RCA

Reference CCS Architecture

An initiative of the ERTMS users group and the EULYNX consortium

Digital Map - System Definition

with focus on airgap between Trackside and On-Board

Document id: RCA.Doc.59

Table of Contents

List of Figures

List of Tables

Version history

Version	Date	Author	Modification/Description
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0.2	06.10.2021	Harish Narayanan	After alignment with DM PHA and DM Evaluation document
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1 Introduction

1.1 Release Information

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1.3 Disclaimer

- The (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.
- The overall MAP process is divided into the phases “Prepare Map Data”, “Publish Map Data to Trackside”, and “Publish Map Data to On-Board”.
- This Digital Map document is focused on the phase “Publish Map Data to On-Board”.
- In general, Digital Map does not have its own subsystem(s), rather Digital Map functionalities that will be allocated to several RCA subsystems. Consequently, Digital Map uses “DM Trackside” and “DM On-Board” as functional clusters (not subsystems/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 regarding independent On-Board Vehicle Localisation component and Virtual Balise.
- While the RCA.Doc.35 [2] defines the overall RCA system, this Digital Map system definition is created additionally to consider the potential integration of Digital Map into legacy system architectures (at least to integrate the functionality of publishing Map Data to On-Board systems) as well as a base for the RCA.Doc.58 [4]. However, all identified functions should be also integrated into the overall RCA system. Therefore, the content and the assumptions have been aligned with the overall RCA architecture and other clusters.
- This document also mentions different subsystems from OCORA like DM-OB, ATP-OB, LOC-OB, PER-OB, IPM-OB. These subsystems are work in progress and their naming are subjective to changes. But the functional aspects defined with regards to these components remain unchanged.

1.4 Purpose of this document

This document involves basic system level understandings, boundaries, detailed functionalities, interfaces, life cycle aspects, operational scenarios, operational context, and exported requirements.

1.5 Target audience

The target group consists of members of the RCA/OCORA.

1.6 Related Documents

The following documents provide related references:

[1] RCA Digital Map Concept [RCA.Doc.46] – published with BL0R2
[2] RCA System Definition [RCA.Doc.35] – published with BL0R2
[3] RCA Digital Map – Evaluation Publish Onboard Map Approaches [RCA.Doc.56] – published with BL0R3
[4] RCA Digital Map PHA [RCA.Doc.58] – published with BL0R4
[5] RCA Terms and Abstract Concepts [RCA.Doc.14] – published with BL0R4
[6] RCA Realisation of RCA Goals [RCA.Doc.48] – published with BL0R2
[7] RCA Solution Concept MAP [RCA.Doc.54] – published with BL0R4
[8] RCA SMI Concept [RCA.Doc.74] – published with BL1R0
[9] 22E126 EUG/LWG LOC-OB System Definition & Operational Context, v1.0, 30.05.2022 [22E126]
[10] RCA Poster [RCA.Doc.40] – published with BL0R4
[11] EN50126-1 - Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1: Generic RAMS Process
[12] ERTMS/ETCS Environmental Requirements, v5, 30.09.1998 [97s066]
[13] ERTMS/ETCS RAMS Requirements Specification (Chapter 2 – RAM), v6, 30.09.1998 [96s126]
[14] RCA Digital Map Quality Framework/Model [RCA.Doc.77] – published with BL1R0
[15] ERA_CSM
[16] RCA Map Object Catalogue [RCA.Doc.69] – Published with BL1R0
[17] OCORA-TWS01-035-CCS-On-Board-(CCS-OB)-Architecture [OCORA035] – Published with OCORA R2

1.7 Terms and Acronyms

For the detailed information on the terms and abbreviations refer to RCA Doc.14 [5].

1.7.1 Terms

The terms provided here are to assist with better understanding and readability of the document.

1. Digital Map (DM/MAP): *see* RCA Doc.14 [5]
2. Map Data: *see* RCA Doc.14 [5]
3. Digital Map Trackside (DM-TS): The functional cluster of Digital Map which is part of the CCS-Trackside responsible for publishing Map Data to the train. (also see chapter 5.1)
4. Digital Map On-Board (DM-OB): The functional cluster of Digital Map which is part of CCS-On-Board responsible for managing and publishing Map Data to the On-Board consumer of Digital Map. (also see chapter 5.2)
5. Map Version Data: Unique version id of (part of) the Map Data.
6. Map Id Data: Unambiguous/unique reference to a certain part of the whole Map Data (id).
7. Map Integrity Data: Suitable information (protection data such as hash) to reveal potential transmission or processing faults.
8. Map Reference Data: Unambiguous reference to a certain version and region of Onboard Map information. It includes information containing Map Version Data, Map Id Data and Map Integrity data required to validate Onboard Map Data.

1.7.2 Acronyms

Table 1: List of acronyms

ATP-OB	Automatic Train Protection On-Board
CCS	Control-Command and Signalling

CCS-OB	Control-Command and Signalling On-Board
CCS-TS	Control-Command and Signalling Trackside
DCM	Device & Configuration Management
DM-OB	Digital Map On-Board
DM-TS	Digital Map Trackside
IPM-OB	Incident & Prevention Mgmt. On-Board
LOC-OB	Localisation On-Board
MOT	Mobile Object Transactor
OCORA	Open CCS On-Board Reference Architecture
PER-OB	Perception On-Board
PHA	Preliminary Hazard Analysis
PREP	Preparation
PROD	Production
PUB	Publish
PUB-OB	Publish On-Board
PUB-TS	Publish Trackside
RCA	Reference CCS Architecture
TFFR	Tolerable Functional Failure Rate
THR	Tolerable Hazard Rate

2 Objectives of Digital Map

Digital Map is a set of functionalities providing track and trackside infrastructure information in the form of structured Map Data. [5]

2.1 Functional clusters under consideration

The functional clusters under consideration are Digital Map Trackside and Digital Map On-Board as introduced in the RCA.Doc.46 [1] and are used to realise the Digital Map functionalities. The primary goal here being provision of Map Data to the trains[1].

Apart from that Digital Map functional clusters also

1. contribute towards realisation of localisation goals (as per ETCS-CR1368) of the RCA;
2. shall be integrable with existing legacy architectures and other introduced game changers like virtual balise.

It is also to be noted that migration scenarios are not considered as part of Digital Map but as part of consuming systems which use the Map Data. The consuming systems should therefore themselves determine a migration strategy for a proper application / utilisation of the Map Data.

2.2 Life cycle of Map Data

As introduced in the RCA.Doc.46 [1] and RCA.Doc.54 [7], the Map Data has a full-fledged life cycle from the preparation of the data till publishing to the consuming systems. The life cycle of the Map Data can be broadly divided into two parts,

Part 1: The engineering, preparation (validation and compilation) aspects build up this part of the Digital Map life cycle. This is also known as PREP phase.

[1] In this document, train(s) refer to CCS-OB system(s).

Part 2: This phase is known as PROD phase The production phase manages the publishing of Map Data to the CCS-On-Board and CCS-Trackside consumers. The PROD phase includes a so called Publish Phase (or PUB Phase) that is further divided into two namely, Publish Trackside phase (PUB-TS) and Publish On-Board phase (PUB-OB). These publish phases are responsible for distribution of Map Data to respective CCS-Trackside (CCS-TS) and CCS-On-Board (CCS-OB) systems. They also include the activation/deactivation of the Map Data within the CCS-On-Board including satisfaction of On-Board consumer needs e.g. localisation.

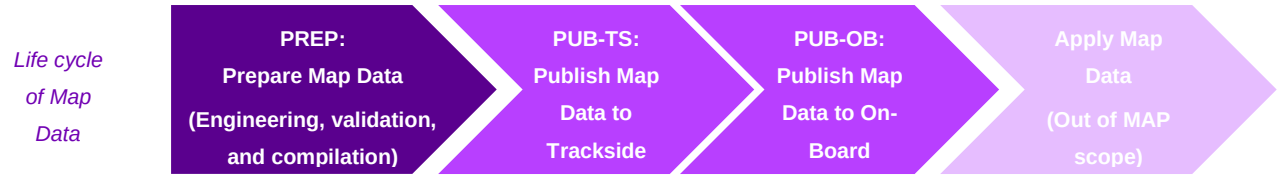


Figure 1: Life cycle of Map Data

These life cycle aspects of Map Data are used to define in-detail the mission profiles of Digital Map. The relevant in/out of scope aspects of the life cycle are defined in chapter 2.3 as a part of mission profiles.

2.3 Mission profile

The following can be derived as the mission profiles for the Digital Map (detailed process description can be found in RCA.Doc.54 [7]),

1. PREP phase
   - ➔ Consisting of preparation aspects (validation, compilation, etc.) of Map Data.
2. PUB-TS phase
   - ➔ Consisting of publish Map Data to CCS-Trackside system aspects;
   - ➔ Consisting of maintaining Map Data aspects (synchronisation of Map Data, versioning, activation/deactivation etc.);
   - ➔ Consisting of ensuring usage of Map Data for CCS-Trackside functionalities e.g., train protection.
3. PUB-OB phase
   - ➔ Consisting of publish Map Data to CCS-On-Board system (according to required map area) aspects;
   - ➔ Consisting of maintaining Map Data aspects (synchronisation of Map Data, versioning, activation/deactivation etc.);
   - ➔ Consisting of distribution of Map Data to CCS-On-Board consumers e.g., LOC-OB, IPM-OB, PER-OB;
   - ➔ Consisting of ensuring usage of Map Data for CCS-On-Board functionalities e.g., localisation.

2.3.1 In scope based on mission profiles

The in-scope aspects as per the foreseen mission profiles can be narrowed down to PUB-OB phase consisting of the publishing of Map Data through the airgap interface to train, maintaining Map Data aspects, and ensuring the usage of Map Data for CCS-On-Board functionalities.

2.3.2 Out of scope based on mission profiles

The following mission profile aspects of the Map Data are currently out of scope for this system definition:

- ➔ PREP phase;
- ➔ PUB-TS phase.

3 Boundaries of Digital Map

This chapter defines the boundaries of the Digital Map functional clusters which realise the airgap interface used to publish the Map Data to the CCS-On-Board.

Based on the initial understandings from the concept phase, the following boundaries are identified.

The Digital Map boundary encompasses of two main Digital Map functional clusters (groups) namely, Digital Map trackside (DM-TS) and Digital Map On-Board (DM-OB). DM-TS and DM-OB are not to be understood as

components or systems or subsystems, rather just as functional cluster (group) consisting of relevant Digital Map functions.

The figure below depicts the boundaries of the Digital Map functional clusters with respective interfaces to systems and actors,

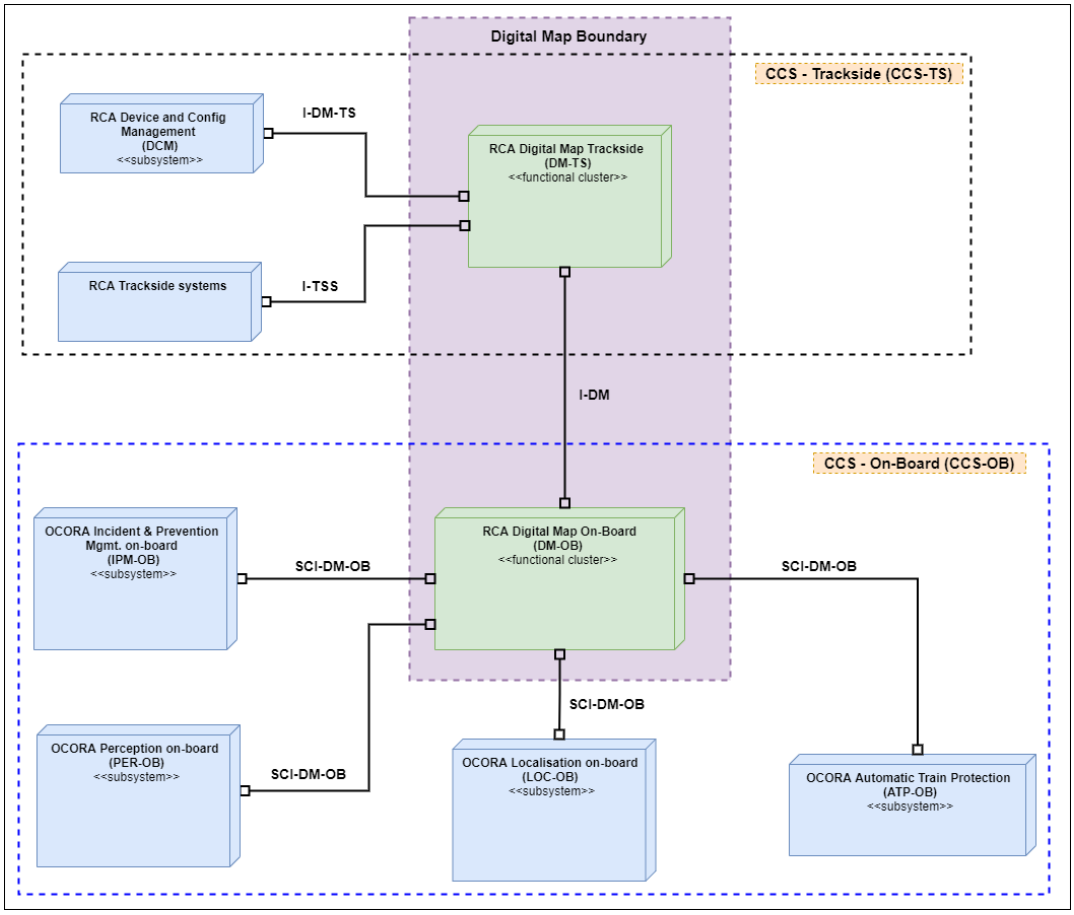


Figure 2: Digital Map boundaries

The Digital Map Trackside functional cluster (DM-TS) as a part of CCS-Trackside, encompasses the trackside Digital Map functionalities (see chapter 5.1 for more details). Keeping in mind the lifecycle of the Map Data from chapter 2.2, the functional cluster Digital Map Trackside is associated with the Publish On-Board phase. It also encompasses the interfaces to Device and Config Management (DCM) and other RCA trackside systems. The systems shown in light blue within CCS-Trackside are considered outside of the Digital Map boundary.

The Digital Map On-Board functional cluster (DM-OB) as a part of CCS-On-Board (also associated with Publish On-Board phase), encompasses the On-board Digital Map functionalities (see chapter 5.2 for more details). The DM-OB is a central functional cluster within CCS-OB which is connected to all the CCS-On-Board Map consumers incl. DM-TS (via air gap) and distributes the Map Data. Currently, the subsystems Localisation On-Board (LOC-OB), Perception On-Board (PER-OB), Incident & Prevention Mgmt. On-Board (IPM-OB) are considered as initial On-Board Map consumers. The listed CCS-OB Map Data consuming subsystems are not exhaustive and subjective to additions in future. The systems shown in light blue within CCS-On-Board are considered outside of the Digital Map boundary.

In addition, the CCS-On-Board also consists of subsystem Automatic Train Protection (ATP-OB) which is not an On-Board Map consumer, rather assists DM-OB with safe deactivation (also see functions DM_O_11 and DM_O_12 in Table 6: Digital Map functions) and update of Map Data.

Note:

1. The interface SCI-DM-OB between ATP-OB and DM-OB currently does not exist in the OCORA system architecture [17] and is subjective to further alignment and coordination with OCORA in the next iterations.
2. The subsystem shown in the Figure 2 have prefixes ‘OCORA’ or ‘RCA’ to indicate the scope of respective subsystems in terms of reference architecture projects. The CCS-OB Map consumers shown in the illustration above are restricted to the ones from RCA.Doc.40 [10]. Other consumers of Map Data that are still part of OCORA system architecture [17] have not been shown here.

The detailed functionalities of Digital Map are listed and analysed later in chapter 6 and allocated to the trackside and On-Board Digital Map functional clusters respectively.

4 Description of Digital Map interfaces

This chapter provides an overview on the interfaces that are part of boundaries of Digital Map.

4.1 I-DM

This is a bi-directional interface between Digital Map Trackside and On-Board, which publishes Map Data to the trains and is responsible for transmission of other applicative aspects like Map Data requests and Map Reference Data. The communication here is ensured through a radio connection. This interface shall be based on the assumptions and requirements derived from RCA.Doc.56 [3].

Note: In RCA, as per conclusions from the RCA.Doc.56 [3] document, this interface could be realised as a part of the SCI-MD between MOT and CCS-OB.

The following table summarises the data flows of I_DM:

Table 2: I-DM data flow

Data flow direction	Exchange item
DM-OB -> DM-TS	1. Map Reference Data Request 2. Map Data request
DM-TS -> DM-OB	1. Map Reference Data 2. Map Data

4.2 SCI-DM-OB

This is a bi-directional interface between the Digital Map On-Board and CCS-On-Board Map consumers. This interface is used to provide the Map Data as well as the Map relevancy check results to the following consumers in train,

1. Localisation On-Board (LOC-OB);
2. Perception On-Board (PER-OB);
3. Incident & Prevention Management On-Board (IPM-OB).

In contrast, this interface is used to provide required Map Area and Map Reference Data information from LOC-OB to DM-OB. The function LOC-OB_SF-101 in 22E126 [9] is responsible to determine the required Map Area around the actual train position in a reliable way.

In addition, this interface is also unidirectionally used between ATP-OB and DM-OB to provide necessary CCS-OB statuses (like Shutdown, disconnection) or Map Data update information to safely deactivate Map Data (see Table 6 – DM_O_11).

The following table summarises the data flows of SCI-DM-OB:

Table 3: SCI-DM-OB data flow

Data flow direction	Exchange item
DM-OB -> LOC-OB/IPM-OB/PER-OB	1. Map Data 2. Map relevancy check result

LOC-OB -> DM-OB	1. Required Map Area 2. Required Map Reference Data
ATP-OB -> DM-OB	CCS-OB statuses

4.3 I-DM-TS

This is an unidirectional interface between the Digital Map Trackside and Device and Config Management. This interface is used to provide the necessary Map Data to the Digital Map Trackside.

Note: In RCA, as per conclusions from the RCA.Doc.74 [8] document, this interface could be realised as a part of the SMI-MOT between DCM and MOT.

The following table summarises the data flows of I-DM-TS:

Table 4: I-DM-TS data flow

Data flow direction	Exchange item
DCM -> DM-TS	Map Data

4.4 I-TSS

This is an unidirectional interface between the Digital Map Trackside and other trackside subsystems. This interface considers other necessary inputs from trackside systems that act as trigger events within the DM-TS. These events might support with Map Data distribution or version update of Map Data, etc. For example, operational plan, MP request, Journey profile, etc.

The following table summarises the data flows of I-TSS:

Table 5: I-TSS data flow

Data flow direction	Exchange item
Trackside systems -> DM-TS	Event triggers like operational plan, MP request, MP, Journey profile

5 Description of Digital Map functional clusters

This chapter provides descriptions of the Digital Map functional clusters, which encompasses the Digital Map functionalities and realise the I-DM airgap interface.

5.1 Digital Map Trackside (DM-TS)

Digital Map Trackside is the CCS-Trackside counterpart that provides the Map Data to all systems needing Map Data for application. The current focus of DM-TS lies on transmission of Map Data to Digital Map On-Board via the airgap interface.

The scope of DM-TS is to obtain the Map Data from Device and Configuration Management (DCM) and distribute it to DM-OB via I-DM. To ensure smooth distribution of Map Data, the Map Data also needs to be managed within the DM-TS. This is done by versioning of Map Data and maintaining the Map versions within the DM-TS. Furthermore, the DM-TS also plays a major role in assuring synchronised Map Data versions between the DM-TS and DM-OB. This is ensured using predefined reference data in the form of Map Reference Data consisting of map Id + integrity information + version data.

In addition, the DM-TS also handles the Map Data/Map Reference Data requests and updates.

Note: In RCA, as per conclusions from the RCA.Doc.56 [3] document, DM-TS could be realised within Mobile Object Transactor (MOT).

5.2 Digital Map On-Board (DM-OB)

Digital Map On-Board is the CCS-On-Board counterpart that obtains Map Data from DM-TS and provides the Map Data to other Map consumers within the train. This functional cluster will have interfaces with all the CCS-

On-Board subsystems that need Map Data (see Figure 2). The current focus of DM-OB lies on satisfying the localisation, perception, and incident & prevention needs of the train.

Similar to DM-TS, DM-OB also needs to maintain the Map Data within the vehicle. Before maintaining the Map Data, it has to be activated.

Activation of Map Data is a crucial part before eventual application of Map Data by consuming systems. Activation process ensures that the Map Data is not corrupted, and the correct Map version is authorised for application. Activation can only be performed when DM-OB has a synchronised/current Map Data based on the Map Reference Data.

In gist, the activation process (see function DM_O_9 Table 6) assures,

1. Integrity of Map Data;
2. Presence of validated (activated) Map Data in train;
3. Usage of correct Map Data version for operation.

Since a synchronised Map Data is imperative for activation and unsynchronised version can potentially compromise safety of consuming systems, such asynchronous states must be safely detected and correspondingly avoided by a deactivation process (for more details see Figure 5).

Deactivation refers to a safe reaction to an unexpected event. Unexpected events can be system shutdowns, Map Data updates, disconnections, etc. A deactivation process is a part/responsibility of DM-OB to deactivate the potential obsolete / asynchronous versions of Map Data in train. This is ensured by deactivating the version of Map Data upon encountering unexpected events (see function DM_O_11 Table 6).

In addition to ensure a safe application of Map Data within train, DM-OB is also responsible for performing Map relevancy checks, wherein the completeness of Map Data is ensured. This is assured by a check between the available minimum/maximum required Map Reference Data in DM-OB and required minimum/maximum required Map Area based on current train position. Map relevancy check basically ensures that the current available Map Data in the On-Board consuming systems (or in DM-OB) suffice for application during the next moments of the train's journey. For more information on scope, context, or definition of Minimum/Maximum Map Reference Data and Minimum/Maximum required Map Area see appendix chapters 9.2 and 9.3.

Furthermore, the DM-OB also evaluates the need of Map Data depending on requests from the Map consumers in train, downloads the Map Data from DM-TS, and updates the Map consumers.

6 Description of Digital Map functionalities

This chapter provides the overview of Digital Map functionalities that are encompassed by DM-TS and DM-OB.

6.1 Processual functional flow

The processual flow of Digital Map defines a detailed process on how the different functions of DM-OB and/or DM-TS functional clusters interact with each other. This process (in brief) includes the following aspects,

1. Requesting of Map Data/Reference Data;
2. Provision of Map Data/Reference Data;
3. Validation of Map Data;
4. Activation of Map Data;
5. Providing Map Data to CCS-On-Board consumer;
6. Deactivation of Map Data.

Note: In the processual illustrations below, the functions related to a single activity are grouped within the blue boxes and identified with IDs. These IDs are correspondingly used in Table 6: Digital Map functions as references. The white boxes within the blue boxes breakdown/define in-detail the functionalities related to the respective activity.

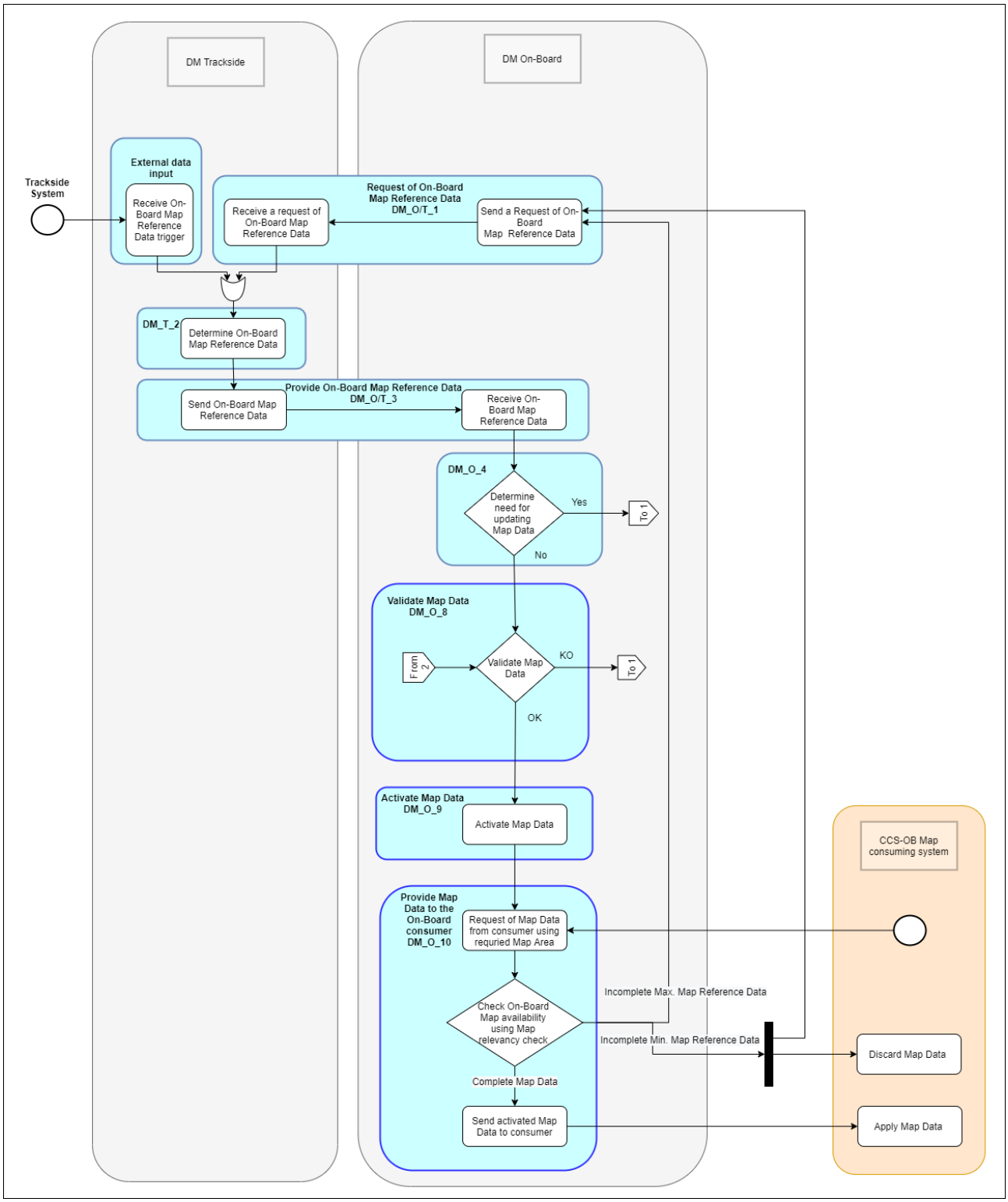


Figure 3: Process for provision/validation/activation of On-Board Map Data

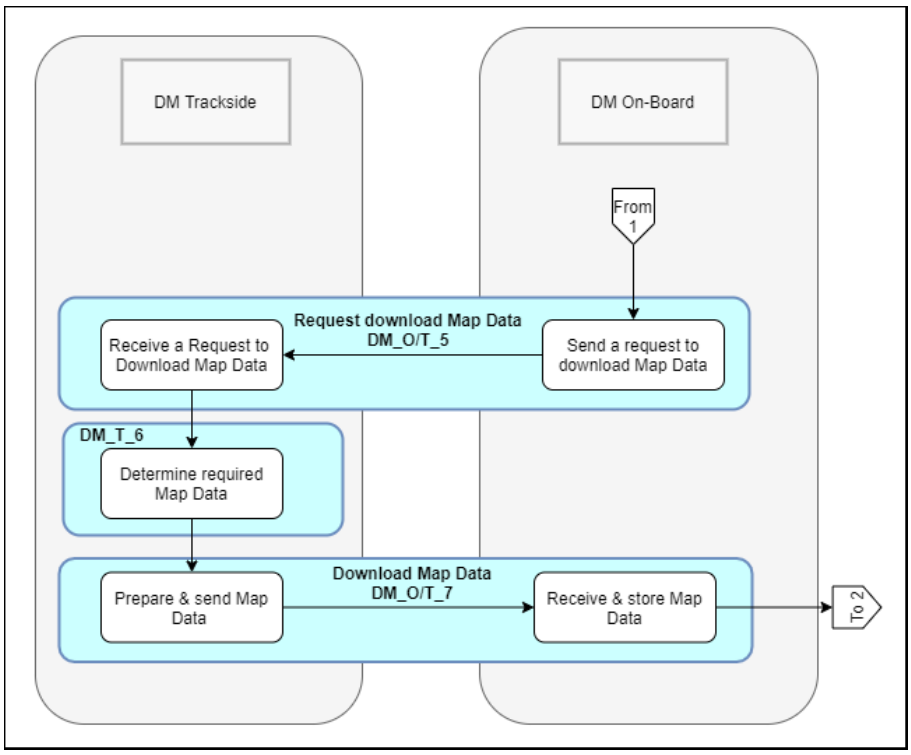


Figure 4: Process for downloading of Map Data

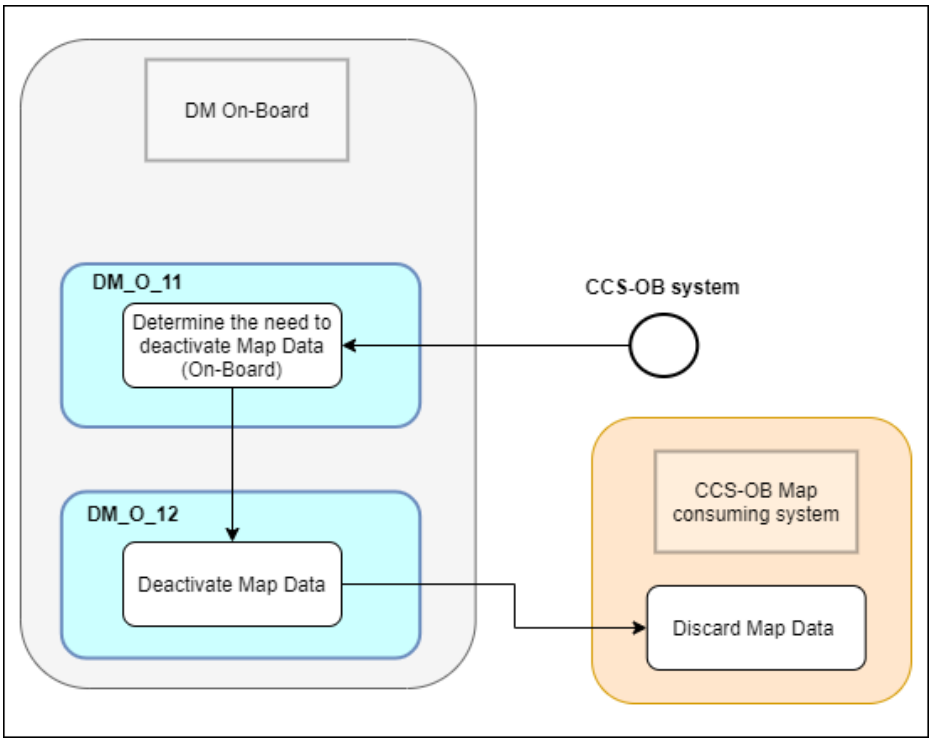


Figure 5: Process for deactivating Map Data

These process flows are developed based on the initial understandings from RCA.Doc.56 [3] and RCA.Doc.58 [4]. The functions that are part of these processes, are identified based on the selected Map Service approach (see RCA.Doc.56 [3] Figure 7) and are listed in Table 6: Digital Map functions. They are allocated to either DM-TS or/and DM-OB. Additionally, colour coded links between the Digital Map functions and certain sequence steps out of RCA.Doc.56 [3] are also provided below (see 'Function' column) to impart a better understanding of concepts.

Table 6: Digital Map functions

Function ID	DM allocation	Function link to step from figure 7 in [3] link to step from figure 8 in [3] link to step from figure 9 in [3]	Description
DM_O/T_1	DM On-Board/Trackside	Request of On-Board Map Reference Data step 4 request [Onboard Map Ref] for [Required Map Area]	This function requests the required Map Reference Data from the DM-TS. This function can be triggered, 1. By requests from consuming systems (e.g. LOC-OB) (DM_O_10) based on Required Map Area; 2. After a re-connect between DM-OB and DM-TS (i.e. due to presence of deactivated Map Data in DM-OB).
DM_T_2	DM Trackside	Determine required On-Board Map Reference Data step 5 Determine required Onboard Map Ref(erence data)	This function determines the required Map Reference Data for a train unit (considering the Required Map Area in the request).
DM_O/T_3	DM Trackside	Provide On-Board Map Reference Data step 6 Provide Onboard Map Ref(erence data) for [Required Map Area]	The function provides the requested Map Reference Data to DM-OB.
DM_O_4	DM On-Board	Determine need for updating Map Data step 3 check activated [Onboard Map] coverage for [required Map Data] step 7 [Onboard Map] (data) available for [Onboard Map Ref]?	This function determines the need for updating the Map Data within DM-OB. The Map Data update can be initiated under several pre-conditions, 1. Unavailable required Map Data in the train; 2. Map Reference Data received from DM-TS; 3. Change in Operational Plan/Journey Profile/Movement Authority of the train, eventually leading to new version of required Map Data; 4. Invalid/deactivated Map Data is present in the On-Board.

Function ID	DM allocation	Function link to step from figure 7 in [3] link to step from figure 8 in [3] link to step from figure 9 in [3]	Description
DM_O/T_5	DM On-Board/Trackside	Request download of Map Data step 8 request [Onboard Map] (data) based on [Onboard Map Ref]	This function requests Map Data from DM-TS. This Map Data download request is dependent on the results of functions DM_O_4 and DM_O_8.
DM_T_6	DM Trackside	Determine required Map Data step 9 determine required [Onboard Map] (data)	This function determines the required Map Data based on a Map Data request.
DM_O/T_7	DM On-Board/Trackside	Download Map Data step 10 provide requested [Onboard Map] (data)	This function provides the requested Map Data from DM-TS to DM-OB.
DM_O_8	DM On-Board	Validate Map Data Step 11 validate available [Onboard Map] (data) against [Onboard Map Ref](erence data)	This function validates the Map Data in DM-OB corresponding to the required Map version provided by DM-TS. This is done by comparing the Map Reference Data received by DM-OB and the downloaded Map Data version in DM-TS.
DM_O_9	DM On-Board	Activate Map Data Step 12 activate validate [Onboard Map] data	This function activates the correct version of Map Data in DM-OB as per the required Map Data and the Map Reference Data. The activation of the Map Data based on the following pre-conditions, 1. Confirmed Integrity of Map Data; 2. Authorised version of Map Data corresponding to the Map Reference Data.
DM_O_10	DM On-Board	Provide Map Data to On-Board consumer Step 2 CCS-OB->DM-OB: request [Onboard Map] for [required map area] Step 14 DM-OB->CCS-OB: provide activated [Onboard Map]	This function evaluates the availability of Map Data depending on a required Map Area request from On-Board Map consumers. This check is performed using a Map relevancy check, wherein the required minimum/maximum Map Reference Data are checked against

Function ID	DM allocation	Function link to step from figure 7 in [3] link to step from figure 8 in [3] link to step from figure 9 in [3]	Description
			the minimum/maximum required Map Area. In case of incomplete minimum Map Reference Data (without foresight buffer), the Map Data is discarded. In case of incomplete maximum Map Reference Data (incl. foresight buffer), the function DM_O/T_1 is triggered, eventually requesting DM-TS for the unavailable Map Data. In case of complete Map Data, the activated Map Data is applied in the On-Board consuming systems.
DM_O_11	DM On-Board	Determine the need to deactivate Map Data (On-board) step 4 initiate disconnect from DM-TS e.g. during handover to new control area step 5 deactivate [Onboard Map] delivered by DM-TS instance	This function determines the need for DM-OB to deactivate the Map Data. The deactivation of a version of Map data can be initiated under certain pre-conditions, 1. New version of Map Data is required as per the Map Reference Data (e.g. due to update of Map Data via I_DM); 2. Due to communication session disconnection from DM-TS (excluding radio holes and other expected events); 3. Due to shut down or restart of CCS-On-Board system; 4. Other safe triggers from CCS-On-Board systems to deactivate Map Data, such as a. Loss of connection between RBC/MT and On-Board (RCA or legacy architecture) or b. "Map Data version update" information

Function ID	DM allocation	Function link to step from figure 7 in [3] link to step from figure 8 in [3] link to step from figure 9 in [3]	Description
			by MT (SS-026 packet) (RCA only). Note: An example for expected event can be a disconnection between DM-TS and DM-OB leading to offline use of Map Data along certain sections of track.
DM_O_12	DM On-Board	Deactivate Map Data	This function deactivates the Map Data within DM-OB and provides a discard Map Data information to the On-Board Map consumers. The deactivation of Map Data is triggered by, DM-OB as per outcome of the function DM_O_11.
External data input	-	Receive On-Board Map Reference Data trigger	For optimisation potentials like earlier Map Data updates, this trackside function receives triggers from external trackside sources which provide sufficient information to DM-TS to determine the required of Map data updates for a train. Examples of such triggers can be Movement Authority/Permission or Journey Profile or Operational Plan (train route part).

6.2 Operational scenarios

To verify the completeness and support understanding of the intended behaviour of the functions defined above, the operational scenarios were created. These scenarios have been defined in appendix chapter 9.1. The scenarios elaborate different operational aspects like,

1. Initialising Map Data service in train (incl. download, activation, and validation processes);
2. Applying Map Data in train;
3. Extending Map Data in train (incl. checking the need to download, update, and handover processes);
4. Terminating Map Data service in train (incl. deactivation processes).

7 Scope of Preliminary Hazard Analysis (PHA)

At the early stage of the Digital Map definition, it is a first attempt approach to identify the potential hazards and events that may lead to an accident and to carry out the risk assessment for these hazards. This allows to define barrier/mitigation measures to reduce identified risks and to derive THR or TFFR apportionments.

It should be shared that the system context used to carry out the analysis is based on the existing ERTMS/ETCS where the concepts of independent onboard vehicle localisation component, virtual balise, and digital map are introduced.

Due to new architecture, game changers, and changing environment, results from RCA/OCORA projects, Digital Map system definition and its environment may change along the way. Therefore, all these impacts have to be taken into consideration when documents, new versions will be released. For this reason, it will be desirable to check and update the PHA according to the results obtained by the RCA/OCORA projects.

The complete PHA including scope definition will be part of the document RCA.Doc.58 [4].

8 Operational context of Digital Map

Note:

1. All Non-Functional Requirements are for the moment defined generically for both DM-OB/DM-TS. This is done to avoid unnecessary redundancies at this stage of specification.
2. Since DM-OB is similar to LOC-OB as a system, the LWG Doc 22E126 [9] has been used as a basis to define all the requirements, assessments, conclusions, values mentioned in this chapter.

8.1 Consumers needs

- ➔ DM-OB/DM-TS shall provide information regarding track axes (e.g. modelled as track points including coordinates, gradient, etc.) and relevant infrastructure elements (e.g. balises) with a pre-defined level of detail (granularity). (Trace: [1] DM.19; [6] T4 (less balises); [3] PPR4)
- ➔ DM-OB/DM-TS shall allow complete or incremental provisioning methods according to region passed by train – fitting to the needs of different network sizes (small regional networks up to whole countries). (Trace: [1] DM.1, DM.4, DM.17; [6] Q4; [3] PPR1)
  Note: Both methods might be applicable exclusively or in combination (hybrid mode: offline or online initial data loading + incremental updates.)
- ➔ DM-OB/DM-TS shall provide consumer specific Map Data having different requirements.

  Rationale: The kind of data and their format have to be defined starting from an analysis to be performed at system level to fulfil the requirements of the different consumers and having in mind the overall functionalities envisaged. The possible consumers of the Map Data are identified in RCA.Doc.69 [16].
- ➔ The DM-TS/DM-OB shall fulfil operational scenarios defined in the appendix chapter 9.1.

8.2 System life-time considerations

- ➔ The life cycle costs must be equal or lower than today's infrastructure data management systems that use different data formats in comparison to RCA's standardised Map Data format.
- ➔ The system shall be standardised as per the defined standard communication/maintenance interfaces with regards to their functions at least to offer product choices of different suppliers. (Trace: [1] DM.7; [3] PPR9)
- ➔ The system shall have a modular structure so that it is flexible for potential future adjustments (incl. lower costs for the same) and facilitate easier migration strategies. Due to the modular architecture, individual components can be exchanged more easily. (Trace: [1] DM.13, DM.3; [6] G1, G3, G2, Q6, Q5, Q8; [3] PPR8, PPR12, PPR13)
- ➔ The system shall encapsulate minimum viable functions in suitable building blocks. (Trace: [6] G1; [3] PPR11)

8.3 Performance requirements

- ➔ The Map Data provided for publishing shall fulfil the quality criteria, minimum quality requirements, acceptable processes, and principles defined within the framework of RCA.Doc.77 [14].
- ➔ DM-OB/DM-TS shall initialise itself at power-on and fulfil operational capabilities (see appendix chapter 9.1 Digital Map operational scenarios) thereafter.

➔ DM-OB/DM-TS shall minimize the transmission data load (volume, amount/number) between track and train. (Trace: [1] DM.2, DM.21; [6] Q4; [3] PPR2)
Note: Digital Map functional cluster shall reduce the need for synchronization, especially between trackside and On-Board systems (airgap)

8.4 RAMSS

8.4.1 Methodology

➔ The methodology to define and to demonstrate the RAMS requirements of the DM-OB/DM-TS shall follow the EN 50126 standard [11].

8.4.2 Reliability

➔ The occurrence of DM-OB/DM-TS to 'not operational' (i.e. major failure or DM-OB/DM-TS is not providing any output) shall be less than 1 event every 10 years.
➔ The hardware failure occurrence of DM-OB shall be less than 4*10-6h (same as LOC-OB).
➔ A software reliability estimation shall be performed utilising metrics and forms 96S126 [13] .
➔ Software failures include (list not exhaustive):
- erroneous warning (no fault found)
- temporary malfunctioning
- erroneous diagnostic

➔ Software failures shall not exceed 60% of the hardware failures target (same as LOC-OB).
Note: It is known that LOC-OB has two different software failure targets of 40% (affecting operational delays) and 60% (not affecting operational delays). Since, the functions of DM-OB/DM-TS shall not lead operational degraded situations, the 40% target was not considered for this system definition.

8.4.3 Availability

➔ The DM-OB/DM-TS shall provide services with a high rate of availability to avoid any impact on train operation.
➔ The DM-OB/DM-TS is considered as available if it provides Map Data / Map Reference Data to consumers.
➔ If the DM-OB/DM-TS is not providing data at the defined rate, the DM-OB/DM-TS is considered as unavailable during this time.
➔ The DM-OB/DM-TS shall have an overall availability of 99,998%. See appendix chapter 9.3 for justification.
➔ The DM-OB/DM-TS shall have a rugged design. The failure of one component shall not lead to lose the DM-OB/DM-TS.

8.4.4 Maintainability

➔ Maintenance costs can negatively affect life cycle costs. For this reason, the system must be designed in such a way that maintenance work is minimal.
➔ The railway operator(IM/RU) must be able to carry out the maintenance themselves or it must be possible for the railway operator to outsource the maintenance work to another company that is officially certified by public authorities to carry out maintenance work.
➔ The long-term maintenance strategy shall include damage-dependent (past) and preventive (forward-looking) measures.
➔ To detect systematic malfunctions early and to carry out preventive maintenance, the system must record relevant diagnostic and maintenance information and share the same, if available, with a diagnostic and maintenance system. This will increase the overall system availability.
➔ Maintenance measures must be carried out in such a way that the system can be operated within the defined RAMS requirements for the entire system life cycle.
➔ DM-OB/DM-TS shall be able to self-diagnose.
Rationale: self-diagnostic capability is necessary to minimise maintenance activities
➔ The results of the self-diagnose shall be able to determine the replaceable unit to be replaced.

- ➔ The Mean Repair Time (MRT) as defined in EN 50126-1 [11] shall be less than 15 minutes.
- ➔ The DM-OB/DM-TS design and maintenance concept shall meet a Mean Time To Restore (MTTR) ≤ 1h. The Mean Time to Restore (MTTR) is defined in EN 50126-1. The administrative delay (MAD), Logistic Delay (MLD) shall not be considered. The time elapsed to restore during service online (incl. reset, reconfiguration) and all architecture-related corrective maintenance tasks shall be considered.

8.4.5 Safety

- ➔ The safety of the DM-OB/DM-TS shall be ensured and demonstrated according to the Common Safety Methods ERA_CSM [15] and the EN 50126 standard [11].
- ➔ The safety level of the DM-OB/DM-TS output data shall be determined according to the safety relevance of consumers (e.g., SIL4 for APS/LOC-OB).
- ➔ The DM-OB/DM-TS input information shall comply with the safety requirement constraints.
- ➔ The failure of one component in DM-OB/DM-TS shall not jeopardise the safety of the whole DM-OB/DM-TS.
- ➔ The DM-OB/DM-TS shall comply to the requirements for transmission systems in EN 50159 to provide safety-related communication between safety related equipment.
- ➔ The manipulations of Map Data shall be avoided by maintaining the integrity of Map Data.

8.4.6 Security

- ➔ The DM-OB/DM-TS shall fulfil requirements and recommendations for cybersecurity as specified in CLC/TS 50701:2021 with the purpose to demonstrate that the system is up to date from a cybersecurity perspective and that it meets and maintains the target level of security for the entire system life cycle.
- ➔ The DM-OB security shall be ensured by using means and technologies in accordance with OCORA security plan.
- ➔ The DM-OB security shall use services provided by the onboard security services (OSS OCORA component [OCORA-TWS01-030]). For information the list of services is:
    - System-wide time service;
    - Central logging;
    - Identity and Access Management;
    - Backup;
    - Asset inventory;
    - Intrusion detection / continuous security monitoring;
    - Public Key Infrastructure;
    - Domain Name Service.
- ➔ Only authorised personnel shall have access to the DM-TS/DM-OB
- ➔ The DM-TS/DM-OB shall be installed in a secure cabinet preventing access to unauthorised people (e.g., passenger and public).

8.5 Operational strategy, conditions, and constraints

8.5.1 Operational strategy

- ➔ The DM-OB/DM-TS operation shall be seamless (no human intervention).
- ➔ The DM-OB/DM-TS shall be designed for an operational use with a life cycle of at least 20 years for individual components and at least 30 years for the entire system.
- ➔ It shall be possible to provide new compatible DM-OB/DM-TS after the system's life cycle has expired.
- ➔ Within RCA, DM-OB shall be operational with all ETCS modes on tracks equipped with radio-based levels (ETCS L2/L3). (Trace: [1] DM.20; [6] T3 (always located); [3] PPR3.1)
- ➔ Within legacy, DM-OB shall be operational with all ETCS modes on track equipped with or without radio-based levels (ETCS L1/L2/L3).

➔ The functionality of DM-OB shall be applicable even without (offline Map Data provisioning and usage) or occasional (online Map Data connection and offline usage of Map Data) connection to DM-TS.

Note: The persistence of validated Map Data in case these cases shall be ensured by safe processes by Infrastructure Manager and is outside the scope of Digital Map cluster.

➔ Digital Map functional cluster shall avoid operational delays due to incomplete Map Data. (Trace: [1] DM.20, DM.16, DM.14; [6] G7, Q2, Q4; [3] PPR5)

8.5.2 Modes of operation

➔ DM-OB shall not operate on tracks not equipped with radio communication. In case such situations occur, the Map Data shall be deactivated (see Table 6 – DM_O_11).

➔ The DM-TS/DM-OB shall not lead to operational degraded situations. Some of the already identified degraded situations for Digital Map are:

- Loss of connection between the trackside and On-Board Digital Map functional clusters;
- Unvalidated Map Data within CCS-On-Board unit;
- Train not localised/located within an Area of Control of MT/RBC.

8.6 Environment

➔ The Digital Map functional clusters shall function under the environmental conditions defined in 97s066 [12], especially for the following:

- Temperature;
- Altitude;
- Humidity;
- Air movements;
- Rain, snow, hail, ice, and water;
- Solar radiation;
- Pollutants and contaminants;
- Fire;
- Electromagnetic compatibility and power supplies;
- Vibration and Shock;
- Chemicals;

➔ 97s066 [12] describes the operational environmental requirements, guidelines, and test requirements for the operation of ERTMS train mounted equipment like the DM-OB.

➔ As 97s066 [12] was derived from preliminary CENELEC standards, updates made in EN 50121, EN 50125, EN 50155, IEC 60721, EN 61373 and EN 45545 shall be considered.

8.7 Logistic considerations

➔ The individual system components must be always ready for use and, if necessary, exchangeable. This assumes that the necessary equipment is in reserve.

➔ The presence of the following points must be ensured:

- spare parts warehouse;
- trained maintenance personnel;
- maintenance tools;
- maintenance manuals.

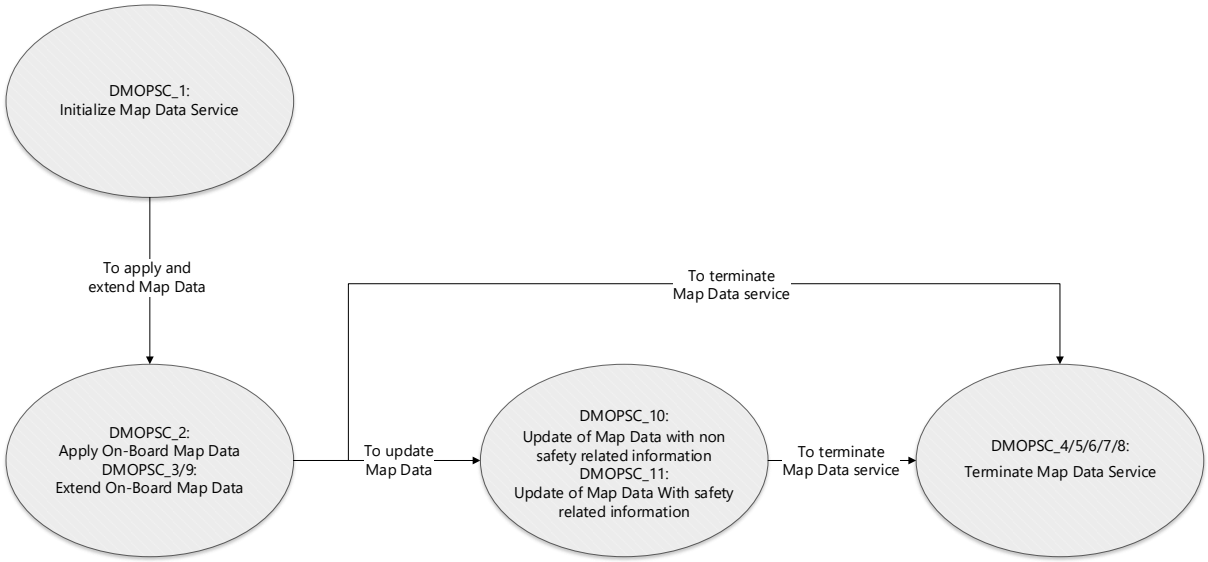
9 Appendix

9.1 Digital Map operational scenarios

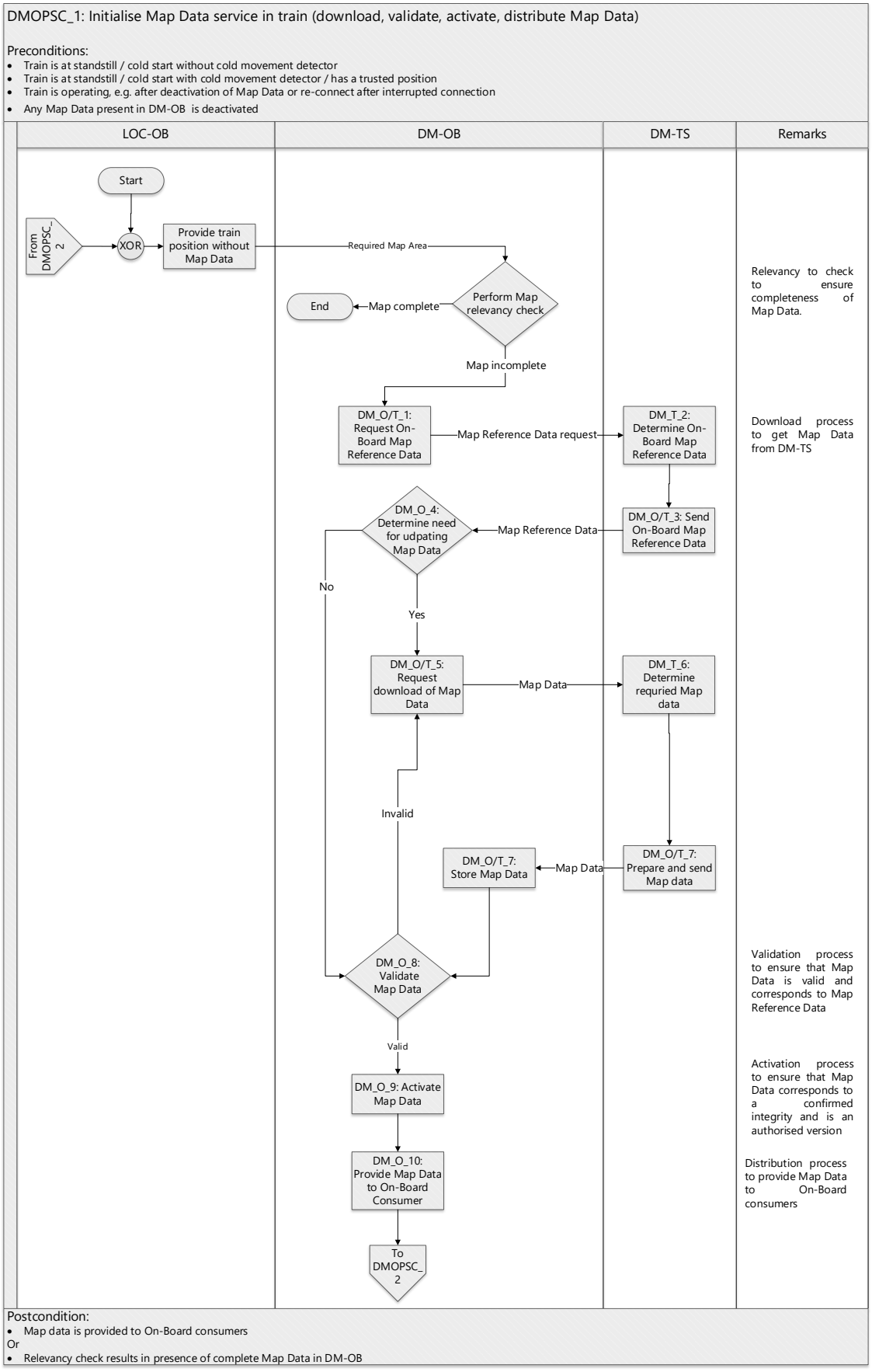
This section of appendix elaborates the Digital Map Operational Scenarios. It is to be noted that the scenarios are not defined formally and hence they might lack compliance to certain modelling semantics like SysML or UML.

9.1.1 Overview of the Digital Map operational scenario

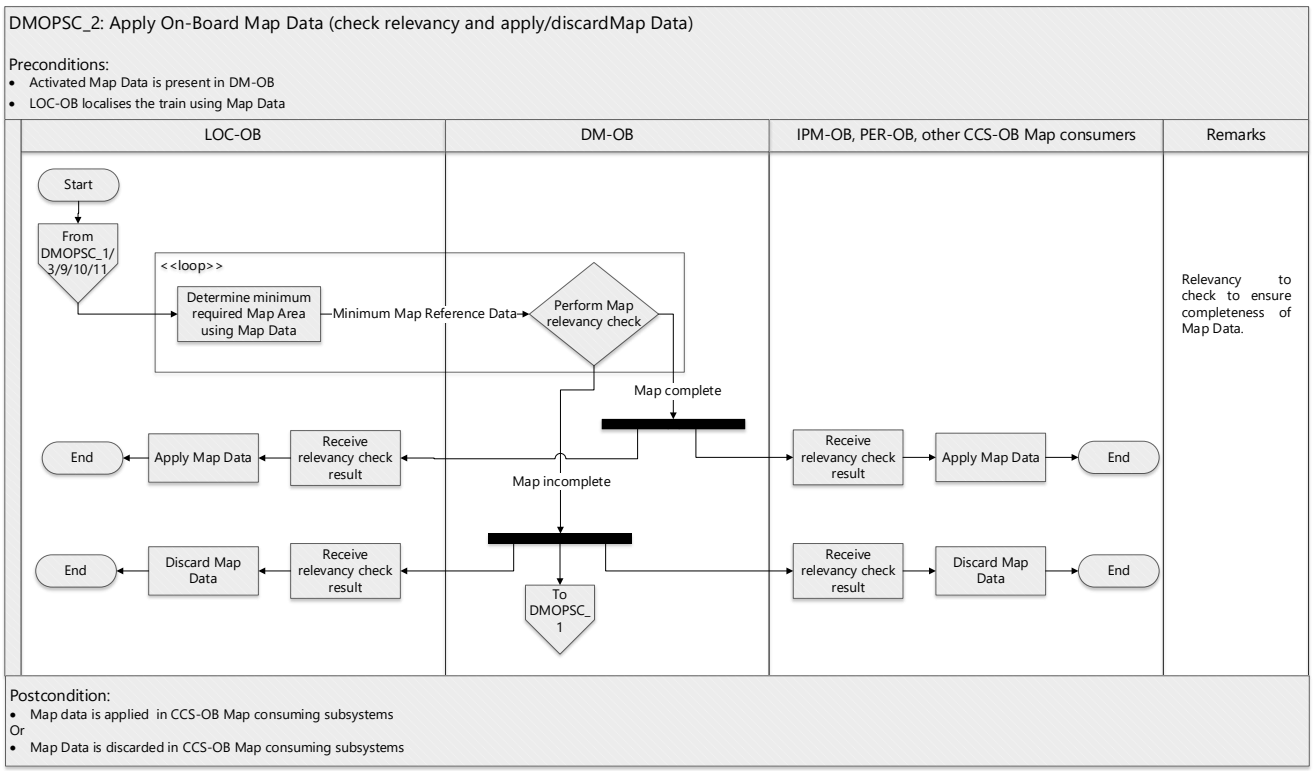
The illustration below provides an overview of the operational scenarios along with certain relationships between them. The bubbles represent the operational scenarios and this overview is not to be confused with a use case diagram.



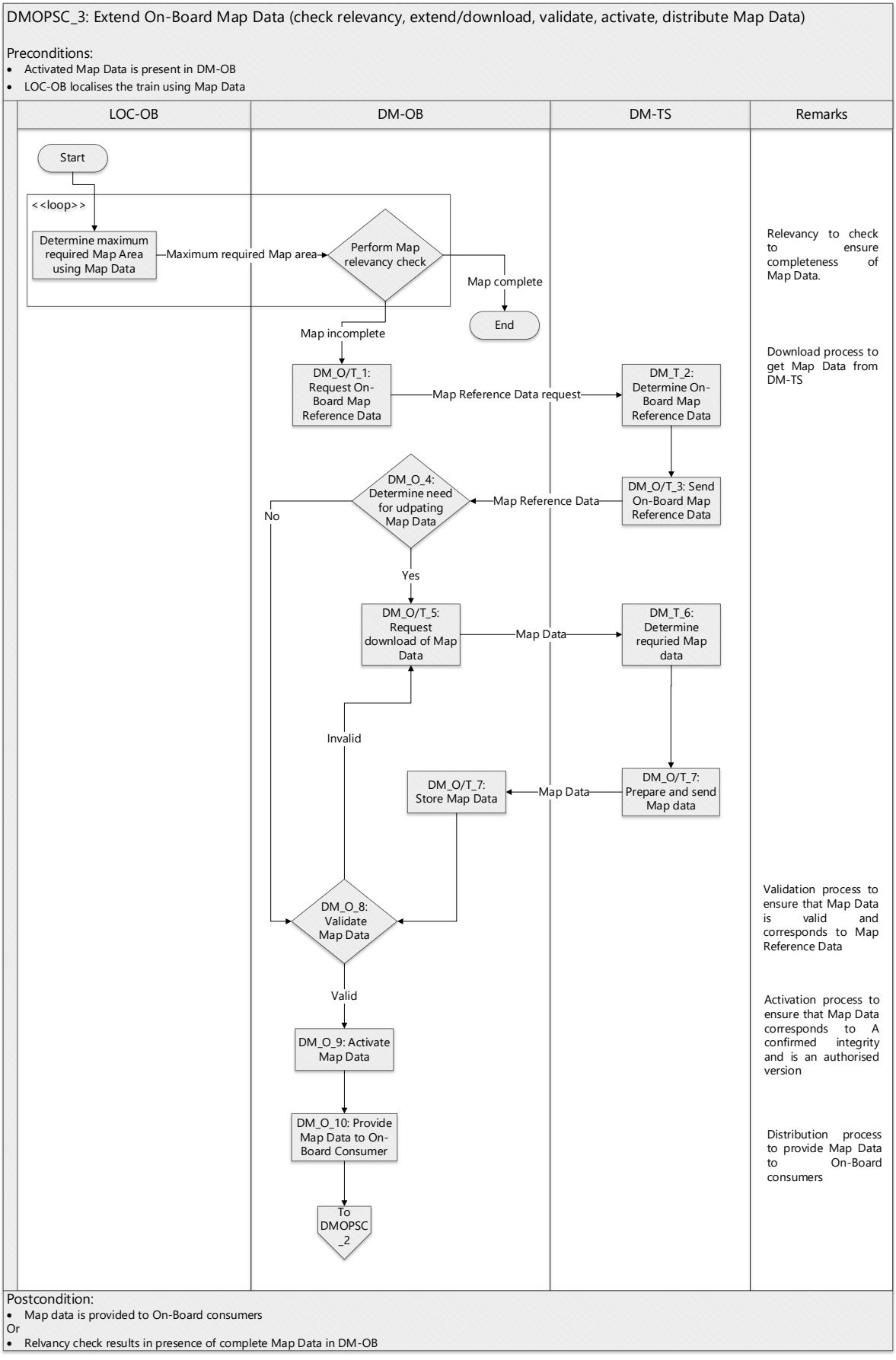
9.1.2 DMOPSC_1: Initialise Map Data service in train (download, validate, activate, distribute Map Data)



9.1.3 DMOPSC_2: Apply On-Board Map Data (check relevancy and apply/discard Map Data)



9.1.4 DMOPSC_3: Extend On-Board Map Data (check relevancy, extend/download, validate, activate, distribute Map Data)

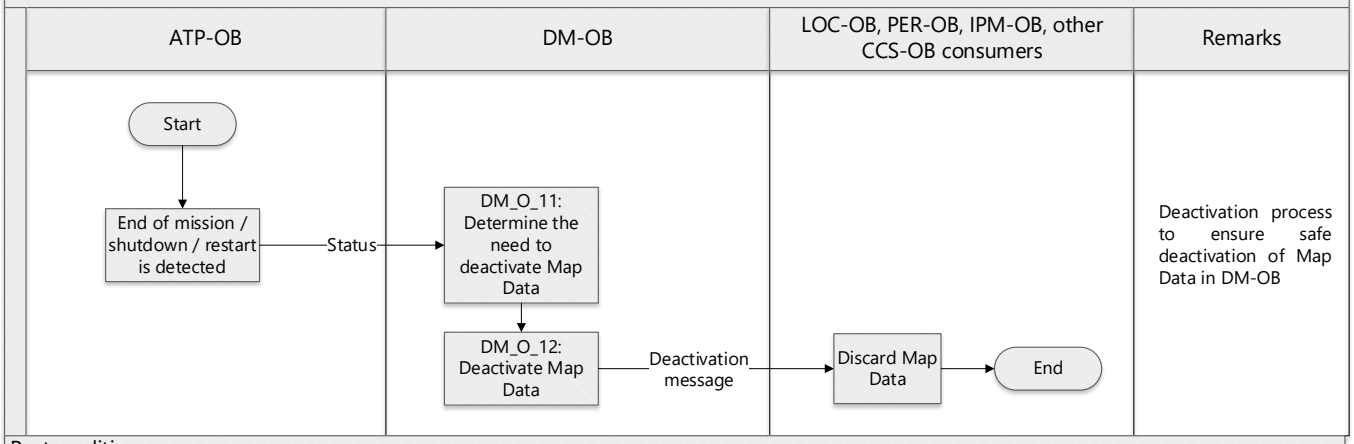


9.1.5 DMOPSC_4: Terminate Map Data Service due to restart/shutdown of ATP-OB or End of Mission

DMOPSC_4: Terminate Map Data Service due to restart/shutdown of ATP-OB or End of Mission

Preconditions:

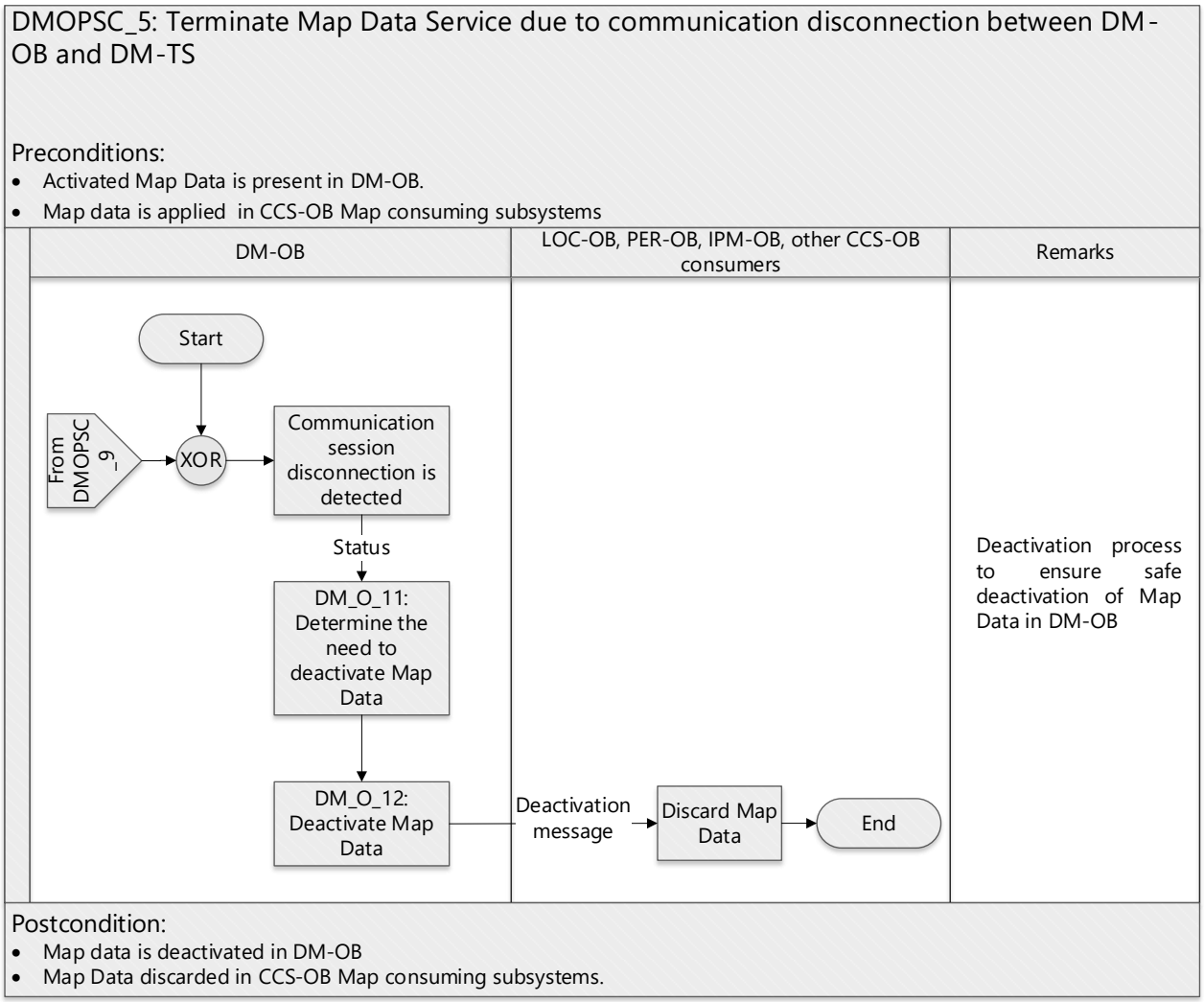
- Activated Map Data is present in DM-OB.
- Map data is applied in CCS-OB Map consuming subsystems



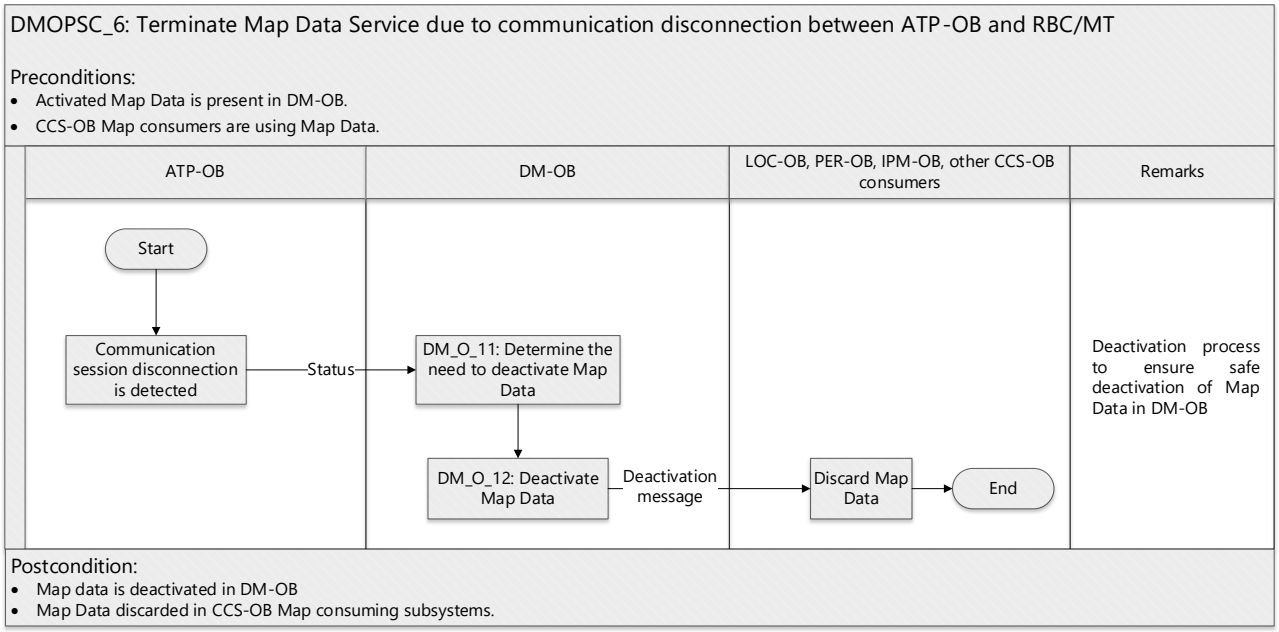
Postcondition:

- Map data is deactivated in DM-OB
- Map Data discarded in CCS-OB Map consuming subsystems.

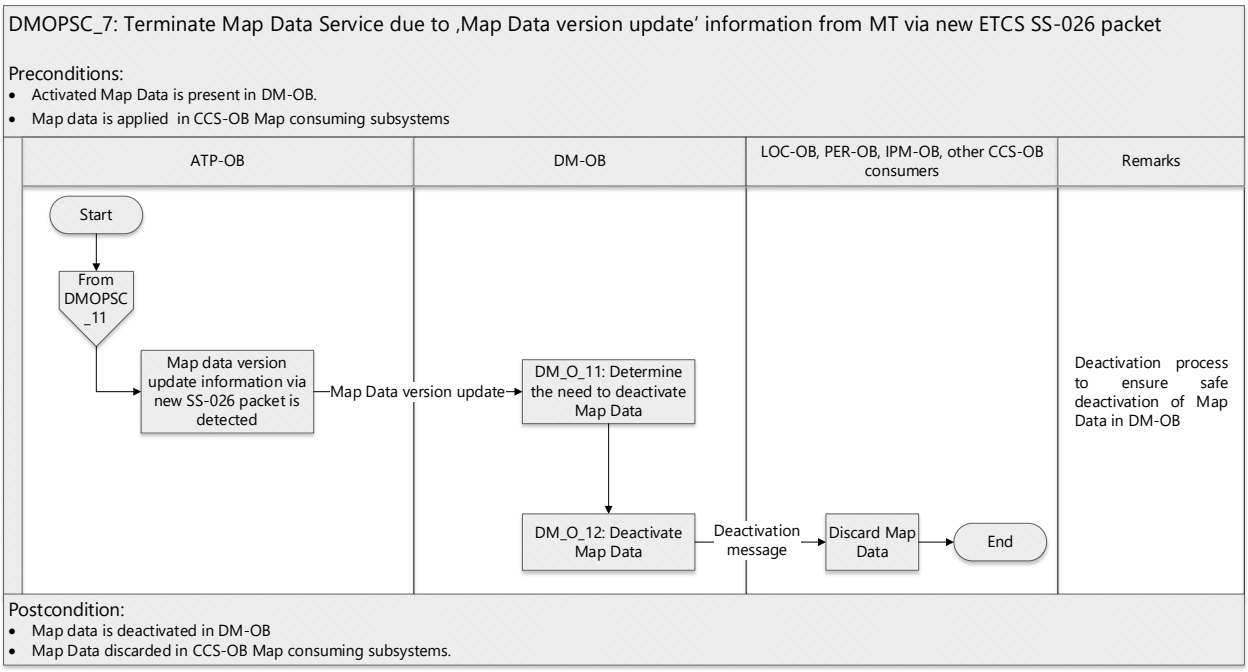
9.1.6 DMOPSC_5: Terminate Map Data Service due to communication disconnection between DM-OB and DM-TS



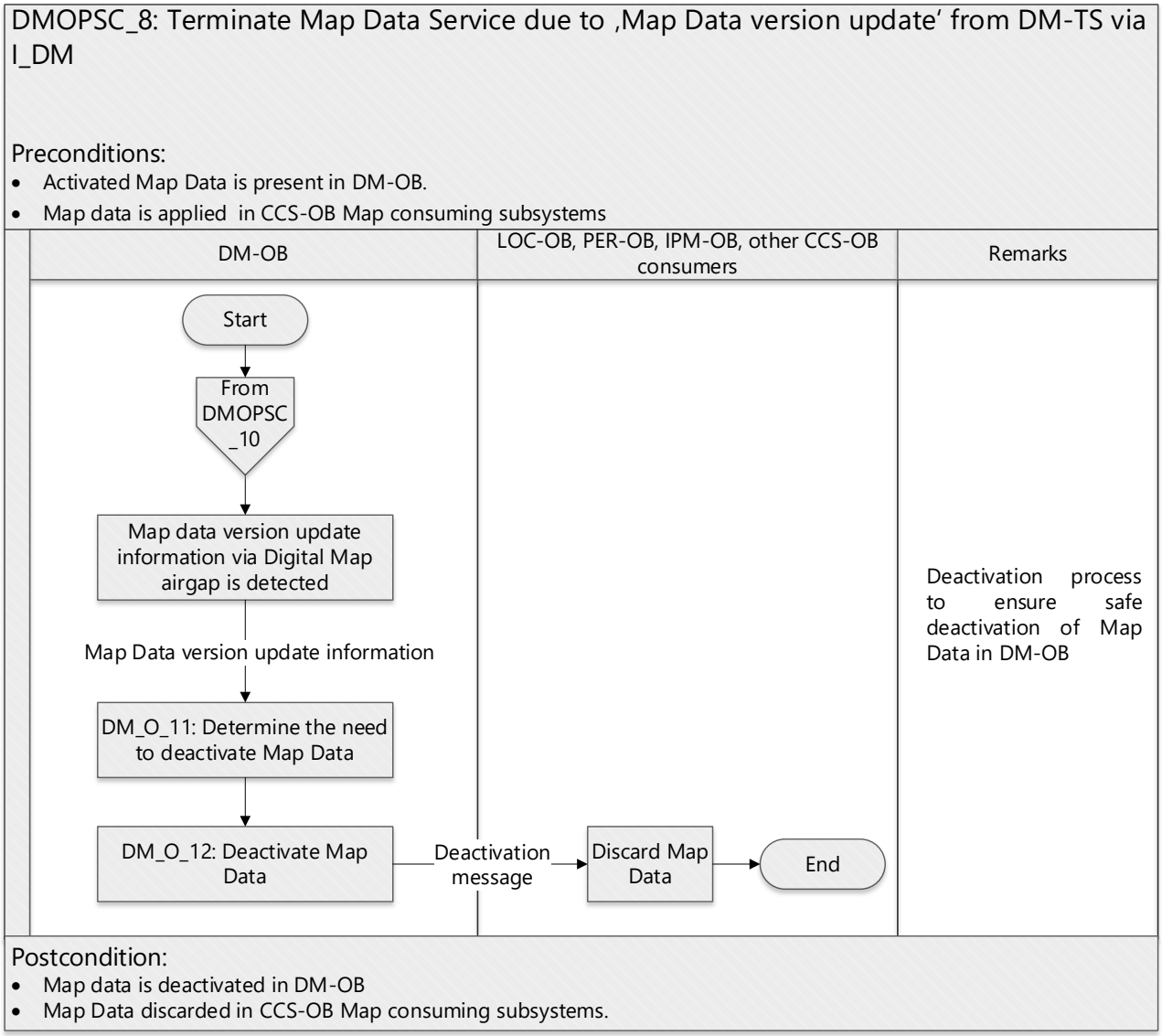
9.1.7 DMOPSC_6: Terminate Map Data Service due to communication disconnection between ATP-OB and RBC/MT



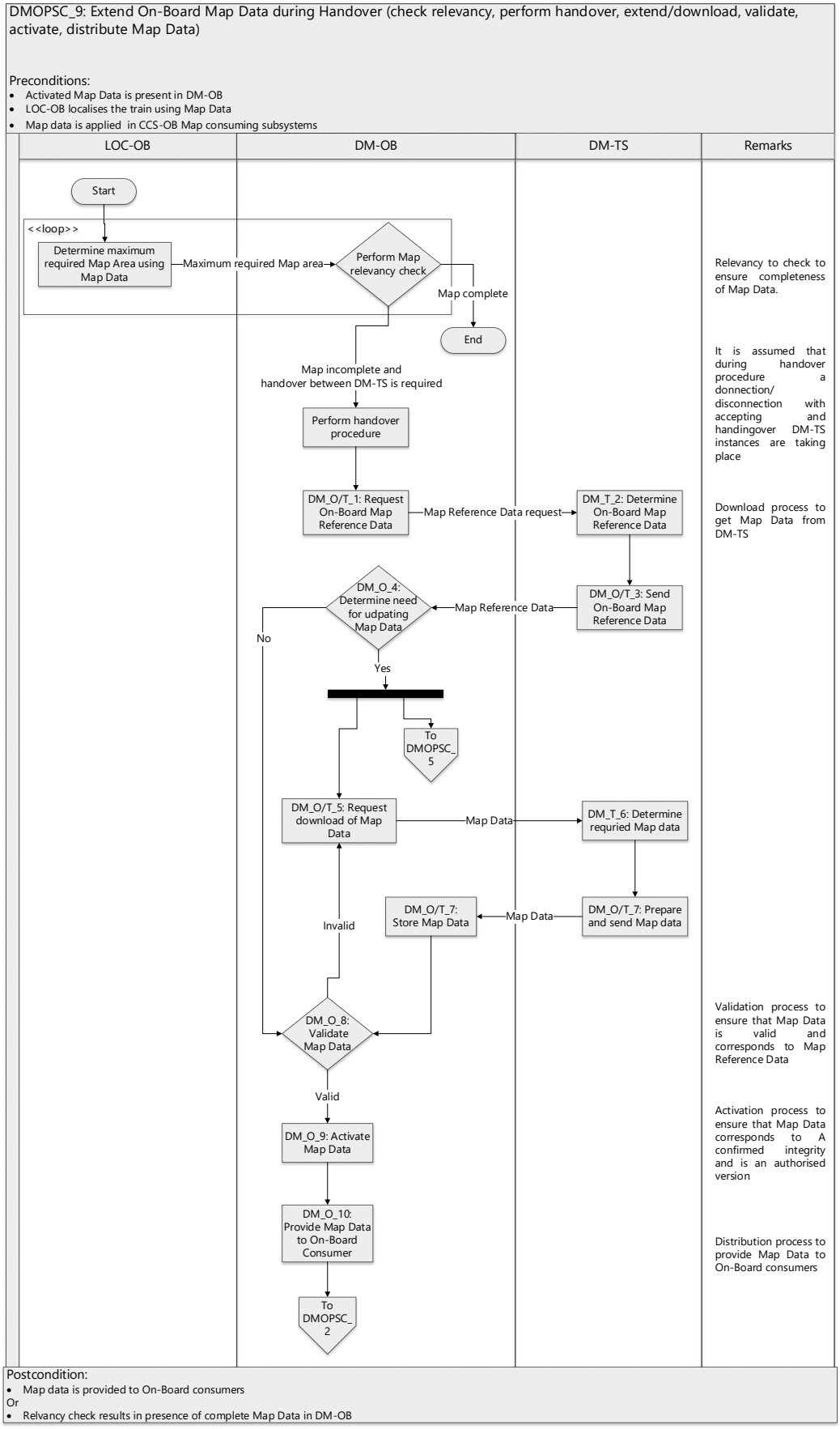
9.1.8 DMOPSC_7: Terminate Map Data Service due to 'Map Data version update' information from MT via new ETCS SS-026 packet



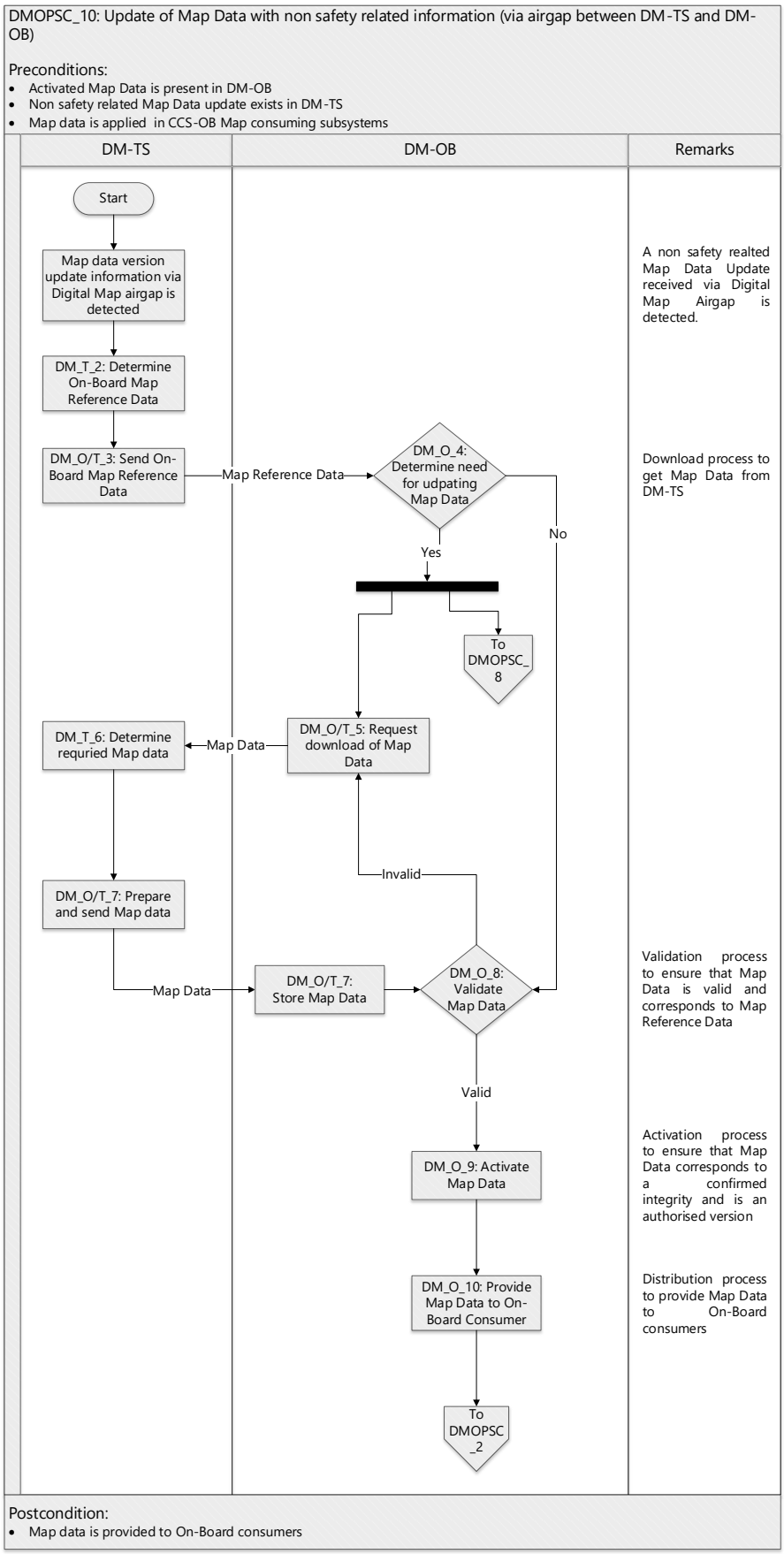
9.1.9 DMOPSC_8: Terminate Map Data Service due to ‘Map Data version update’ from DM-TS via I_DM



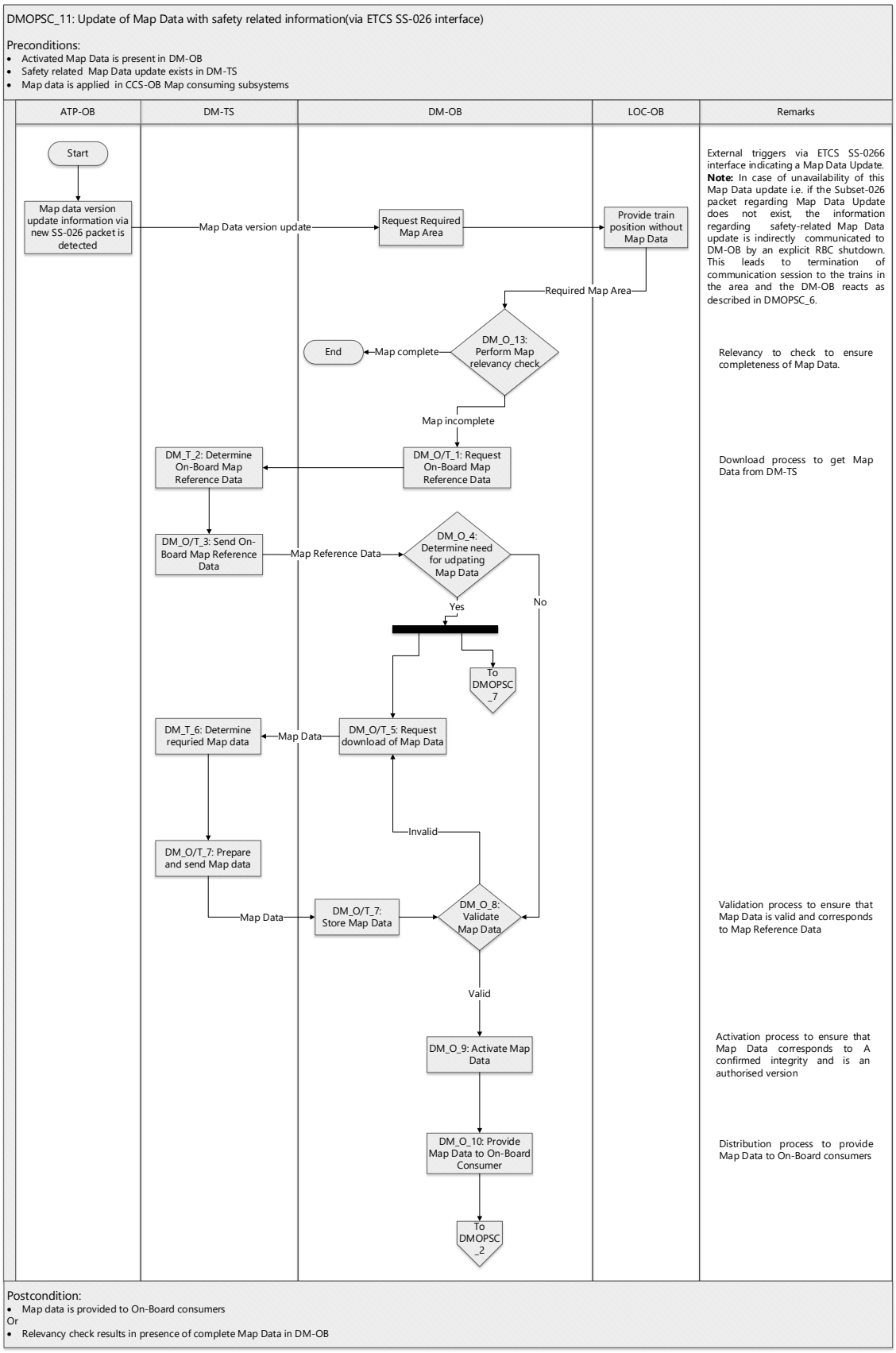
9.1.10 DMOPSC_9: Extend On-Board Map Data during Handover (check relevancy, perform handover, extend/download, validate, activate, distribute Map Data)



9.1.11 DMOPSC_10: Update of Map Data with non safety related information (via airgap between DM-TS and DM-OB)



9.1.12 DMOPSC_11: Update of Map Data with safety related information (via ETCS SS-026 interface)



9.2 Concept: Minimum and Maximum Map Reference Data

This concept is provided as an informative aspect to improvise the understanding of the Map relevancy check in Digital Map operational scenarios. This concept is a draft and is not be considered as a deadlock for this system definition document.

The following definitions in brief define the minimum/maximum Map Reference Data.

- ➔ **Max. Map Reference Data** is derived from the Map Data corresponding **Max**. **Required Map Area request**. The Max. Required Map Reference Data refers to the data within blue (including orange) boxes in the image below.
- ➔ **Min. Map Reference data** is derived from the Map Data corresponding **Min. Map Required Map Area**. The Min. Required Map Reference Data refers to the data within orange boxes.

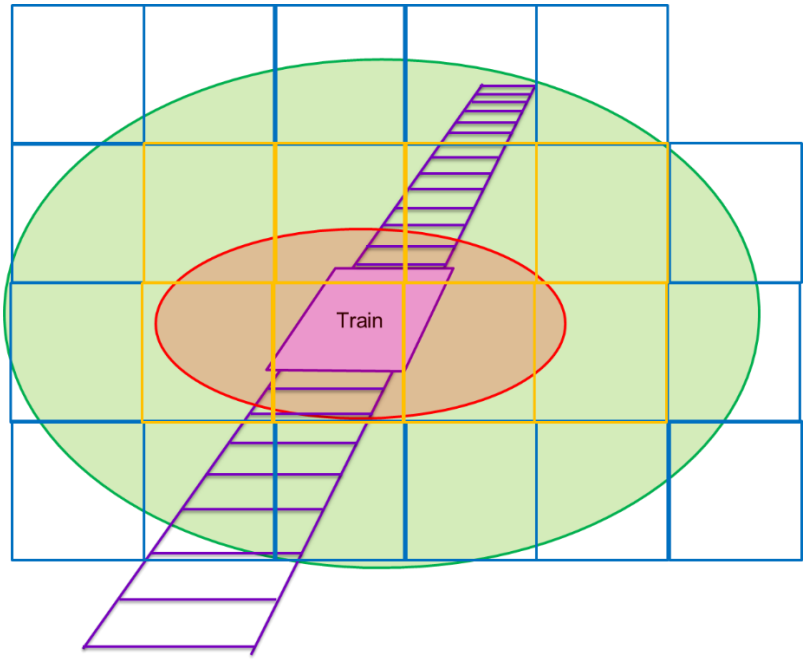


Figure 6: Minimum/maximum Map Reference Data

Note: The areas are assumed to be tile based map regions just for illustration purposes.

9.3 Concept: Minimum and Maximum required Map Area

This concept is provided as an informative aspect to improvise the understanding of the Map Data requests in Digital Map operational scenarios. This concept is a draft and is not to be considered a deadlock for this system definition document.

The following definitions in brief define the minimum/maximum required Map Area.

- ➔ **Min. Required Map Area** is a geo-positioned data defined by using a configured minimum foresight (or estimated positioning inaccuracy if this value is higher than configured **minimum foresight** due to bad confidence) around the estimated train position.
- ➔ **Max. Required Map Area** is a Geo-positioned data consisting of the Min. Required Map Area and buffer in-front of/around train. The buffer is calculated using current speed, configured **minimum foresight buffer**, and if required can also consider ATO Journey Profile or ETCS Movement Authority.
- ➔ **Min. Foresight Buffer** is the minimum (foresight) buffer according to On-Board consuming system needs. The highest value amongst all On-Board systems will be used for generic **Max. Required Map Area.**
- ➔ **Min. Foresight** is the minimum foresight according to On-Board consuming system needs (e.g. PER/IPM needs several 100 meters around or along the track for its position). The highest value amongst all On-Board systems will be used for generic **Min. Required Map Area.**

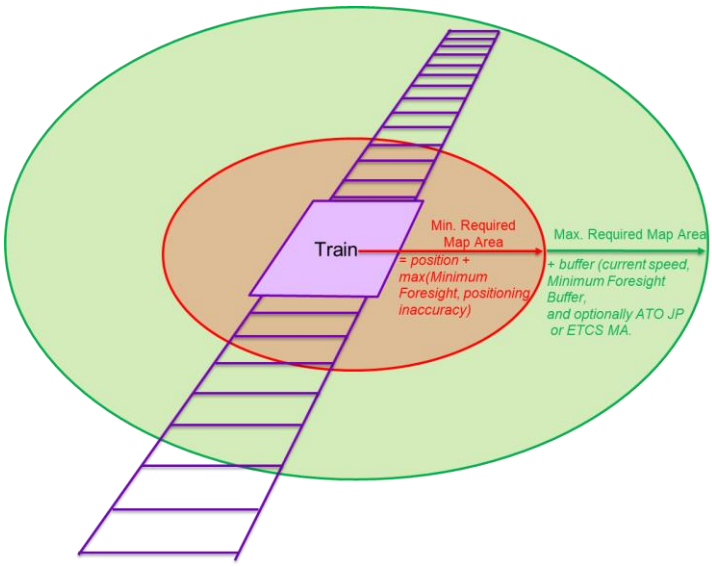


Figure 7: Minimum/maximum required Map Area

Note: The areas are assumed to be circles with radii just for illustration purposes.

9.4 DM-OB/DM-TS availability target justification

The availability is assessed on a monthly period and the method used to define the availability target of the DM-OB/DM-TS is based on the goal of the overall availability to be achieved at the level of a line. From the overall availability target, at the level of the line, an apportionment is made on the main systems. Finally, the DM-OB/DM-TS availability target is derived.

The overall availability target of a line used in the calculation is 99.9% (which is not so high, in general it is more 99.97%).
This availability figure leads to a downtime of 43.2 minutes per month (considering line is operated 24 hours a day, 30 days per month).

The downtime is considered as the loss of time in operation (train delayed) with regard to the transportation plan. It denotes the time during which the system is not performing as it should be, eventually leading to delay and to loss of capacity.

The three main subsystems considered at the level of the line are:

- ➔ Traction power and track
- ➔ Rolling stock
- ➔ Signaling and protection system

The following apportionment of the down time are made between these systems

Table 7: Allocation of downtime per month for each subsystem

Subsystem	Ratio	Downtime in minutes per month
Overall downtime	1	43.2 minutes
Traction power and track	0.25	10.80 minutes
Rolling stock	0.25	10.80 minutes
Signalling and protection system	0.50	21.60 minutes

The signalling and protection system is broadly divided in following parts of our interest: the on-board localisation system, interlocking, ETCS trackside/MT/RBC, ETCS on-board/ATP, IPM, PER, DM-OB/DM-TS, etc.

DM-OB/DM-TS being new systems will also vastly contribute to the downtime of signalling and protection system.

As per LOC-OB System Definition [9], the estimated apportionment for On-Board localisation system is 1/3 of the total contribution from signalling and protection system. In consequence, only the remaining 2/3 of the apportionment from signalling and protection systems can be used to calculate the downtime of DM-TS/DM-OB.

Therefore, the apportionment of the downtime used for DM-TS/DM-OB is estimated to be 35% of the remaining 2/3 of total contribution is calculated to be 5.04 minutes.

To assess the operating time of the DM-OB/DM-TS, the analysis is based on a transportation plan (train planning) for main line corridor and high-speed line.
The number of trains running per hour in both directions are counted, then a mean of train running per hour can be derived (i.e. number of trains per hour during the day/24h).
Therefore, the operating time per month of DM-OB/DM-TS in minutes is: number of trains per hour * 24*60*30.

For the main line corridor, an average of 5 trains (both directions) per hour is used as an assumption leading to an operating time of 216000 minutes per month.
For the high-speed line, an average of 12 trains (both directions) per hour is used as an assumption leading to an operating time of 518400 minutes.

Finally, the DM-OB/DM-TS availability figure is deduced for these two use cases.

Table 8: DM-OB/DM-TS availability target based on two use cases (5 and 12 trains per hour)

Number of trains per hour (mean, both directions)	5 trains per hour	12 trains per hour
DM-OB/DM-TS operating time in minutes	216000 minutes	518400 minutes
Downtime (35% of remaining 2/3 downtime)	5.04 minutes	5.04 minutes
DM-OB/DM-TS availability	**99,9976%**	**99,9990%**

From this study the DM-OB/DM-TS availability target is set to **99,998%.**

10 Open points

1. Definition of Map Data update process sufficient trackside information as trigger in DM-TS. See the functional description for Receive On-Board Map Reference Data trigger in Table 6
2. Processes for definition and transmission On-Board Map Data within trackside systems.