic rules should be part of the Map Data specification and are the result of the design process of the consuming systems. Optionally, the rule engine allows project specific adaptions or extensions. In general, it should be implemented as a cooperative tool, which allows the automatic checks to be combined with manual checks by a human validator.

Validation of the data must always be performed, independent of whether the imported engineering data is marked by the IM as already compared to acquisition data or not. This would only ensure completeness and not accuracy, consistency, rule conformity, etc. In addition, there is also data that cannot be acquired, i.e. that cannot be validated by means of acquisition.

Validation must be able to reveal a maximum set of engineering problems - only a small part is then left to manual, but still controlled processes.

In any case the module checks whether all remaining checks that take place outside of MAP have been carried out, so that no unvalidated safety-related data reaches the consuming systems (validation coverage).

Validation must ensure that the Map Data can be regarded as reliable and meet the required demands of accuracy, completeness, correctness / consistency and actuality.

4.5.6 Generate validation report

High-level process: Validation

4.5.6.1 Allocated requirements

Based on the list of all requirements allocated to PREP the following requirements are identified as relevant in this functional context:

Table 9 Allocated requirements for Generate validation report

ID	Requirement
RQ-MO08-1	$The #PREP must be the single reliable source of Map Data, which is distributed to all the consuming systems.
RQ-MO20-1	$The #PREP shall avoid publishing Map Data that is not successfully validated to exclude operational impacts.

4.5.6.2 Conceptual approach

The results of comparison and rule checks are listed in a validation report. This report is transmitted to the IM specific engineering systems where the validation violations must be solved by adjusting the input Engineering Data.

After correcting the data, they can be re-imported. In this case, however, a validation is also carried out again to ensure that all validation errors have been eliminated. This loop is repeated until all discrepancies have been corrected and the validation report no longer contains any errors.

The next step, the compilation of the Engineering Data to Map Data is only possible, when all validation errors have been resolved. There will be no compilation of valid parts of the data while other parts are still invalid.

4.5.7 Compile Engineering Data to Map Data

High-level process: Compilation

4.5.7.1 Allocated requirements

Based on the list of all requirements allocated to PREP the following requirements are identified as relevant in this functional context:

Table 10 Allocated requirements for Compile Engineering Data to Map Data

ID	Requirement
RQ-MO02-3	$The #PREP-2 shall automate the compilation of Map Data to transform the Engineering Data into Map Data as required by the consuming systems, so additional data transformations by the consuming systems are avoided.
RQ-MO02-6	$The #PREP-1 shall introduce a fully digitised Engineering- and Map-Data flow.
RQ-MO08-6	$The #MAP shall ensure the integrity of Map Data over the whole data flow from the engineering up to the provision to the Trackside and On-Board systems.
RQ-MO08-7	$The #PREP shall maintain safety requirements of the data over the whole life cycle of the system engineering.

ID	Requirement
RQ-MO08-8	The #MAP shall apply a generic approach to ensure that data used by safety application are trusted.
RQ-MO11-1	$The #PREP-2 shall use standardised interfaces to PUB-TS.
RQ-MO12-5	$The #PREP shall generate Map Data for On-Board applications (On-Board Map), such as localisa-tion, which is reliable (i.e. complete, accurate, up to date).
RQ-MO13-3	$The #PREP and #PUB-TS shall provide Map Data for all trackside interfaced systems (incl. warning systems).
RQ-MO14-1	$The #PREP shall provide a stable and reliable ID-management for Map Data with cross-system consistency, i.e., in order to allow an efficient safe binding procedure between FOT and OCs.
RQ-MO14-2	$The #PREP shall provide Map Data with all information (protection data), that is required by Trackside to confirm the safe binding to OC/trackside assets.
RQ-MO16-2	$The #PREP and #PUB-TS must provide information about the actual changes (diff), such as deletion, insertion, replacements of specific elements, edges or other parts of the Map Data.
RQ-MO16-3	$The #PREP must define sufficient anchor points to cut the Map Data into parts, that can be changed independently/autonomously. The definition of anchor points must consider the con-straints of all trackside systems, that consume the Map Data as configuration.

4.5.7.2 Conceptual approach

The system makes the data packages available to the consumers in the required compilations by transforming the Engineering Data in a consumer specific layout and content. The output of this function is the Map Data which can then be published to the consuming systems that rely on Map Data. As a result the Map Data within the consuming systems can be pre-loaded (and activated afterwards) after distribution without the need for additional transformation.

During the compilation (or even the previous engineering) step the setting of anchor points, which serve as cross-system compatible borders for partial Map Data changes, is considered according to the to be defined system needs and restrictions.

4.6 Function allocation

The illustration below shows the proposed allocation of the different PREP phases defined in chapter 4.4 High-level PREP Process to the subsystems of the RCA logical architecture as illustrated in Figure 4 PREP in the RCA Logical Architecture. Additionally, the involvement of external actors and the data flow between the sub-systems resp. external systems is shown.

The Acquisition Data is marked as optional, as it is only required, if the imported Engineering Data is marked as non-validated (see 0

Comparison of Acquisition Data with Engineering Data).

Note: The allocation to the RCA subsystems is shown only from the PREP perspective, i.e. only functions that are allocated to the PREP phase are taken into account.

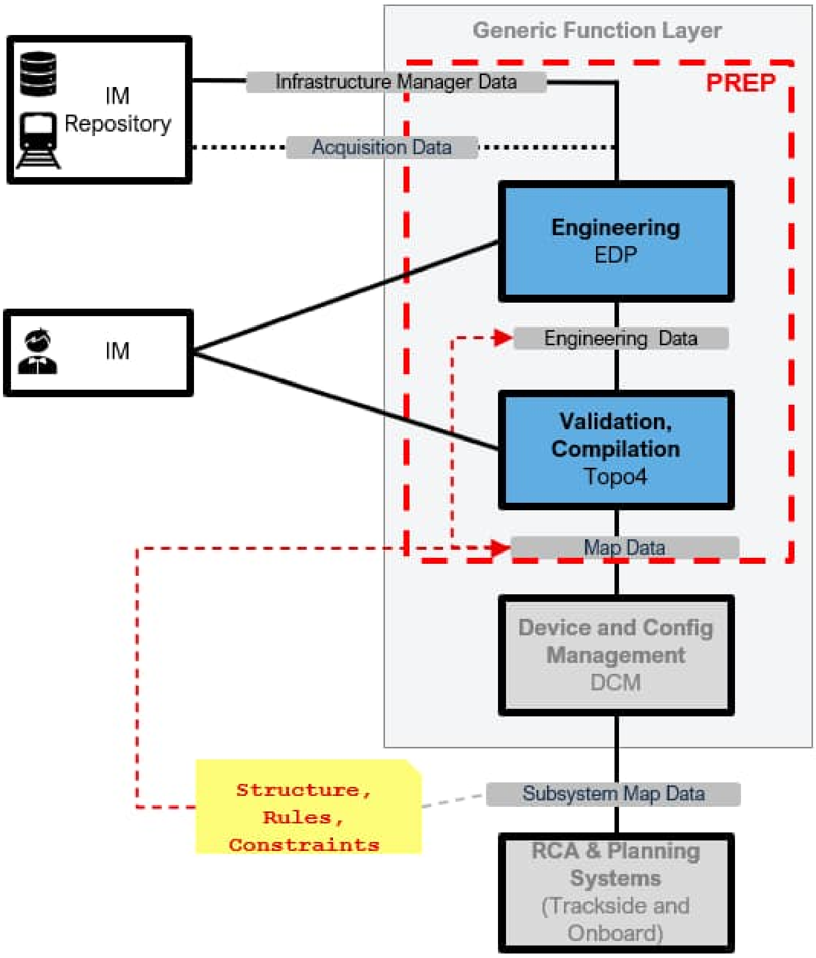

Figure 8 Allocation of the PREP phases

According to the sketched process, the IM interacts with the PREP system as follows:

- Control the import of the infrastructure manager data and acquisition data
    - Trigger the import of the Infrastructure Manager Data from the IM repository
    - Trigger the import of the Acquisition Data (if applicable)
    - Check whether the import was completed successfully
    - Handle the import errors that have occurred
- Control the aggregation of the engineering data
    - Aggregate missing data in the imported Infrastructure Manager Data
        - Automatic aggregation using engineering rules
        - Manual aggregation of the data where no automatic aggregation is possible
- Control the validation of the Engineering Data
    - Manage the generic engineering rules
    - Check that they meet the required demands of accuracy, completeness, correctness / consistency and actuality
    - Execute the comparison between the engineering and the acquisition data

- Control the validation result
    - Check the validation result if any errors occurred
    - Handle and resolve the errors directly by either correcting the data or by marking them as correct (with justification)
    - The data that can be changed is defined by a user and role concept.
- Control the export of the validation result
    - Trigger the export of the validation result into the IM Repository
- Control the compilation of the Engineering Data
    - Trigger the process to compile the Engineering Data to Map Data
    - Check whether the compilation was completed successfully
    - Handle the compilation errors that have occurred
- Verify that the safety requirements on the Map Data and the compiled Map Data are fulfilled
    - Ensure that all validation and verification steps have been completed successfully
    - Ensure that the Map Data are complete and correct according to the underlying data model and the accuracy/quality requirements

The functions for the interaction shall be integrated into the RCA Workbench as the platform for providing process specific user interfaces.

The following table summarises the PREP functions and their allocation to the high-level processes and RCA subsystems:

Table 11 Function allocation PREP

Function	Process	RCA Subsystem
Import and aggregate Infrastructure Manager Data	Engineering	EDP
Manage construction phases and data versions	Engineering	EDP
Rule-based (automated) data engineering	Engineering	EDP
Comparison of Acquisition Data with Engineering Data	Validation	Topo4
Rule Checks	Validation	Topo4
Generate validation report	Validation	Topo4
Compile Engineering Data to Map Data	Compilation	Topo4

5 Solution Concept MAP – PUB-TS phase

The chapter is based on the overarching MAP requirements analysed in chapter 3.2 and is valid for all business objectives assigned to the **PUB-TS** phase. In general, the overall PUB functionality is responsible for the distribution and activation of Map Data to/in the consuming systems, which is conceptually divided into the publication to the trackside and On-Board systems. This document focuses on the data distribution to trackside consumers, abbreviated by PUB-TS. This phase covers the complete Map Data flow for distribution (incl. Preloading and activation) in the trackside consuming systems.

The pre-condition for the PUB-TS process is the completed PREP phase, which prepared the Map Data version incl. successful validation and compilation.

The post-condition of the PUB-TS process is the state that all trackside systems have successfully activated the Map Data version provided by PREP.

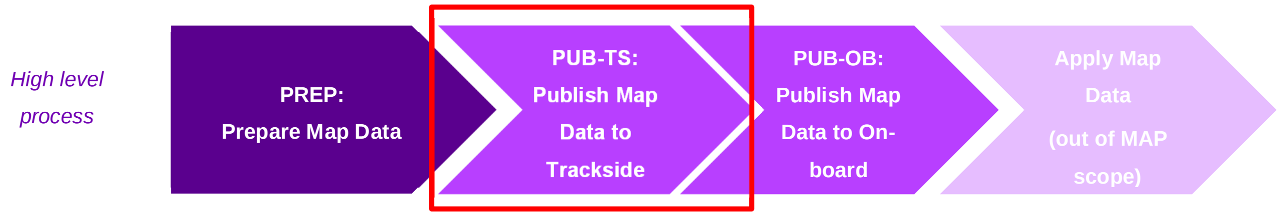

Figure 9 PUB-TS in the high-level process of MAP

The whole process of PUB-TS and the involved systems/interfaces are considered within the scope of standardisation due to the generic character.

5.1 PUB-TS References

The introduced PUB-TS process and functions based on the requirements within this document are further elaborated by the design of capability "87 Activate Map Data" within the Capella model of RCA [11]. This capability only covers the activation phase (via SCI) of the lifecycle of Map Data. The other relevant lifecycle phases like validation, compilation are not covered for current iteration of this capability.

In addition, the capability is only detailed until the logical architecture (as per Capella) for Map Data activation and their corresponding definition / allocation to subsystems is not yet done.

This chapter on the other hand provides a detailed definition on how the Map Data would be distributed, activated (via SCI and SMI), and deactivated within the subsystems. The processes defined here would eventually be considered as input for the next iteration of this capability.

As a pre work for the next iteration for the Map Data capability, a Trade Off analysis had been performed to identify the possible subsystem candidates for the physical architecture of Map Data. This trade-off eventually concluded with subsystem Device & Config Management (DCM) as a potential Map Data distributor candidate (explained in detail in upcoming sections).

5.2 PUB-TS Terms

The following terms are used in this chapter:

- Map Data

For the definition of these terms, see chapter 1.9 Terms and Abbreviations.

5.3 PUB-TS in the RCA context

The functions of PUB-TS in the currently defined logical architecture of RCA will be potentially covered by the subsystem DCM, which provides the new Map Data, and the interaction with trackside system (e.g. PE, SL, MOT or AE) that consume the Map Data as essential part of their overall configuration. The configuration is complemented by system specific parameter data, which is considered to be part of the Map Data in this context, since it is also provided by PREP and provided in the same way as Map Data.

The Figure 10 shows the integration into RCA including used subsystems and SMI interfaces for the process part of Map Data distribution. In addition, as shown in Figure 11 and detailed in chapter 5.4.2, the actual activation of Map Data is carried out via the SCI interfaces.

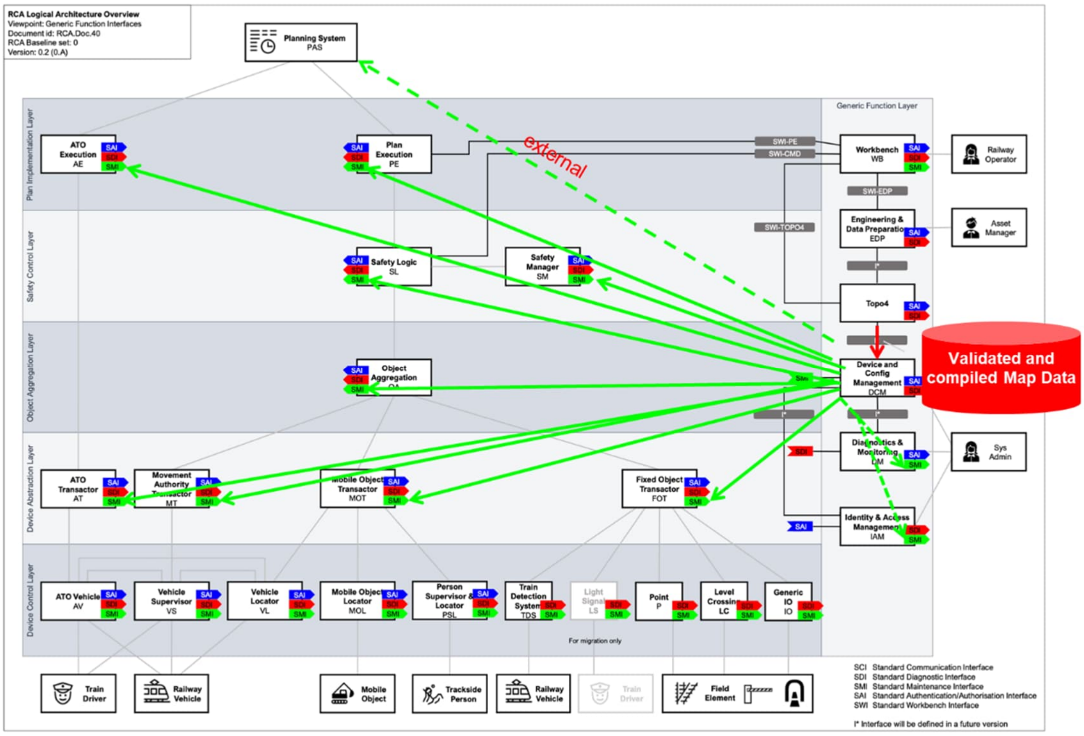

Figure 10 Distribution of Map Data by PUB-TS process in RCA

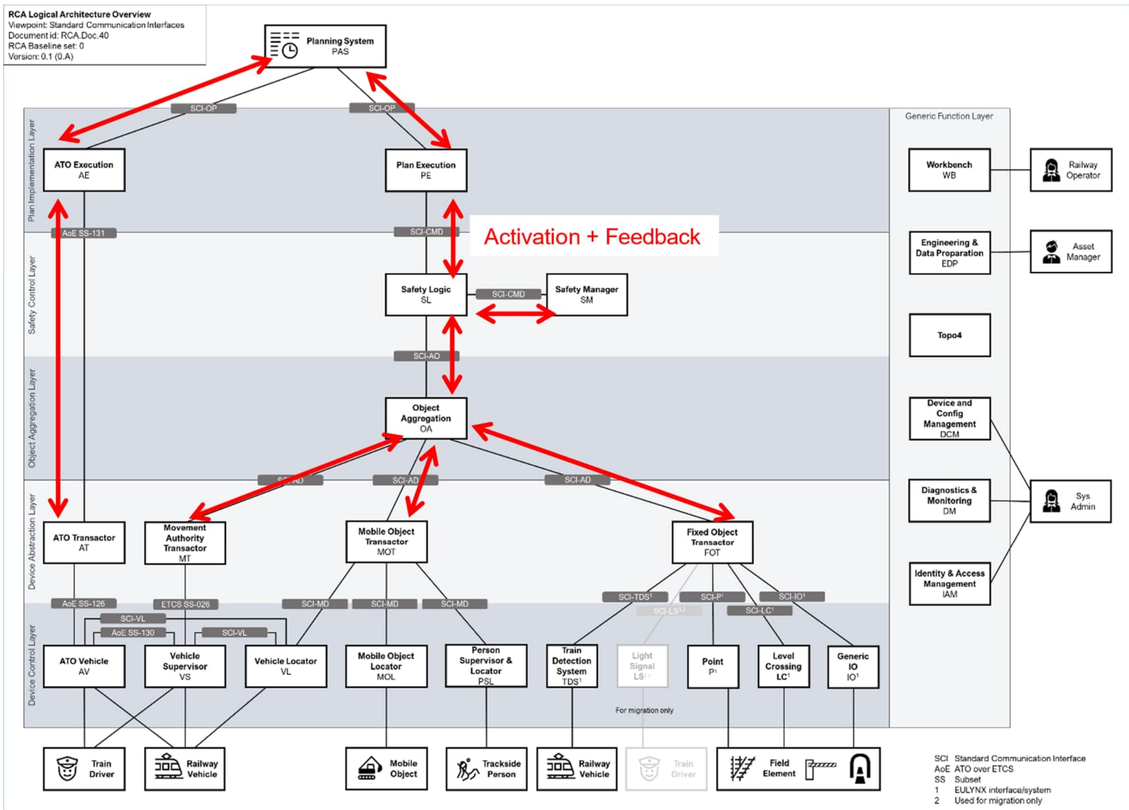

Figure 11: Activation of Map Data by PUB-TS process in RCA

5.4 Functions

The following chapter defines the functions that must be realised by the PUB-TS related subsystems to enable the sketched process for providing Map Data. For each function the relevant requirements to be fulfilled are identified.

5.4.1 Maintain Map Data

5.4.1.1 Allocated requirements

Based on the list of all requirements allocated to PUB-TS the following requirements are identified as relevant in this functional context:

Table 12 Allocated requirements for Maintain Map Data

ID	Requirement
RQ-MO01-5	$The #PUB-TS shall provide the next version of Map Data before it is required for operation.
RQ-MO04-1	$The #PUB-TS shall introduce a fully digitised Map Data flow.
RQ-MO04-2	$The #PUB-TS shall offer the highest grade of automatisation for the distribution of Map Data.
RQ-MO04-3	$The #PUB-TS shall always have a single reliable source of Map Data as provided by PREP.
RQ-MO08-5	$The #PREP and #PUB-TS shall develop the deliveries for the acceptance of automated tools to minimise manual activities during data generation, validation, transformation/compiling, storing and further distribution.
RQ-MO08-6	$The #MAP shall ensure the integrity of Map Data over the whole data flow from the engineering up to the provision to the Trackside and On-Board systems.
RQ-MO08-8	The #MAP shall apply a generic approach to ensure that data used by safety application are trusted.
RQ-MO11-2	$The #PUB-TS shall use standardised interfaces for Map Data provision and management.
RQ-MO16-2	$The #PREP and #PUB-TS must provide information about the actual changes (diff), such as deletion, insertion, replacements of specific elements, edges or other parts of the Map Data.
RQ-MO16-4	$The #PREP and #PUB-TS must provide a versioning system, that is compatible with partial Map Data updates.
RQ-MO16-6	$The #PREP and #PUB-TS must provide a versioning system that shall ensure the management of the different versions in a safe way.

5.4.1.2 Conceptual approach

The validated and compiled Map Data from the previous PREP process is potentially received as input for the PUB-TS process by the RCA subsystem DCM. The compiled Map Data is assumed to be successfully validated, so it is accepted (authorised, certified, approved) to be used within safety-related context. The imported data is stored as next version of Map Data, that will be provided to the consuming systems. It contains the initial Map Data or all incrementation changes compared to the previous version.

The potential subsystem DCM needs to handle at least the active and the next version of Map Data.

After the Map Data is received, the Map Data is provided to the RCA subsystems. As prepared by the PREP process, the data follows the introduced versioning system and contains also the description of the changes (diff/delta).

5.4.2 Provide Map Data

5.4.2.1 Allocated Requirements

Based on the list of all requirements allocated to PUB-TS the following requirements are identified as relevant in this functional context:

Table 13 Allocated requirements for Provide Map Data

ID	Requirement
RQ-MO04-1	$The #PUB-TS shall introduce a fully digitised Map Data flow.
RQ-MO04-2	$The #PUB-TS shall offer the highest grade of automatisation for the distribution of Map Data.
RQ-MO04-4	$The #PUB-TS shall allow a distribution and activation of next Map Data version for all consuming systems.
RQ-MO04-5	$The #PUB-TS shall provide feedback loops for coordination and issue solving by external actors.
RQ-MO04-6	$The #PUB-TS shall have a minimal impact on operation (i.e., solve potential issues during preloading phase, decision for activation by TMS, ...).
RQ-MO08-6	$The #MAP shall ensure the integrity of Map Data over the whole data flow from the engineering up to the provision to the Trackside and On-Board systems.
RQ-MO08-8	The #MAP shall apply a generic approach to ensure that data used by safety applications are trusted.
RQ-MO11-2	$The #PUB-TS shall use standardised interfaces for Map Data provision and management.
RQ-MO12-4	$The #PUB-TS shall provide the Map Data for On-Board applications (On-Board Map) to the trackside system responsible for PUB-OB process.
RQ-MO13-3	$The #PREP and #PUB-TS shall provide Map Data for all trackside interfaced systems (incl. warning systems).

ID	Requirement
RQ-MO13-5	$The #PUB-TS shall be capable to process and provide the Map Data coming from PREP for the specific segment size (Area of Control).
RQ-MO14-3	$The #PUB-TS shall maintain the integrity of the Map Data.
RQ-MO18-1	$The #PUB-TS shall support asynchronous loading and synchronous activation of Map Data Versions to support centralised as well as decentralised trackside system platforms solutions.
RQ-MO20-2	$The #PUB-TS and #PUB-OB shall provide feedback regarding errors during Map Data distribution and activation.
RQ-MO20-3	$A failure in the #PUB-TS and #PUB-OB process shall not lead to operational degraded modes.
RQ-MO22-1	$The #PUB-TS shall be integratable with legacy architectures (i.e., no other RCA systems should be essentially required except for MAP systems), which offers a wider range of application and different migration scenarios.

5.4.2.2 Conceptual approach

The following assumptions or principles are applied:

- The provision of Map Data should have minimal effect on the train operation. This can be assured by,
  - ➔ Optimal planning of the activation of Map Data taken into account the operational situation (Traffic Management), e.g. Movement Permissions within/through the area where the Map Data update takes place are avoided.
  - ➔ The provisioning is divided into *distribution* and *activation*. The *distribution* does not affect the operation and prepares the RCA subsystems for a quick activation of Map Data (the active version is still used during this process). The actual *activation* of Map Data updates to the new version of Map Data in a synchronised way.
- Within the RCA system, there is always exactly one active Map Data Version in use.
- From RCA subsystem point of view, the Map Data activation process starts at that moment when the subsystem receives an update request.
- To minimise eventual (most possible) unavailability of Map Data Elements and related functionalities during update of Map Data, the activation process (updating a new version of Map Data) shall consist of four steps:
  - ➔ Distribution of Map Data: Done from DCM to all RCA subsystems, until all RCA subsystems have provided the feedback about received Map Data or the process is aborted (in case of errors).
  - ➔ Preload of Map Data: Done for each RCA subsystem in order to assure that this Map Data can be consumed and activated by all RCA subsystems*. Note: Preloading the Map Data Version is not time critical compared to its activation from an operational point of view.*
  - ➔ Activation of Map Data: Done for all RCA subsystems. Activation is only possible after all RCA subsystems have provided their feedback about positive activation ability.
    Note: Post successful activation of Map Data in all trackside RCA subsystems the corresponding PUB-OB processes can begin.
  - ➔ Deactivation of Map Data: Done for all RCA subsystems. Deactivation of previous version of Map Data is only done after the new verion of Map Data is successfully activated in a subsystem.
- A Map Data is provided for the whole Area of Control of the RCA subsystems (i.e. for PE, APS). In case of a Map Data update, it lists all Map Data Elements to be updated (new, change, delete) as the difference to the currently active Map Data Version.
- The actual Activation of Map Data requires operational information and therefore should be initially triggered by PAS/Planning System via SCI-OP or, as alternative, over subsystem Workbench via SWI-PE to PE when a Planning System is absent.
- Since the PAS/Planning System is not part of the RCA, the provisioning of Map Data to this system is not part of standardisation yet. However, it is assumed, that PAS is aware of the next version of Map Data and considers the new Map Data update in the planning accordingly before the actual activation. Hence, PAS should be directly involved into the activation triggering. Also, to support the goal of consistent Map Data between RCA and surrounding systems such as PAS or integrated legacy systems (e.g. RBC), DCM (and/or Topo4) should provide a generic interface for Map Data which can be accessed by external systems (data interface only, without process or service integration).

5.4.2.3 Distribute and load Map Data

Before activating a new version of Map Data, this new version shall be preloaded by all RCA subsystems consuming Map Data to reveal potential conflicts applying the new Map Data version or allow some system specific check routines *before* the new Map Data is used in operation. Each RCA subsystem consuming Map

Data will then provide – according to the RCA subsystem specific rules - a state (as a part of so-called Distribution Feedback) indicating whether the activation of the preloaded Map Data update is possible or not.

According to this concept the Map Data will be potentially provided by the system Device & Config Management via SMI to all trackside RCA subsystems consuming Map Data. The following sequence diagram below shows a preliminary approach on distribution of Map Data along with feedback using the SMI interfaces between DCM and other subsystems.

Note: The illustration below is only preliminary approach and does not show all the potential subsystems requiring Map Data.

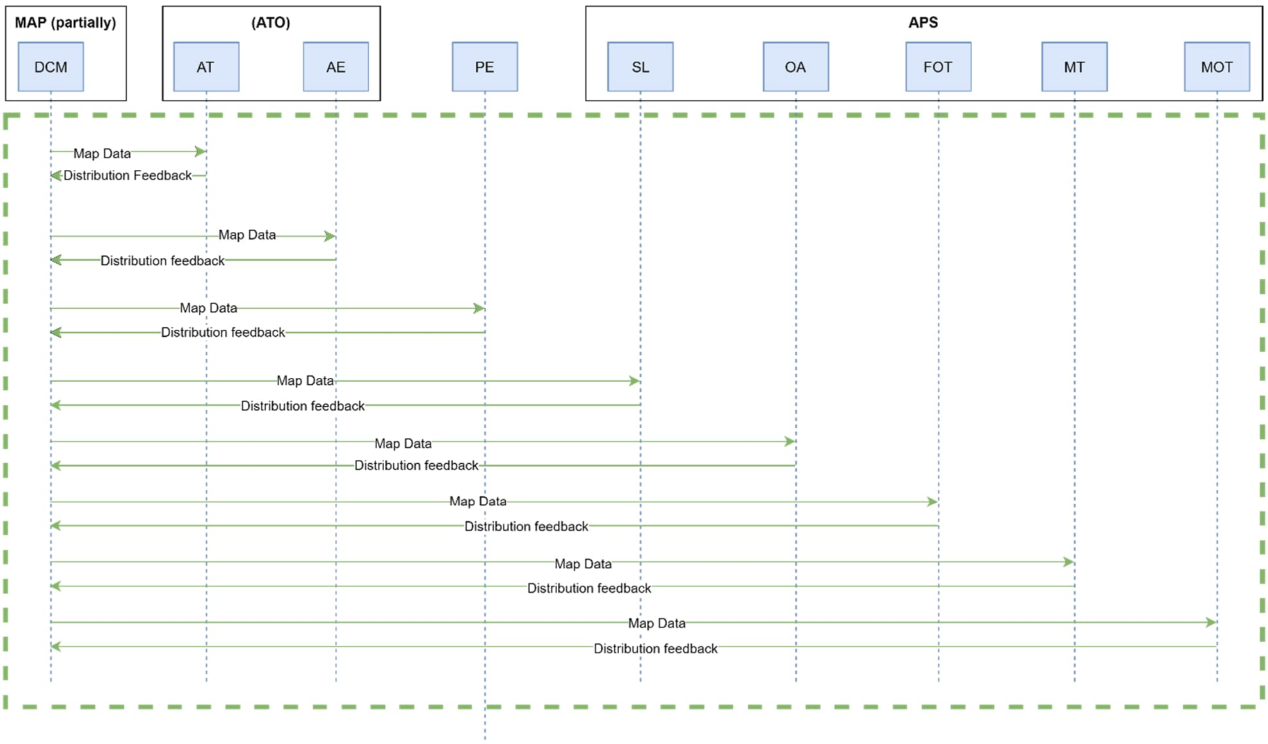

Figure 12: Distribution of Map Data

The state indicating whether the activation of the preloaded Map Data is possible or not shall be provided by each RCA subsystem consuming Map Data to DCM via SMI. If the state changes, an update of the state will be sent by the respective RCA subsystem to DCM via SMI.

Note: a state change may occur from 'not possible' to 'possible' and vice versa.

Each RCA subsystem consuming Map Data is itself responsible for determining whether it can activate the preloaded Map Data. Basic requirements for activation to be performed for each subsystem are:

- Map data is present within the subsystem
- Subsystems in a required state for activation
- Other required local activation inputs are considered

A permission is given if each rule of the subsystem specific ruleset is not violated. Exemplary rules or conditions to be also considered for activation may be:

- the RCA subsystem is "In Operation State"
- the change and deletion of a Map Data Element in currently active Version of Map Data shall NOT be allowed when there is any of the following internal logical elements referencing the (currently used) Map Data Element Version: e.g. a granted Movement Permission, an active Warning Area, a Usage Restriction Area.

Note: Reason: all these logical element references would become lost after activation, leading to potential safety hazards

- For the subsystem Plan Execution, no requested Operational Plan shall reference Map Data Elements marked to be updated.

5.4.2.4 Activate Map Data

The activation is possible as soon as each RCA subsystem consuming Map Data indicates that activation is possible. This is indicated using a state which elaborates the fact, whether the RCA subsystems can activate the preloaded Map Data or not.

In addition, during the activation process the potential authorising subsystem APS should ensure that the affected elements of the current / new Map Data are set to a restrictive state and post successful activation the elements are set back to an operable state. This being a safety-critical aspect in terms of railway operation, APS should also ensure that these states are transmitted to all the subsystems. This should secure the affected areas of Map Data from not being used for operation during Map Data activation.

The activation of Map Data can be performed architecturally in 2 ways:

1. Activation via SCI, as defined in Capability 87: Activate Map Data
2. Activation via SMI, as in discussion in scope of Concept SMI

5.4.2.4.1 Activation via SCI

The activation approach uses the SCI interfaces for the transmission of the activation command since the activation has a direct impact on operation and therefore should be part of the operational message data stream sequence.

The activation of a Map Data will most likely be initiated by an actor 'Infrastructure Manager' presumably via an interfaced subsystem such as Safety Logic (SL). This is due to the fact that the connection to Workbench via SWI-CMD can be applied as interface between SL and the actor 'Infrastructure Manager'.

The Infrastructure Manager is operationally responsible for activation of the Map Data. The Infrastructure Manager authorises the activation of Map Data by ensuring that the changes to the actual railway infrastructure has been built as per plan and is ready to be operated.

The request for activating the Map Data will be initiated by the Subsystem PE or Planning System (Operational Plan) and the Infrastructure Manager. This is eventually authorised by the Safety Logic and forwarded as activation command cascading down to all other trackside RCA subsystem.

In addition, the authorising subsystem SL also ensures that affected elements of a current / new Map Data are set to a restricted state and this state information is transmitted to all the subsystems.

To activate the Map Data, each system checks, if it has the Map Data in the 'ready for activation' state and the system specific activation conditions are met (see section 5.4.2.3). *Note: Even though these checks have been performed the final trigger coming from a potentially safety-related function that grants activation requests for each Map Data consuming subsystem.*

Consequently, post successful activation of Map Data, the authorising subsystems SL ensures that the restricted states of affected elements of the Map Data are set back to an operable state (might involve actions like "clearing the track by first train movement in restricted mode over new/change edge") and also all other subsystems are informed about this state change.

The idea of cascading down the interfaces can be foreseen as sending a command from top layers of the architecture to the bottom layers.

This cascading down logic in case of Map Data serves as activation command loops for transmission of activation command from (e.g.) SL to other sub-systems which are located on the lower layers. The same logic when used upwards would serve as activation feedback loops for transmission of activation feedback from (e.g.) OA to other sub-system that are located on the upper layers.

An example sequence below shows how the activation command cascaded down/up through the RCA sub-systems.

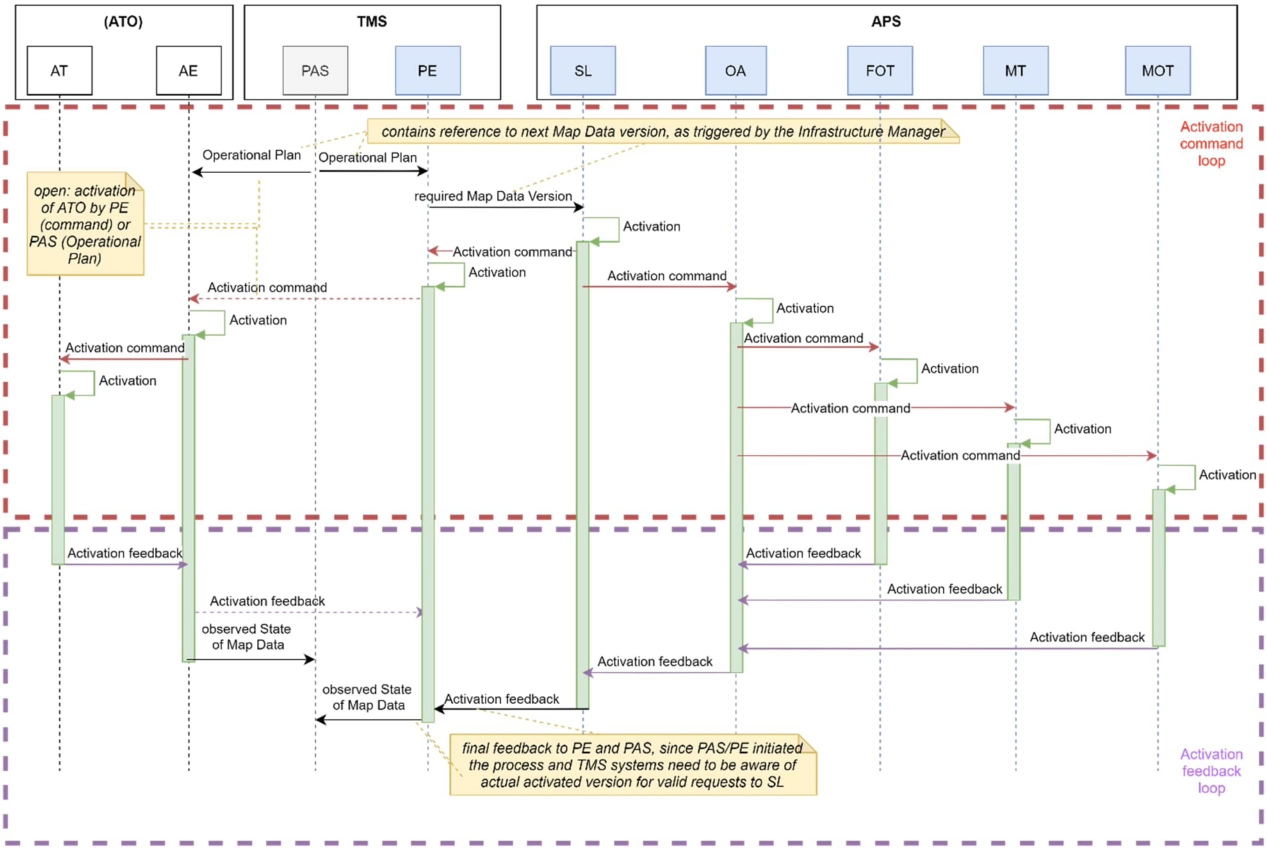

Figure 13: Conceptual approach - Activation of Map Data via SCI

Here, SL is the authorising system which sends the activation command to other OA and PE. The corresponding receiving subsystems (OA and PE) are responsible for activation of Map Data within them and transmitting the command further to other relevant subsystems (AE, FOT, MT, MOT).

Regarding the activation of ATO systems two alternatives are sketched:

- If the activation is triggered by PE (similar to the other systems) then PE waits for the activation until ATO (AE and AT) also provided a positive activation feedback to PE. While this process avoids activation in PE without positive feedback from AE it does not comply with the actual RCA, since no SMI interface between AE and PE is defined yet and ATO and PE/APS are defined as independent message streams.
- If the activation trigger is derived from the Operational Plan sent from PAS to AE (similar to PAS to PE), then the two activation loops for ATO and PE/APS are handled separately and only PAS gets the feedback of both streams. Consequently, PAS needs to provide appropriate reaction in case of deviating feedbacks from both streams (e.g. update Operational Plan with previous Map Data version)

The actual activation must be performed by each subsystem according to its own rules and processes (e.g. APS could state: each updated or changed Map Data Element shall be marked as potentially occupied at that moment of activation within the Operating State). The detailed process is to be defined in the design phases of the specific RCA subsystem.

Based on respective feedbacks from the subsystems as shown in the sequence diagram, the activation of Map Data within each subsystem is finalised.

5.4.2.4.2 Activation via SMI

This activation approach uses the SMI interfaces for the transmission of the activation command. This approach can be seen as an alternative for SCI.

Note: The following explanations below refer to APS as one bundle and do not really focus on the different subsystems that are part of the bundle like OA, FOT, MT, MOT.

The activation of a Map Data will most likely be initiated by two major actors, namely Infrastructure Manager and Plan Execution/Planning System.

The Infrastructure Manager is operationally responsible for activation of the Map Data. The Infrastructure Manager authorises the activation of Map Data to DCM by ensuring that the changes to the actual railway infrastructure have been built and approved as per plan and is ready to be operated, also regarding potential other involved non-RCA systems.

PAS via PE on the other hand is responsible to provide the optimal activation time to DCM.

Based on these initiation parameters, DCM requests APS to prepare the Map Data for activation. APS as an authorising system, is responsible for setting the affected Map Data elements to a restricted state. A restrictive state is any state that blocks the affected elements of Map Data to be used in railway operation during Map Data activation. Due to cruciality of this information, APS informs the other subsystems regarding the restrictive state of the affected Map Data elements via existing SCIs (“Operating State”).

Consequently, APS will inform DCM regarding the prepared state of the Map Data.

Based on this prepared state of Map Data from APS, DCM provides a synchronised activation command to all the subsystems. This activation command on the one hand triggers APS to check if there are any new elements as part of the input Map Data that are also required to be set to a restricted state. When present, respective elements are also set to a restricted state. These corresponding state changes are also transmitted to other subsystems via existing SCIs.

This activation command on the other hand acts as a trigger within all subsystems to eventually activate the Map Data. To activate the Map Data, each system checks, if it has the Map Data in the ‘ready for activation’ state and the system specific activation conditions are met (see section 5.4.2.3). Depending on the status of activation, the subsystems provide a Map Data acknowledgement to DCM.

Note: Even though these checks have been performed the final trigger (activation command) has to be provided by a potentially safety-related function that grants activation requests for each Map Data consuming subsystem.

These Map Data acknowledgements are collected by DCM and once the Map Data acknowledgements from all the subsystems are received (considering all acknowledgements are positive), DCM provides a synchronised “activation completed” command to all subsystems.

This “activation completed” command on the one hand ensures to commit the activation process within individual subsystems (bad case scenario: “rollback” is initiated) and on the other hand acts as a trigger for APS to set the affected elements to an operable state. An operable state is any state that allows the elements of Map Data to be used in railway operation post Map Data activation (might involve actions like “clearing the track by first train movement in restricted mode over new/changed track edge”). Due to cruciality of this information, APS informs the other subsystems regarding the operable state of the affected Map Data elements via existing SCIs.

Activation via SMI solves the complex activation scenarios with regards to the activation of Map Data for ATO system (as given in previous section).

An example sequence below shows how the activation command is transmitted in a synchronised way through the RCA subsystems.

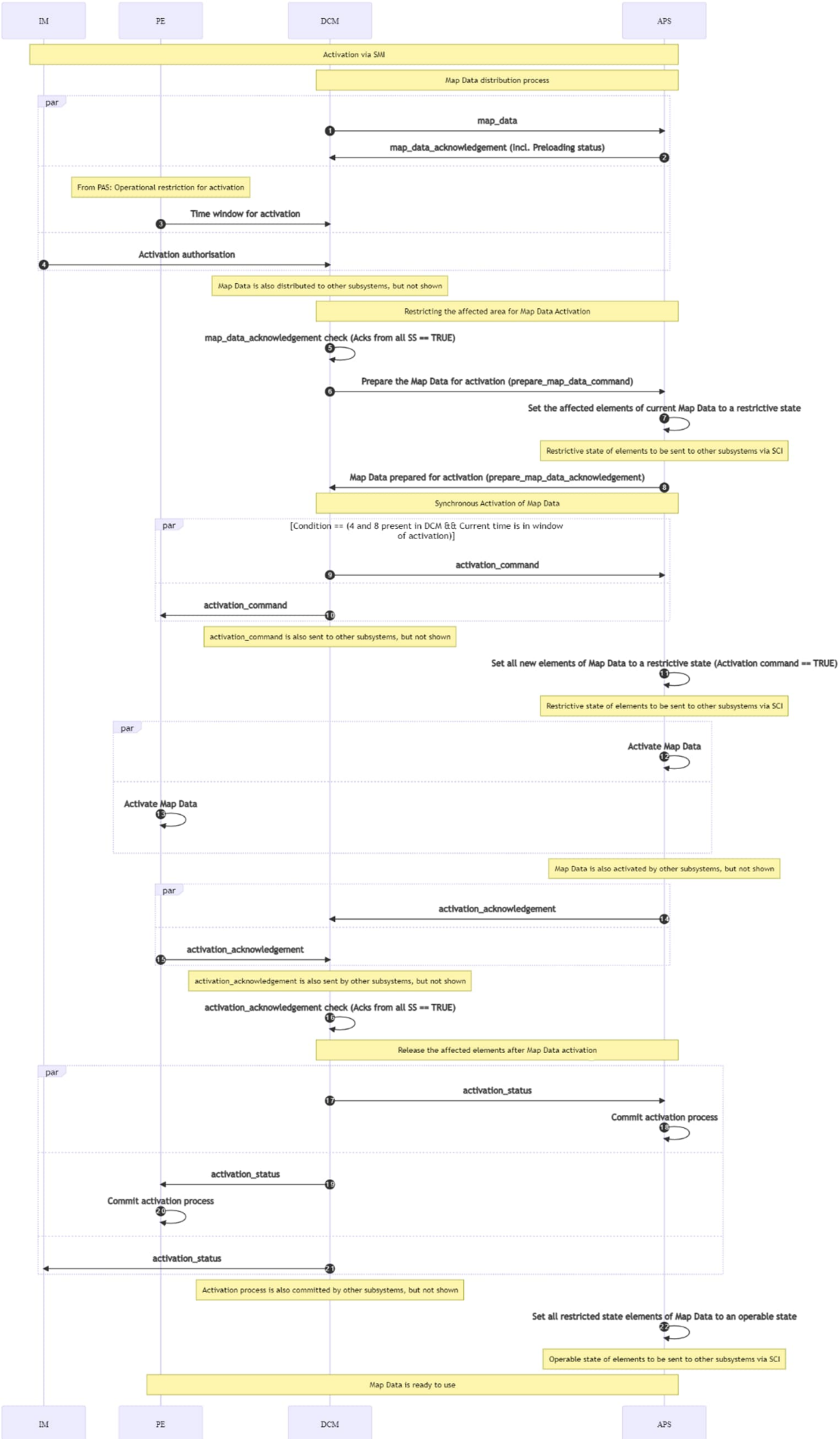

Figure 14: Conceptual approach - Activation of Map Data via SMI

5.4.2.4.3 SCI vs SMI: Pro's and Con's

Activation command via SCI	**Activation command via SMI**
Con: Cascading activation consumes more time, more dependencies (if not solved differently in architecture) Note: This con is based on the current layered interface architecture decisions and is subjective to changes	Pro: Simultaneous activation/request activation of all subsystems connected to DCM
Con: Activation command must be included in all SCI specifications	Pro: SCI Message stream does not need to deal with activation commands -> Strict seperation of Map aspects from SCI aspects
Con: AE/AT cannot be adressed directly, indirect interface via TMS (not standardised yet in RCA) Note: This con is based on the current layered interface architecture decisions and is subjective to changes	Pro: Direct interface to AE/AT
Pro: No new interfaces needed Note: This pro is based on the current layered interface architecture decisions and is subjective to changes	Con: New interfaces to DCM from IM needed Note: This con is based on the current layered interface architecture decisions and is subjective to changes
Con: Fallback procedures have to introduced in almost all subsystems separately	Pro: Fallback procedures can be introduced centrally in DCM, due to centralised activation
..	..

Note: This analysis is very preliminary and is likely to be extended. Therefore this collection of pro's and con's at this stage should not be decisive to make solution decisions.

6 Solution Concept MAP – PUB-OB phase

The chapter is based on the overarching MAP requirements analysed in chapter 3.2 and is valid for all business objectives assigned to the **PUB-OB** phase.

In general, the overall PUB functionality is responsible for the distribution and activation of Map Data in the consuming systems, which is conceptually divided into the publication to the trackside and On-Board systems. This document focuses on the data distribution from trackside to the On-Board consumers, abbreviated by PUB-OB. In contrast to the PUB-TS process the required data for PUB-OB might change during operation depending on the selected principle of data provisioning (provide whole network at once vs. demand driven according to actual journey of vehicle).

The pre-condition for the PUB-OB process is the state that all trackside systems successfully activated the Map Data version provided by PREP and are operating on the same activated version of Map Data.

The post-condition of the PUB-OB process is the state that the On-Board systems have activated Map Data according to their operational needs (i.e. as defined by the journey profile).
Note: since the need for Map Data changes for each vehicle, the process might be repeated accordingly during operation.

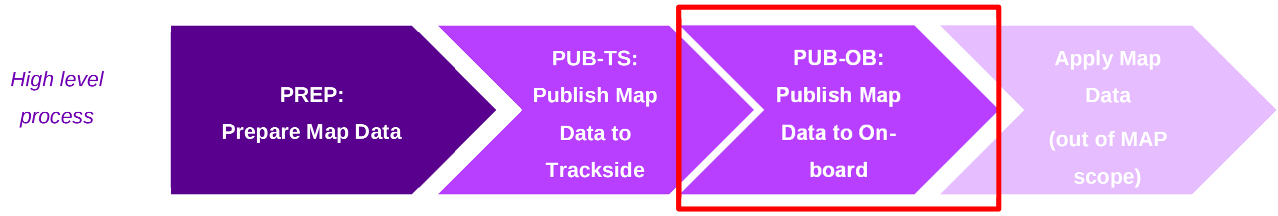

Figure 15 PUB-OB in the high-level process of MAP

The whole process of PUB-OB and the involved systems/interfaces are considered within the scope of standardisation due to the generic character and need for interoperability.

6.1 PUB-OB References

The conceptual process as well as a first allocation of PUB-OB functions to the RCA systems are evaluated in detail in the document Digital Map – Evaluation Publish On-Board Map Approaches [2].

Since the Digital Map cluster initially focuses on this PUB-OB/"airgap" topic, the following documents are delivered yet:

Ref	Document	Status
[3]	RCA Digital Map Concept [RCA.Doc.46]	Published with BL0R2
[9]	RCA Digital Map Evaluation Reference Model [RCA.Doc.57]	Published with BL0R3
[2]	RCA Digital Map – Evaluation Publish Onboard Map Approaches [RCA.Doc.56]	Published with BL0R3
[12]	RCA Digital Map System Definition [RCA.Doc.59]	Published with BL0R4
[13]	RCA Digital Map Preliminary Hazard Analysis [RCA.Doc.58]	Published with BL0R4
[14]	RCA Digital Map Business Case [RCA.Doc.55]	Published with BL0R3

6.2 PUB-OB Terms

The following terms are used in this chapter:

- Map Data
- On-Board Map Data

For the definition of these terms, see chapter 1.9 Terms and Abbreviations.

6.3 PUB-OB in the RCA context

The functions of PUB-OB in the currently defined logical architecture of RCA are not clearly allocated yet, so different possibilities exist such as:

1. **Dedicated Map Service:** Provide Map Data from trackside subsystem MOT via SCI-DM to On-Board
   → to be checked if the advantage of dedicated channel is worth the investment, also regarding migration
2. **Integrated into ETCS Message Stream:** Provide Map Data from trackside subsystem MT via Subset 026 interface to On-Board
   → to be checked if the interface can handle the additional requirements of handling Map Data, especially also regarding future-proofness (expected additional Map Data needs by new On-Board systems such as Perception etc.)
3. **Integrated into ATO Message Stream:** Provide Map Data from trackside subsystem AT via Subset 126 interface to On-Board
   → should be excluded due to safety criticalness of transmitted Map Data, i.e. for the support of localisation.
4. **Maintenance Interface:** Provide Map Data from trackside subsystem DCM via SMI to On-Board
   → should be excluded due to limited performance of SMI for this real-time application

According to the first analysis especially the first two interface candidates should be analysed in more detail This analysis is performed in the document Digital Map – Evaluation Publish On-Board Map Approaches [2] based on the initial use case of providing Map Data for On-Board localisation, but also considering future extensions of Map Data for other On-Board applications.

For the following generic descriptions, the following abbreviations are used:

- DM-TS: Digital Map Trackside System (e.g. MOT, MT,..)
- DM-OB: Digital Map On-Board System (to be defined by OCORA based on the trackside interface partner)

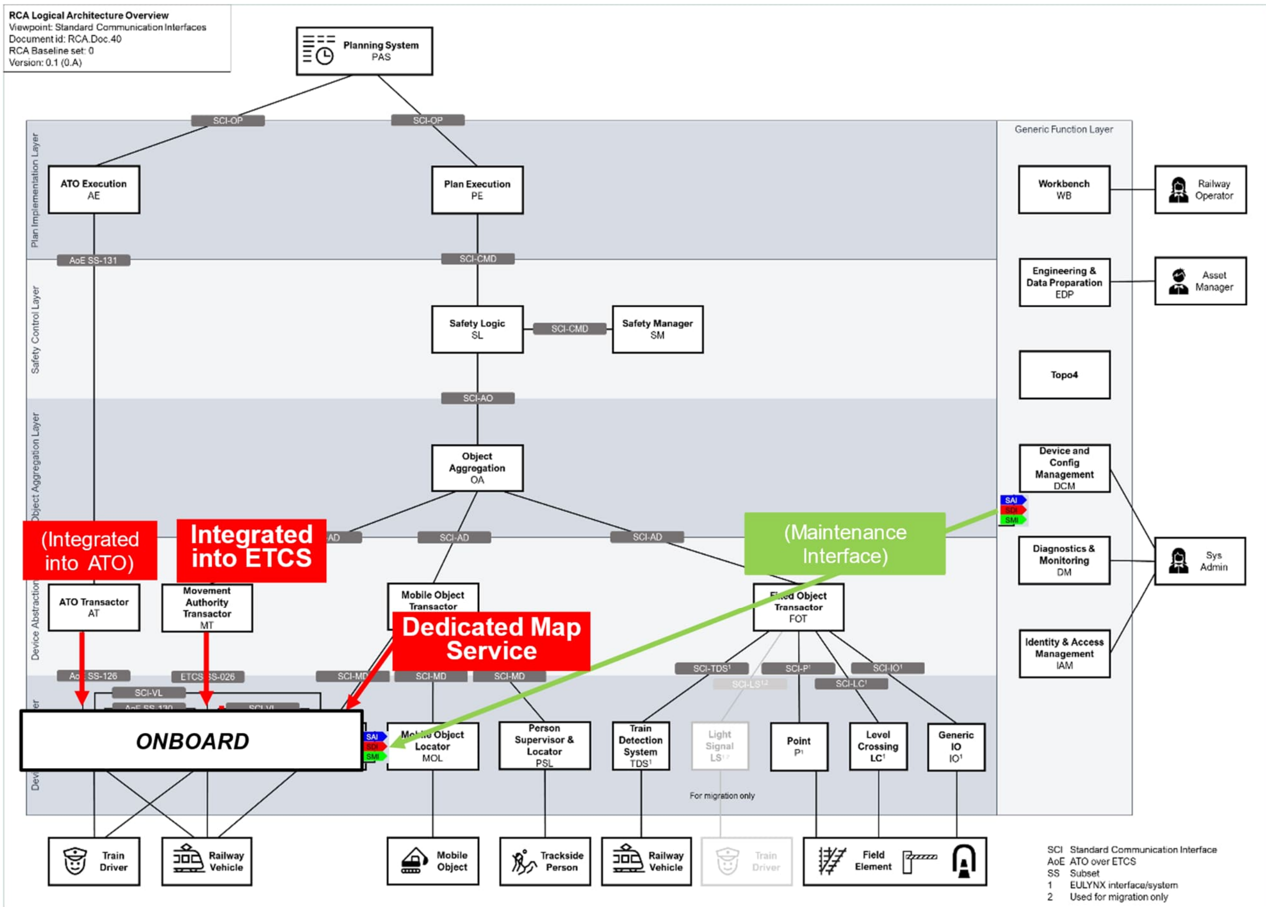

Figure 16 Distribution of Map Data by PUB-OB process in RCA

6.4 Functions

The following chapter defines the functions that must be realised by the PUB-OB related subsystems to enable the sketched process for providing Map Data to the On-Board systems. For each function the relevant requirements to be fulfilled are identified. The mentioned functions mainly describe the interaction between DM-TS and DM-OB (see chapter 6.3), which are analysed in more detail in the Evaluation Document: Publish On-Board Map.

6.4.1 Provide On-Board Map Data

6.4.1.1 Allocated requirements

Based on the list of all requirements allocated to PUB-OB the following requirements are identified as relevant in this functional context:

Table 14 Allocated requirements for Provide On-Board Map Data

ID	Requirement
RQ-MO03-1	$The #PUB-OB shall provide Map Data for localisation and future On-Board applications such as ATO/Perception.
RQ-MO03-2	$The #PUB-OB shall offer a dedicated or sufficiently capable channel for Map Data, which is able to transmit the required data volume.

ID	Requirement
RQ-MO03-3	$The #PUB-OB shall provide Map Data for each connected vehicle within its area of operation/control.
RQ-MO03-5	$The #PUB-OB shall minimise the transmitted data volume, i.e., avoid redundant transfers by safe cache, avoid downloading of Map Data areas that are not required during operation.
RQ-MO03-6	$The #PUB-OB shall be able to use public radio to transmit the Map Data until FRMCS will be available.
RQ-MO06-1	$The #PUB-OB shall allow complete or incremental provisioning methods – fitting to the needs of different network sizes (small regional networks up to whole countries).
RQ-MO08-6	$The #PUB-TS and #PUB-OB shall ensure the integrity of Map Data over the whole data flow in trackside and On-Board systems.
RQ-MO08-8	The #MAP shall apply a generic approach to ensure that data used by safety application are trusted.
RQ-MO11-3	$The #PUB-OB shall use standardised interfaces for map update and management.
RQ-MO12-1	$The #PUB-OB shall provide Map Data for improved localisation (map as sensor).
RQ-MO12-2	$The #PUB-OB shall provide Map Data for virtualisation of balises: To enable this function, the balise telegrams according to the engineering needs to be provided as part of Map Data including a virtual position of the balise.
RQ-MO15-1	$The #PUB-OB shall provide Map Data independent from the ETCS communication (with or without movement authority).
RQ-MO15-5	$The #PUB-OB shall provide Map Data for the localisation during Start of Mission process.
RQ-MO15-6	$The #PUB-OB shall allow an operation which can use messages from other RCA systems (such as Journey Profile) as supporting trigger, but not necessarily rely on it.
RQ-MO17-1	$The #PUB-OB shall rely on interfaces and functions that are part of standardisation (e.g., RCA/OCORA, System Pillar, EULYNX, ERTMS, TSI…) only.
RQ-MO17-3	$The #PUB-OB shall support a seamless cross border traffic (between two IMs) by sufficiently robust handover procedures (e.g. overlapping control areas of trackside Map System).
RQ-MO17-4	$The #PUB-OB shall avoid any variants in standardisation which increase the complexity for map management and application during operation.
RQ-MO17-5	$The #PUB-TS shall provide a standardised interface to #PUB-OB.

ID	Requirement
RQ-MO19-1	$The #PUB-OB shall be integratable with legacy architectures (i.e., no other RCA systems should be essentially required except for MAP systems), which offers a wider range of application and different migration scenarios.

6.4.1.2 Conceptual approach

Pre-Condition: The Map Data within DM-TS, that serve as On-Board Map Data provider for DM-OB (On-Board counterpart), shall be activated and ready for operation.

The Map Data is provided to the On-Board based on the request, which is usually sent from DM-OB to DM-TS and shall contain the required map area. Therefore, the required map area is safely defined by the vehicle locator function of the On-Board system (external system) and provided to DM-OB.

To avoid redundant data transfers but still ensure a synchronised state of relevant Map Data between DM-OB and DM-TS, the DM-TS provides Map Reference information in a first step before the actual Map Data is downloaded. The Map Reference identifies and refers to the Map Data within the required map area.

Based on the Map Reference information provided from DM-TS to DM-OB, the DM-OB requests the download of actual missing or outdated parts of Map Data from DM-TS only.

The process is applicable for legacy as well as new architectures such as RCA – integrated into exiting systems and channels or as dedicated, independent systems and channels.

The Map Data is structured in a layer model, which allows a high grade of flexibility and the extension to consider further needs by a growing number of consuming On-Board and trackside systems. The general approach for data modelling is described in document Digital Map – Evaluation Reference Model [9] , which is linked with the topology domain of Abstract Concept [5]. Specific modelling variants in the context PUB-OB are discussed in the document Evaluation On-Board Map Digital Map – Evaluation Publish On-Board Map Approaches [2].

Also, the further details of this process are analysed in the document Digital Map – Evaluation Publish On-Board Map Approaches [2], which is the base for system definition and requirement analysis.

6.4.2 Activate and deactivate On-Board Map Data

6.4.2.1 Allocated requirements

Based on the list of all requirements allocated to PUB-OB the following requirements are identified as relevant in this functional context:

Table 15 Allocated requirements for activate and deactivate On-Board Map Data

ID	Requirement
RQ-MO03-4	$The #PUB-OB shall maintain Map Data safety over the whole life cycle of the vehicle (e.g. shut down train, start of mission, national or international handover procedures between two areas of control, handling degraded modes like “connection lost between trackside and On-Board”, …).
RQ-MO08-6	$The #PUB-TS and #PUB-OB shall ensure the integrity of Map Data over the whole data flow in trackside and On-Board systems.

ID	Requirement
RQ-MO08-8	The #MAP shall apply a generic approach to ensure that data used by safety application are trusted.
RQ-MO12-3	$The #PUB-OB shall maintain the integrity of the Map Data provided to the vehicle (On-Board Map).
RQ-MO15-2	$The #PUB-OB shall ensure that relevant Map Data updates in the trackside systems are communicated to the vehicles.
RQ-MO15-3	$The #PUB-OB shall ensure that no vehicle operates with outdated Map Data.
RQ-MO15-4	$The #PUB-OB shall ensure that Map Data is not used if a potential change of Map Data could be missed (e.g. no connection between trackside and On-Board).
RQ-MO19-1	$The #PUB-OB shall be compatible with legacy architectures (i.e., no other RCA systems should be essentially required except for MAP systems), which offers a wider range of application and different migration scenarios.
RQ-MO20-2	$The #PUB-TS and #PUB-OB shall provide feedback regarding errors during Map Data distribution and activation.
RQ-MO20-3	$A failure in the #PUB-TS and #PUB-OB process shall not lead to operational degraded modes.

6.4.2.2 Conceptual approach

After completion of the download procedure the Map Reference information should also be used to confirm the integrity of received Map Data. Beside the active version and unique reference to Map Data, the Map Reference shall contain protection data, which supports the validation of Map Data received by On-Board. If the validation fails, the Map Data download is requested again. If the validation of Map Data vs. Map Reference is successful, the received Map Data is activated and stored for the usage in applications like On-Board localisation.

In order to maintain the safe state, the stored Map Data shall be deactivated, if the data is outdated. Potential triggers could be

- On-Board system is shut down or re-started (OCORA or legacy)
- The connection between On-Board and trackside system is not established (RCA/OCORA or legacy)
- An identified mismatch between trackside and On-Board Map Version (presumably in RCA/OCORA only)

The details of this process are analysed in the document Digital Map – Evaluation Publish On-Board Map Approaches [2], which is the base for system definition and requirement analysis.

7 Generic MAP requirements

The following requirements are generic requirements in the sense that they cannot be assigned to a specific function or phase (PREP, PUB-TS, PUB-OB). For each requirement it is indicated in which later phase of the specification or development of MAP they have to be considered.

Table 16 Generic MAP requirements

ID	Requirement	Considered by
RQ-MO05-4	$The #MAP and #TRACKSIDE and #ONBOARD shall consider technical feasibility as well as economic efficiency for the configuration of the systems during system design (e.g. avoid very restrictive accuracy requirements (e.g. <10cm) for position data due to higher costs and project durations). The decision process shall be supported by a continuous impact analysis, which directly links the parts and quality criteria of Map Data to the relevant functionality of the consuming systems (e.g. MAP quality framework).	Will be elaborated in “impact analysis” of RCA MAP Quality Model. Perform cross-system impact analysis, that shows the relationship between Map Data and consuming system function on attribute level and evaluates the impact of quality criteria (such as “accuracy”) in the functional context.
RQ-MO09-1	$The #MAP shall be implemented based on “security by design”.	To be considered during formal development process: safety incl. input from security
RQ-MO09-2	$The #MAP shall implement multi-level security zones.	To be considered during formal development process: security
RQ-MO09-3	$The #MAP shall implement security monitoring functions.	To be considered during formal development process: safety incl. input from security
RQ-MO09-4	$The #MAP shall use a central identity and access management.	To be considered during formal development process: safety incl. input from security
RQ-MO09-5	$The #MAP shall ensure providing Map Data in a secure way to the consuming systems avoiding undetected / unintended manipulations.	To be considered during formal development process: safety incl. input from security
RQ-MO10-1	$The #MAP shall enable modularity of a single framework in order to facilitate migration strategies allowing different configurations, which can be independently created, modified, replaced or exchanged with other modules or between different systems (i.e., by minimum number of dependencies to other systems).	To be considered during formal development process: architecture
RQ-MO10-2	$The #MAP processes, tools, system functions and interfaces shall be extendable and scalable for future needs.	To be considered during formal development process/ ARCH process (architecture)

ID	Requirement	Considered by
RQ-MO10-3	$The #MAP shall allow future updates of components and extensions of On-Board Map at low costs and in an independent way (by avoiding impact on other systems).	To be considered during formal development process: architecture & idesign/development
RQ-MO10-4	$The #MAP shall encapsulate minimum viable functions in suitable building blocks.	To be considered during formal development process: architecture
RQ-MO10-5	$The #MAP shall apply a generic safety approach by encapsulating smallest possible safety rel-evant functions in its own building blocks that allow a separate safety assurance (e.g. separate engineering and validation functions).	To be considered during formal development process: architecture & RAMS
RQ-MO11-4	$The #MAP shall ensure that the characteristics/parameters/quality aspects are reusable irrespective of consuming systems.	Elaborated in “impact analysis”
RQ-MO18-2	$The #MAP shall offer fast recovery times to avoid processual or operational delays.	To be considered during formal development process: architecture & design/development
RQ-MO18-4	$The #MAP shall support an automated and remote-controllable deployment concerning the MAP functionality.	To be considered during formal development process: architecture & design/development
RQ-MO21-1	$The #MAP shall monitor the processing of its functions by collecting information about the processing states and results (based on the definition of RAMSS related parameters).	To be considered during formal development process: architecture & design/development
RQ-MO21-2	$The #MAP shall store the monitoring and diagnostic data for later reports and analysis.	To be considered during formal development process: architecture & design/development
RQ-MO21-3	$The #MAP shall provide the monitoring and diagnostic data over a defined monitoring and diagnostic interface.	To be considered during formal development process: architecture design/development
RQ-MO23-1	$The #MAP shall support a cross-system GUI by offering a harmonised interface which can be integrated into a superordinated GUI (i.e. generic Workbench).	To be considered during formal development process: architecture & design/development
RQ-MO23-2	$The #MAP shall support a cross-system Single-Sign-On (SSO).	To be considered during formal development process: architecture & design/development

ID	Requirement	Considered by
RQ-MO23-3	$The #MAP should allow that they are operable or controllable from a superordinated GUI.	To be considered during formal development process: architecture & design/development
RQ-MO23-4	$The #MAP should be able to feedback their current status to enable system-wide synchronisation.	To be considered during formal development process: architecture & design/development

8 Exported MAP requirements

The following two tables contain the requirements that cannot be implemented directly in MAP but are delegated to other systems for implementation. However, these exported requirements are related to other requirements addressed to MAP, so that successful implementation of the requirements in MAP depends on the implementation of the exported requirements in the target systems.

8.1 Exported requirements for Trackside

The table lists all exported requirements for all systems of the trackside domain, that consume Map Data.

Table 17 Exported requirements for Trackside

ID	Requirement
RQ-MO01-4	$The #TRACKSIDE shall pre-load the data for testing/check activities.
RQ-MO01-5	$The #TRACKSIDE shall confirm the successfully accomplished Map Data distribution and loading process (incl. required checks and error management).
RQ-MO02-5	$The #TRACKSIDE shall develop generic engineering rules during standardisation process, which allow an efficient automation of PREP processes (i.e. abstract concepts instead of supplier specific solutions). This includes cross-system compatible and consistent data structures for the configuration of the systems (Map Data).
RQ-MO05-1	$The #TRACKSIDE and #ONBOARD shall minimise the need for physical trackside assets.
RQ-MO05-2	$The #TRACKSIDE shall minimise the need for configuration data, which should basically consist of the Map Data and a very limited set of application specific parameter data (for this goal the interaction with On-Board must be considered as well).
RQ-MO05-3	$The #TRACSKIDE and #ONBOARD shall replace complex fixed configurations by dynamical functional capabilities as far as possible (find the best balance between complexity and required data).
RQ-MO05-4	$The #MAP and #TRACKSIDE and #ONBOARD shall consider technical feasibility as well as economic efficiency for the configuration of the systems during system design (e.g. avoid very restrictive accuracy requirements (e.g. <10cm) for position data due to higher costs and project durations). The decision process shall be supported by a continuous

	impact analysis, which directly links the parts and quality criteria of Map Data to the relevant functionality of the consuming systems (e.g. MAP quality framework).
RQ-MO05-6	$The #MAP and #TRACKSIDE and #ONBOARD should take into account the overall life cycle of the Map Data (including the maintenance phases) for defining the accuracy of the data. The guarantee of the accuracy should not imply an excessive and costly track maintenance work.
RQ-MO11-5	$The #TRACKSIDE shall be based on the overall, common definition of Map Data (incl. domain knowledge for “topology”) to ensure that all building blocks use an identical Map Data reference and to avoid interpretation errors.
RQ-MO14-4	$The #TRACKSIDE shall provide a binding function which confirms that the connected OC fits to the FOT configuration (part of provided Map Data) in a safe way.
RQ-MO16-5	$The #TRACKSIDE shall provide the functionality of partial updates of configuration, also referred to as Map Data.

8.2 Exported requirements for On-Board

The table lists all exported requirements relevant for all systems of the On-Board domain, that consume Map Data.

Table 18 Exported requirements for On-Board

ID	Requirement
RQ-MO05-1	$The #TRACKSIDE and #ONBOARD shall minimise the need for physical trackside assets.
RQ-MO05-3	$The #TRACSKIDE and #ONBOARD shall replace complex fixed configurations by dynamical functional capabilities as far as possible (find the best balance between complexity and required data).
RQ-MO05-4	$The #MAP and #TRACKSIDE and #ONBOARD shall consider technical feasibility as well as economic efficiency for the configuration of the systems during system design (e.g. avoid very restrictive accuracy requirements (e.g. <10cm) for position data due to higher costs and project durations). The decision process shall be supported by a continuous impact analysis, which directly links the parts and quality criteria of Map Data to the relevant functionality of the consuming systems (e.g. MAP quality framework).
RQ-MO05-6	$The #MAP and #TRACKSIDE and #ONBOARD should take into account the overall life cycle of the Map Data (including the maintenance phases) for defining the accuracy of the data. The guarantee of the accuracy should not imply an excessive and costly track maintenance work.
RQ-MO17-2	$The #ONBOARD shall be based on standardised Map Data requirements regarding content, structure, accuracy, etc.
RQ-MO20-4	$The #ONBOARD shall allow the operation in a degraded situation even without available Map Data (e.g. with potentially reduced performance in localisation).

RQ-MO20-5	$The #ONBOARD shall report potential deviations between provided Map Data and data provided by sensors on the vehicle.

Annex A: List of the derived requirements

RQ-MO01-1 $The #PREP-1 shall be able to manage different versions of Map Data (incl. preliminary test/check versions) and ensure its maintainability and updatability.

RQ-MO01-2 $The #PREP-2 shall provide Map Data before it is put into operation for testing purposes.

RQ-MO01-3 $The #PUB-TS shall provide the next version of Map Data before it is required for operation.

RQ-MO01-4 $The #TRACKSIDE shall pre-load the data for testing/check activities.

RQ-MO01-5 $The #TRACKSIDE shall confirm the successfully accomplished Map Data distribution and loading process (incl. required checks and error management).

RQ-MO02-1 $The #PREP-1 shall create the design of the layout of still existing trackside CCS assets (like balises) from the physical track layout with the max. economical grade of automation.

RQ-MO02-2 $The #PREP-2 shall automate the validation of Map Data based on generic rules (structure, consistency, relations, …).

RQ-MO02-3 $The #PREP-2 shall automate the compilation of Map Data to transform the Engineering Data into Map Data as required by the consuming systems, so additional data transformations by the consuming systems are avoided.

RQ-MO02-4 $The #PREP-1 shall not define engineering constraints which will lead to unnecessary restrictions in the Trackside and Onboard systems (e.g. location of segment borders).

RQ-MO02-5 $The #TRACKSIDE shall develop generic engineering rules during standardisation process, which allow an efficient automation of PREP processes (i.e. abstract concepts instead of supplier specific solutions). This includes cross-system compatible and consistent data structures for the configuration of the systems (Map Data).

$The #PREP-1 shall introduce a fully digitised Engineering- and Map-Data flow.

RQ-MO03-1 $The #PUB-OB shall provide Map Data for localisation and future Onboard applications such as ATO/Perception.

RQ-MO03-2 $The #PUB-OB shall offer a dedicated or sufficiently capable channel for Map Data, which is able to transmit the required data volume.

RQ-MO03-3 $The #PUB-OB shall provide Map Data for each connected vehicle within its area of operation/control.

RQ-MO03-4 $The #PUB-OB shall maintain Map Data safety over the whole life cycle of the vehicle (e.g. shut down train, start of mission, national or international handover procedures between two areas of control, handling degraded modes like “connection lost between trackside and Onboard”, …).

RQ-MO03-5 $The #PUB-OB shall minimise the transmitted data volume, i.e., avoid redundant transfers by safe cache, avoid downloading of Map Data areas that are not required during operation.

RQ-MO03-6 $The #PUB-OB shall be able to use public radio to transmit the Map Data in order to be independent of the FRMCS availability.

RQ-MO04-1 $The #PUB-TS shall introduce a fully digitised Map Data flow.

RQ-MO04-2 $The #PUB-TS shall offer the highest grade of automatisation for the distribution of Map Data.

RQ-MO04-3 $The #PUB-TS shall always have a single reliable source of Map Data as provided by #PREP.

RQ-MO04-4 $The #PUB-TS shall allow a distribution and activation of next Map Data version for all consuming systems.

RQ-MO04-5 $The #PUB-TS shall provide feedback loops for coordination and issue solving by external actors.

RQ-MO04-6 $The #PUB-TS shall have a minimal impact on operation (i.e., solve potential issues during preloading phase, decision for activation by TMS, ...).

RQ-MO05-1 $The #TRACKSIDE and #ONBOARD shall minimise the need for physical trackside assets.
RQ-MO05-2 $The #TRACKSIDE shall minimise the need for configuration data, which should basically consist of the Map Data and a very limited set of application specific parameter data (for this goal the interaction with Onboard must be considered as well).
RQ-MO05-3 $The #TRACKSIDE and #ONBOARD shall replace complex fixed configurations by dynamical functional capabilities as far as possible (find the best balance between complexity and required data).
RQ-MO05-4 $The #MAP and #TRACKSIDE and #ONBOARD shall consider technical feasibility as well as economic efficiency for the configuration of the systems during system design (e.g. avoid very restrictive accuracy requirements (e.g. <10cm) for position data due to higher costs and project durations). The decision process shall be supported by a continuous impact analysis, which directly links the parts and quality criteria of Map Data to the relevant functionality of the consuming systems (e.g. MAP quality framework).
RQ-MO05-5 $The #PREP-1 shall focus the engineering capabilities to only those assets and configuration parameters which remain as required input for #TRACKSIDE. This involves the generation of specific, abstract concepts which are required for the RCA safety logic.
RQ-MO05-6 $The #MAP and #TRACKSIDE and #ONBOARD should take into account the overall life cycle of the Map Data (including the maintenance phases) for defining the accuracy of the data. The guarantee of the accuracy should not imply an excessive and costly track maintenance work.
RQ-MO06-1 $The #PUB-OB shall allow complete or incremental provisioning methods – fitting to the needs of different network sizes (small regional networks up to whole countries).
RQ-MO07-1 $The #PREP-1 shall define a structured, semantically consistent, and comprehensive Engineering Data model covering all the input information required for generating Map Data of the consuming systems.
RQ-MO07-2 $The #PREP-1 shall define an interface for the Engineering Data which will be used by the different IMs and vendors to import or process Engineering Data.
RQ-MO07-3 $The #PREP-1 shall re-use existing Engineering Data model standards (i.e. EULYNX PREP, railML) to ensure compatibility across vendor solutions or infrastructure managers and reduce integration efforts.
RQ-MO07-4 $The #PREP-1 shall allow the generalisation of IM/supplier specific engineering processes based on the standardisation and abstract concepts of the consuming systems (e.g. APS).
RQ-MO07-5 $The #PREP shall support the parametrisation of OCs and FOTs in the engineering process.
RQ-MO08-1 $The #PREP must be the single reliable source of Map Data, which is distributed to all the consuming systems.
RQ-MO08-2 $The #PREP-2 must maintain the state of already validated (i.e. by external processes) parts of Engineering Data or Map Data.
RQ-MO08-3 $The #PREP-2 should ensure the consistency of the Map Data with the actual infrastructure situation (complete, accurate/correct, current) by automated comparison between Map/Engineering Data and Acquisition Data.
RQ-MO08-4 $The #PREP-2 must validate the Map Data against proving rules which are derived from the generic engineering rules of the consuming systems.
RQ-MO08-5 $The #PREP and #PUB-TS shall develop the deliveries for the acceptance of automated tools to minimise manual activities during data generation, validation, transformation/compiling, storing and further distribution.
RQ-MO08-6 $The #MAP shall ensure the integrity of Map Data over the whole data flow from the engineering up to the provision to the Trackside and Onboard systems.

RQ-MO08-7 $The #PREP shall maintain safety requirements of the data over the whole life cycle of the system engineering.

RQ-MO08-8 The #MAP shall apply a generic approach to ensure that data used by safety application are trusted.

RQ-MO09-1 $The #MAP shall be implemented based on "security by design".

RQ-MO09-2 $The #MAP shall implement multi-level security zones.

RQ-MO09-3 $The #MAP shall implement security monitoring functions.

RQ-MO09-4 $The #MAP shall use a central identity, access and key management.

RQ-MO09-5 $The #MAP shall ensure providing Map Data in a secure way to the consuming systems avoiding undetected / unintended manipulations.

RQ-MO10-1 $The #MAP shall enable modularity of a single framework in order to facilitate migration strategies allowing different configurations, which can be independently created, modified, replaced or exchanged with other modules or between different systems (i.e., by minimum number of dependencies to other systems).

RQ-MO10-2 $The #MAP processes, tools, system functions and interfaces shall be extendable and scalable for future needs.

RQ-MO10-3 $The #MAP shall allow future updates of components and extensions of Map Data at low costs and in an independent way (by avoiding impact on other systems).

RQ-MO10-4 $The #MAP shall encapsulate minimum viable functions in suitable building blocks.

RQ-MO10-5 $The #MAP shall apply a generic safety approach by encapsulating smallest possible safety relevant functions in its own building blocks that allow a separate safety assurance (e.g. separate engineering and validation functions).

RQ-MO11-1 $The #PREP-2 shall use standardised interfaces to PUB-TS.

RQ-MO11-2 $The #PUB-TS shall use standardised interfaces for Map Data provision and management.

RQ-MO11-3 $The #PUB-OB shall use standardised interfaces for Map Data update and management.

RQ-MO11-4 $The #MAP shall ensure that the characteristics/parameters/quality aspects are reusable irrespective of consuming systems.

RQ-MO11-5 $The #TRACKSIDE shall be based on the overall, common definition of Map Data (incl. domain knowledge for "topology") to ensure that all building blocks use an identical Map Data reference and to avoid interpretation errors.

RQ-MO12-1 $The #PUB-OB shall provide Map Data for improved localisation (map as sensor).

RQ-MO12-2 $The #PUB-OB shall provide Map Data for virtualisation of balises: To enable this function, the balise telegrams according to the engineering needs to be provided as part of Map Data including a virtual position of the balise.

RQ-MO12-3 $The #PUB-OB shall maintain the integrity of the Map Data provided to the vehicle (Onboard Map).

RQ-MO12-4 $The #PUB-TS shall provide the Map Data for Onboard applications (Onboard Map) to the trackside system responsible for PUB-OB process.

RQ-MO12-5 $The #PREP shall generate Map Data for Onboard applications (Onboard Map), such as localisation, which is reliable (i.e. complete, accurate, up to date).

RQ-MO13-1 $The #PREP shall support construction phases (versioning, process times, …).

RQ-MO13-2 $The #PREP shall not be limited to a specific segment size or a maximum number of assets.

RQ-MO13-3 $The #PREP and #PUB-TS shall provide Map Data for all trackside interfaced systems (incl. warning systems).

RQ-MO13-4 $The #MAP shall allow quick data updates (short-term adjustments) considering temporary states of construction phases.

RQ-MO13-5 $The #PUB-TS shall be capable to process and provide the Map Data coming from PREP for the specific segment size (Area of Control).
RQ-MO14-1 $The #PREP shall provide a stable and reliable ID-management for Map Data with cross-system consistency, i.e., in order to allow an efficient safe binding procedure between FOT and OCs.
RQ-MO14-2 $The #PREP shall provide Map Data with all information (protection data), that is required by Trackside to confirm the safe binding to OC/trackside assets.
RQ-MO14-3 $The #PUB-TS shall maintain the integrity of the Map Data.
RQ-MO14-4 $The #TRACKSIDE shall provide a binding function which confirms that the connected OC fits to the FOT configuration (part of provided Map Data) in a safe way.
RQ-MO15-1 $The #PUB-OB shall provide Map Data independent from the ETCS communication (with or without movement authority).
RQ-MO15-2 $The #PUB-OB shall ensure that relevant Map Data updates in the trackside systems are communicated to the vehicles.
RQ-MO15-3 $The #PUB-OB shall ensure that no vehicle operates with outdated Map Data.
RQ-MO15-4 $The #PUB-OB shall ensure that Map Data is not used if a potential change of Map Data could be missed (e.g. no connec-tion between trackside and onboard).
RQ-MO15-5 $The #PUB-OB shall provide Map Data for the localisation during Start of Mission process.
RQ-MO15-6 $The #PUB-OB shall allow an operation which can use messages from other RCA systems (such as Journey Profile) as supporting trigger, but not necessarily rely on it.
RQ-MO16-1 $The #PREP shall provide a stable and reliable ID-management for Map Data, which ensures robustness for unmodified areas.
RQ-MO16-2 $The #PREP and #PUB-TS must provide information about the actual changes (diff), such as deletion, insertion, replacements of specific elements, edges or other parts of the Map Data.
RQ-MO16-3 $The #PREP must define sufficient anchor points to cut the Map Data into parts, that can be changed independently/autonomously. The definition of anchor points must consider the constraints of all trackside systems, that consume the Map Data as configuration.
RQ-MO16-4 $The #PREP and #PUB-TS must provide a versioning system, that is compatible with partial Map Data updates.
RQ-MO16-5 $The #TRACKSIDE shall provide the functionality of partial updates of configuration, also referred to as Map Data.
RQ-MO16-6 $The #PREP and #PUB-TS must provide a versioning system that shall ensure the management of the different versions in a safe way.
RQ-MO17-1 $The #PUB-OB shall rely on interfaces and functions that are part of standardisation (e.g., RCA/OCORA, System Pillar, EULYNX, ERTMS, TSI…) only.
RQ-MO17-2 $The #ONBOARD shall be based on standardised Map Data requirements regarding content, structure, accuracy, etc.
RQ-MO17-3 $The #PUB-OB shall support a seamless cross border traffic (between two IMs) by sufficiently robust handover procedures (e.g. overlapping control areas of trackside Map System).
RQ-MO17-4 $The #PUB-OB shall avoid any variants in standardisation which increase the complexity for map management and application during operation.
RQ-MO17-5 $The #PUB-TS shall provide a standardised interface to #PUB-OB.
RQ-MO18-1 $The #PUB-TS shall support asynchronous loading and synchronous activation of Map Data Versions to support centralised as well as decentralised trackside system platforms solutions.
RQ-MO18-2 $The #MAP shall offer fast recovery times to avoid processual or operational delays.
RQ-MO18-3 $The #PREP shall ensure multi-tenant operation by defining different user groups and separating the data for each group.
RQ-MO18-4 $The #MAP shall support an automated and remote-controllable deployment concerning the MAP functionality.

RQ-MO19-1 $The #PUB-OB shall be integratable with legacy architectures (i.e., no other RCA systems should be essentially required except for MAP systems), which offers a wider range of application and different migration scenarios.
RQ-MO20-1 $The #PREP shall avoid publishing Map Data that is not successfully validated to exclude operational impacts and safety hazards.
RQ-MO20-2 $The #PUB-TS and #PUB-OB shall provide feedback regarding errors during Map Data distribution and activation.
RQ-MO20-3 $A failure in the #PUB-TS and #PUB-OB process shall not lead to operational degraded modes.
RQ-MO20-4 $The #ONBOARD shall allow the operation in a degraded situation even without available Map Data (e.g. with potentially reduced performance in localisation).
RQ-MO20-5 $The #ONBOARD shall report potential deviations between provided Map Data and data provided by sensors on the vehicle.
RQ-MO21-1 $The #MAP shall monitor the processing of its functions by collecting information about the processing states and results (based on the definition of RAMSS related parameters).
RQ-MO21-2 $The #MAP shall store the monitoring and diagnostic data for later reports and analysis.
RQ-MO21-3 $The #MAP shall provide the monitoring and diagnostic data over a defined monitoring and diagnostic interface.
RQ-MO22-1 $The #PUB-TS shall be integratable with legacy architectures (i.e., no other RCA systems should be essentially required except for MAP systems), which offers a wider range of application and different migration scenarios.
RQ-MO23-1 $The #MAP shall support a cross-system GUI by offering a harmonised interface which can be integrated into a superordinated GUI (I.e. generic Workbench) .
RQ-MO23-2 $The #MAP shall support a cross-system Single-Sign-On (SSO).
RQ-MO23-3 $The #MAP should allow that they are operable or controllable from a superordinated GUI.
RQ-MO23-4 $The #MAP should be able to feedback their current status to enable system-wide synchronisation.