RCA

Reference CCS Architecture

An initiative of the ERTMS users group and the EULYNX consortium

Digital Map – Evaluation Publish On-board Map Approaches

Preliminary issue

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1. Introduction

1.1. Release information

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1.2. Imprint

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Support and Feedback: For feedback, or if you have trouble accessing the material, please contact rca@eulynx.eu.

1.3. Scope and purpose of the document

The focus of this document from the RCA Digital Map cluster is the provisioning of Map Data from trackside to on-board. In the following this data is referred to as “On-board Map”, in order to separate it from the Map Data that is provided to other systems.

In this initial scope the On-board Map should be primarily used for enhancement of the train localization function (including new reference points or the reduction of number balises), which is used, among other possible functionalities, by ERTMS. Examples for future use cases related to On-board Map are about Perception (e.g. ATO GoA 4) or Passenger Information Systems.

For basic explanation regarding the motivation, scope, principles, and the environment, this document refers to the RCA Digital Map – Concept [3].

During the discussions, regarding providing On-board Map for odometry enhancement from trackside to on-board, different scenarios are discussed, which range from solutions that are *highly integrated* into the existing message stream between trackside and on-board (ETCS/ATO) up to *dedicated map service* approaches, which are delivering the On-board Map by a specific channel and synchronize actual and already provided map version in relevant situations (e.g. new movement authority).

Usually, the level of detail of this discussion does not fit to the actual phase of development since the RCA process is still in the “system analysis” and early “logical level” phase. However, since the discussions are pushed by other international or national activities and by the need to come to a solution proposal for the airgap interface (TSI), this evaluation shall structure and document the discussion incl. advantages and disadvantages of the approaches. While the higher level of the architecture process can still be open regarding different approaches, the following levels and development phases require a decision regarding the approaches that should be followed to avoid unnecessary efforts and ensure interoperability.

Therefore, this document sketches and evaluates different approaches for the publishing of On-board Map from trackside to on-board systems, based on assumptions and requirements that are introduced before. While the initial focus is providing On-board Map for odometry enhancement, further use cases should be considered to ensure scalability.

1.4. Related documents

The following documents provide related information:

[1] RCA System Architecture [RCA.Doc.35]
[2] RCA Digital Map System Definition [RCA.Doc.59] – not published yet
[3] RCA Digital Map Concept [RCA.Doc.46]
[4] OCORA System Architecture, v1.05 [OCORA-TWS01-030]
[5] RCA Glossary [RCA.Doc.41]
[6] Realization of RCA Goals [RCA.Doc.48]
[7] EUG - Digital Map management for localisation purposes in ERTMS domain, 20E073, v 0.d
[8] EUG-LWG Vehicle locator Architecture Concept reference 21E109 version 1.0

1.5. Target audience

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

1.6. Structure

This document pursues the following procedure:

- Analyse the assumptions regarding the environment. This could be constraints, available systems, and functions, etc.
- Collect and summarize the basic requirements relevant for the publish process
- Introduce general possible approaches, that are in discussion
- Evaluate approaches based on requirements
- Conclusion incl. recommendation and next steps

1.7. Terms and Abbreviations

In general, the document is based on the RCA terminology [5] or already published Digital Map documents:

- Engineering Data → RCA terminology [5]
- Map Data → RCA terminology [5].
- Reliable Data → RCA Digital Map Concept [RCA.Doc.46]

In addition, the following terms are introduced as proposals in this document and might be later synchronized with RCA terminology:

- **On-board Map (Data)**: part of the Map Data that is transmitted to the On-board systems, i.e. for the purpose of localisation enhancement with ERTMS.
- **On-board Map Integrity (Data):** Map Integrity Data for on-board applications - required information for validation of On-board Map information to detect unintentional modifications (i.e. insertion, deletion, manipulation) of transmitted On-board Map information.
- **On-board Map Reference (Data):** Map Reference Data for on-board applications - unambiguous reference to a certain version and region of On-board Map information. In addition, it includes information for On-board Map Integrity regarding the referenced version and region of On-board Map.

The generic terms of Table 1 and Figure 1 are introduced to be adaptable for *legacy (meaning: existing architectures)* as well as future *RCA/OCORA architecture* and to be not too detailed regarding trackside or on-board internal data flows. In general the on-board system is handled as black-box under the responsibility of OCORA. Details can be found also in the Digital Map System Definition [2], which is based on the results of this document.

Table 1: Terms in Legacy and RCA/OCORA environment

Term	Legacy	Possible RCA/ OCORA System	Description
DM-OB (Digital Map On-board)	not available, new system	DM-OB (Digital Map On-board by OCORA)	Dedicated On-board map system, which is responsible for requesting, receiving, storing, and providing the On-board Map to the CCS-OB systems. It is subject of this document, if the DM-OB is even required and if so, which functions should be allocated regarding publishing On-board Map to the On-Board system. *Note: The allocation is preliminary based on this solution concept and must be challenged during the actual (model based) system engineering process.* More details: [4] chapter 2.3.5
DM-TS (Digital Map Trackside)	not available, new system	e.g. part of DCM* (Device & Configuration Management) or MOT* (Mobile Object Transactor) **allocation of this function in the RCA not decided*	Dedicated trackside map system, which is responsible for storing, management and sending of the On-board Map to the DM-OB system. It is subject of this document, if the DM-TS as dedicated system is even required and if so, which functions should be allocated regarding publishing On-board Map to the On-Board system. *Note: The allocation is preliminary based on this solution concept and must be challenged during the actual (model based) system engineering process.*
CCS-TS (Trackside Control Command Signalling Systems)	RBC, Interlocking	MT	Group of trackside systems with safety related functions for the protection of movements of movable objects like trains. It is subject of this document, which role these systems take regarding the safe publishing of On-board Map to the on-board units.
CCS-OB (On-board Control Command Signalling Systems)	OBU (EVC)	VL...Vehicle Locator (LOC-OB by OCORA), VS… Vehicle Supervisor (ATP-OB by OCORA)	Group of on-board systems with safety related functions for the protection of movements of trains. It is subject of this document, which role these systems take regarding the safe publishing of On-board Map to the on-board units.

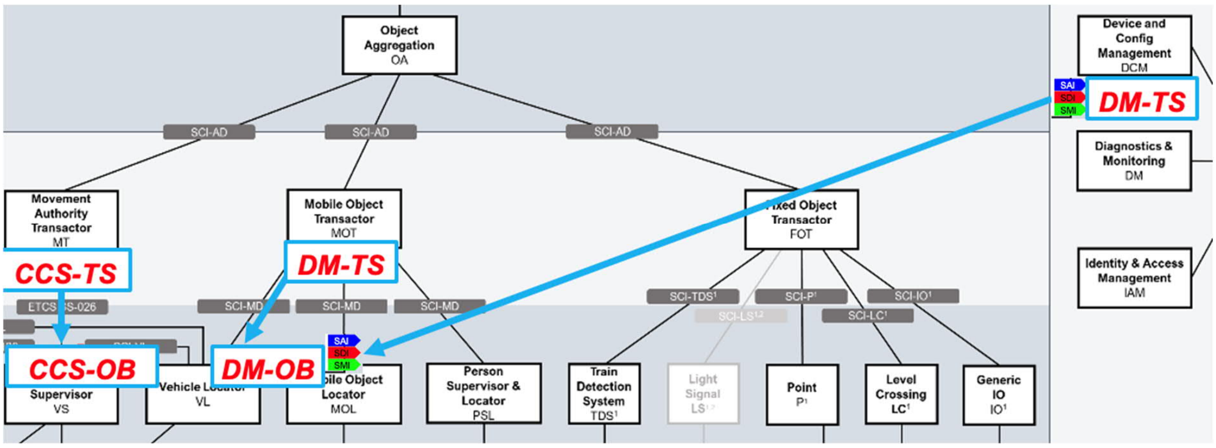

Figure 1: Generic terms DM-TS, DM-OB, CCS-OB, CCS-TS

2. Assumptions

As a base for the On-Board Map evaluation, the environmental needs are identified/defined in the form of assumptions. During the analysis of this evaluation, the following assumptions have been considered as relevant to design and evaluate the publishing variants (PPA…Publish Process Assumption). Also, the assumptions and the document must be aligned to decisions in the overall RCA/OCORA design process, if required.

Table 2: Publish Process Assumptions

PPA ID	Assumption
PPA1	The On-board Map publish process will primarily transmit (engineered) Map Data. *Note: This data might be enriched by information created during operation (e.g. route of train), so the process should be open for both. However, this additional data could also be provided by different interfaces.*
PPA2	The On-board Map will consist of safety-related as well as non-safety-related data.
PPA3	The primary use case of On-board Map will be the support of safety-related on-board localisation functionality (i.e. odometry enhancements) in the context of ERTMS.
PPA4	The secondary use case of On-board Map will be the support of safety or non-safety functions such as ATO/IPM, information systems on the train, optimization, or diagnostic systems (extended scope of Digital Map, see [3]).
PPA5	The ETCS (safety-related system) will be used and is available as train control system. *Note: for a deeper analysis regarding the applicability On-board Map in certain ETCS levels and modes it is referred to chapter 3.1.1.*
PPA6	The ATO will be partially available/equipped within the infrastructure network, so regions without ATO implementation are expected. *Note: therefore, map supported localisation cannot rely on ATO*
PPA7	The available radio network will be GSM-R or better, so the solution can rely on a (quasi)permanent radio connection but must be compatible with the limitations of GSM-R as well. The FRMCS rollout is not assumed to be finished for the implementation of Digital Map. Alternatively, the usage of public radio network can be considered if applicable (to be analysed in this document) Regarding a first estimation of assumed data volume it is referred to chapter 3.2. For Legacy architecture only: If the On-board Map shall be used *without* radio connection (e.g. Level 1 LS/FS), then the persistence of the validated state of Map Data is ensured by safe processes, which are IM specific and are not part of Digital Map cluster. *Note: The cost-benefit-ratio for non-radio-based applications of On-board Map requires additional business cases considering the national situation regarding processes, installed equipment, rollout strategy, safety targets.*
PPA8	The safe operation would still be possible without support of On-board Map but should be avoided since the confidence and/or operational performance decreases potentially to an unacceptable level. The reaction to the Digital Map not being available needs to be defined in the VL specification. *Note: in general, it must be defined how the VL performs if Digital Map is not implemented at all, at least for the migration strategy. This needs to be defined by VL or overall migration strategy. In this document the implementation of Digital Map is assumed.*

PPA ID	Assumption
PPA9	The CCS-TS system will maintain the safe state of operation during updating Map Data including the possible train movements (e.g. shorten MA...) with safety considerations. *Note: it should be ensured in the same way as it is done today by SIL4 functions. The new situation with the RCA would be the partial map data update without complete shut-down of the systems.*
PPA10	Operational data such as route information (as defined in [8] "An interlocked (safe) train path uniquely assigned to a train/vehicle. This information is seen useful to validate the determined position by the vehicle locator against track selectivity.") is *not* part of On-board Map. *Note: it must be ensured, that the reference points used by route description fit to On-board Map. Also, it is assumed that the reference points allow an unambiguous route description (under this condition the Movement Authority itself could be sufficient as route description)*
PPA11	The CCS-OB system (i.e. VL) will request On-board Map with the provided current and safe position of the vehicle incl. a defined area around the position according to the estimated accuracy (and potentially other VL internal parameters). Therefore, VL defines the area that must be covered by the On-board Map. Consequently CCS-OB must provide a safe position without use of On-board Map, though the position can be very rough for initial request (i.e. safe 3D coordinate provided by CCS-OB) The CCS-OB system (i.e. VL) does not request or use On-board Map if this localisation condition cannot be fulfilled. *Note: This is a pre-condition, that the Digital Map is able to provide the On-board Map that fits sufficiently to the actual vehicle position. This position needs to be current but does not need to be "trust-worthy in terms of ETCS".*

3. Requirements

During the analysis of this document the following requirements are considered relevant for evaluating the publish process approaches. (PPR…Publish Process Requirement), which are based on the high-level principles and non-functional requirements (NFR) of the DM concept [3] as well as the overall RCA goals and quality attributes as defined in “Realization of RCA Goals” [6] (see “Trace” column).

The *system* under consideration will be defined in detail in the document RCA Digital Map System Definition [2] and will comprise the macro functions as defined in RCA Digital Map Concept [3], which comprise the functionality for providing Map Data from Trackside to On-board systems incl. the interface specification of this airgap.

Table 3: Publish Process Requirements

PPR ID	Title	Category	Requirement	Trace
PPR1	Flexible	Mandatory	The system 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). *Note: Both methods might be applicable exclusively or in combination (hybrid mode: offline or online initial data loading + incremental updates*.)	[3] Principles: Universal, Regionalising [3] NFR: Scalability [6] Q4
PPR2	Efficient	Mandatory	The system shall minimize the transmission data load (volume, amount/number) between track and train. *Note: The system shall reduce the need for synchronization, especially between trackside and on-board systems (airgap)*	[3] Principles: Simple, [3] NFR: Capacity [6] Q4
PPR3.1	Versatile	Mandatory	The system shall provide the On-board Map for localisation support at least for mandatory use cases, as defined in chapter 3.1.	[3] NFR: Availability [6] T3 (always located)
PPR3.2	Versatile	Optional	The system should provide the On-board Map for localisation support for further optional use cases, as defined in chapter 3.1.	[3] NFR: Availability [6] T3 (always located)
PPR4	Comprehe nsive	Mandatory	The system shall provide information regarding track axes (e.g. modelled as track points including coordinates, gradient...) and relevant infrastructure elements (e.g. balises) with a defined level of detail (granularity) as defined in detail by chapter 3.2.	[3] NFR: Granularity [6] T4 (less balises)
PPR5	Robust	Mandatory	The system shall avoid operational delays due to incomplete On-board Map.	[3] NFR: Availability, Precision, Time Behaviour [6] G7, Q2, Q4

PPR ID	Title	Category	Requirement	Trace
PPR6	Safe	Mandatory	The system shall ensure that the vehicle locator can rely on the valid On-board Map for safety-related applications (e.g. map as sensor, map matching). Besides the initial distribution, this includes the safe update of On-board Map in case of new versions.	[3] Principles: Maintainable, Reliable, Validity [3] NFR: Safety, Reliability [6] Q1
PPR7	Secure	Mandatory	The system shall ensure providing secure Map Data to the consuming systems avoiding undetected/ unintended manipulations	[3] NFR: Security [6] G14, Q3
PPR8	Migratable	Mandatory	The system shall be compatible with legacy architectures as well, in order to provide a technical and economical migration path. According to the RCA goals [6] the solution shall allow interfacing to existing systems in the environment around the RCA, protecting existing investments.	[6] G3, Q8
PPR9	Inter-operable	Mandatory	The system shall support a seamless cross border traffic (between two IMs) and therefore rely on interfaces that are part of standardization (e.g. RCA, OCORA, EULYNX, ERTMS, TSI…) only.	[3] Principles: Interoperable [3] NFR: Interoperability
PPR10	Adaptable	Mandatory	The system shall ensure, that future use cases (e.g. perception systems) with additional data needs can also be realized.	[3] Principles: Future proof [6] G4, Q7
PPR11	Low LCC	Mandatory	The system shall minimize usage of system components and apply standardized components in order to simplify the architecture for implementation and operations.	[6] G1
PPR12	Modifiable	Mandatory	The system 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).	[3] NFR: Modifiability [6] G1, Q5
PPR13	Modular / Extensible	Mandatory	The system shall enable modularity of 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).	[3] Principles: Modular [6] G2, Q6

Note regarding coverage of principles/requirements from DM concept [3]: The principle “Efficient” and the NFRs “Accuracy”, “Resolution”, “Reusability” are considered not relevant in this scope of data transmission between trackside and on-board, but more relevant for the data preparation process as well as the overall Map Data flow definition of RCA.

3.1. Use Cases for On-board Map Support

Within RCA it could be stated that the On-board Map should be available in all radio-based levels (ETCS L2/L3) and modes.

However, since legacy architectures shall not be excluded from On-board Map support, a deeper analysis regarding the ETCS level/mode specific requirements and actual benefits of applying On-board Map is carried out. After this analysis it should be clear, under which conditions the On-board Map shall be applied:

- With or without Movement Authority?
- With or without Connection between On-board Unit and RBC?
- Which levels/modes can be neglected due to lack of benefit or should be considered optionally?

3.1.1. Level/Mode-specific evaluation of On-board Map

The following list provides the mode-specific analysis (Table 5). To support mode-specific analysis, the requirement of Map Data for each level/mode combination depending on the possible benefits arising from using Map Data for improvisation of localisation aspects are categorised. The Table 4 below explains this categorisation in detail.

Note: The Categories are classified into three types, Mandatory, Optional, and Not required. The categorisation is addressed only the improvisation of localisation point of view and not the overall ETCS point of view.

Table 4: Categories for On-board Map priorities

Cate-gory	Movement Authority	Connected to RBC	Benefit of Map	Category Description
1	partially	yes	yes	On-board Map is *mandatory* in these levels/modes. Since there is a connection between RBC and OBU the extension of Subset 026 could be used for On-board Map management (i.e. for On-board Map activation)
2	no	yes	yes	On-board Map is *mandatory* in these levels/modes since it can improve the performance by maintaining a highly accurate position, which accelerates the transition to following modes such as FS. The possible radio connection between OBU-RBC can be used for validation of On-board Map.
3	no	no	yes	On-board Map is *optional and would be useful* in these levels/modes, if a safe way to maintain the validated/activated state of On-board Map is implemented. Otherwise the validation state of On-board Map data must be maintained by safe processes, which are not in the scope of the Digital Map Cluster or standardization.
4	no	no	no	On-board Map is *not required* in these levels/modes, since the VL does not provide position/distance information or On-board Map would not improve the situation.

Table 5: Level/Mode specific evaluation of On-board Map requirements

Level	Mode	Movement Authority	Connected to RBC	Benefit of Map	Comment/Rational	Category
L2/L3	FS (Full Supervision)	yes	yes	yes	highest requirement regarding precision of localisation	1
L2/L3	OS (On Sight)	yes	yes	yes	see L2/L3 FS	1
L2/L3	AD (Automatic Driving)	yes	yes	yes	see L2/L3 FS	1
L2/L3	SR (Staff Responsible)	no	yes	yes	reduce need for SR mode by position validation with the support of On-board Map *During the start procedure the on-board unit usually has an estimated train position based on stored data about train movements and passed balises. Due to possible undetected train movements this position is not accepted as valid position by trackside system (RBC/MT).* *Usually, the train is required to drive until the first balise in the mode Staff Responsible. This procedure limits the performance of the system and is even worse, when balises are reduced in the network due to enhanced on-board localisation/odometry.*	1
L2/L3	SB (Standby)	no	yes	yes	localisation with map data required to prepare movement in following mode	1
L2/L3	SH (Shunting) *– with MA*	yes	yes	yes	With Movement Authority the situation is similar to FS.	1
L2/L3	RV (Reversing)	yes	yes	yes	Available On-board Map could be used, but mode only used during short time.	2
L2/L3	TR (Trip)	yes	yes	yes	Map Data should be used further from previous mode	2
L2/L3	PT (Post Trip)	yes	yes	yes	see L2/L3 TR	2
L2/L3	SF (System Failure)	no	yes	yes	the On-board Map can be used further, if the previous mode had On-board Map support	2
L2/L3	SL (Sleeping)	no	optional	yes	continuous localisation with map support could help to have a valid position during following start-up. Optional radio connection to RBC could be used for providing the information for On-board Map validation.	2
L2/L3	NL (Non Leading)	no	optional	yes	see L2/L3 SL	2
L2/L3	SH (Shunting) *– without MA*	no	no	no	since there is no valid train data (i.e. train length) on-board there is no relevant improvement by On-board Map. *Nowadays, during the shunting mode the train disconnects from the RBC. Therefore, potentially relevant On-board Map must be transmitted in advance or by an independent*	3

Level	Mode	Movement Authority	Connected to RBC	Benefit of Map	Comment/Rational	Category
					map service connection, which is maintained during Shunting mode. In both cases no train data is available (which is required for train integrity monitoring and better capacity usage), so the added value of a map is very limited to the possible reduction of balises. In the future, it is planned and described by TSI change requests to do the shunting with MA supervision in FS/OS mode. In this case, the requirement is already covered by PPR3.1. Therefore, the business case of supporting shunting mode with On-board Map is expected to be worse compared to modes with movement authority.	
L2/L3	PS (Passive Shunting)	no	no	no	see L2/L3 SL, but without the possibility of radio connection to RBC	3
L1	FS (Full Supervision)	yes	no	yes	non-radio levels are not part of RCA. Due to missing safe radio connection to trackside, the implementation of On-board Map requires offline-based loading procedures. While technically possible, the required processes to ensure overall safety are not part of standardization.	3
L1	OS (On Sight)	yes	no	yes	see L1 FS	3
L1	AD (Automatic Driving)	yes	no	yes	see L1 FS	3
L1	RV (Reversing)	no	no	yes	see L1 FS	3
L1	SR (Staff Responsible)	no	no	yes	see L1 FS	3
L1	TR (Trip)	yes	no	yes	see L1 FS	3
L1	PT (Post Trip)	yes	no	yes	see L1 FS	3
L1	SB (Standby)	no	no	yes	see L1 FS	3
L1	SH (Shunting) *– without MA*	no	no	no	see L1 FS	3
L1	SF (System Failure)	no	no	yes	see L1 FS	3
L1	SL (Sleeping)	no	no	yes	see L1 FS	3
L1	NL (Non Leading)	no	no	yes	see L1 FS	3
L1	PS (Passive Shunting)	no	no	no	see L1 FS	3
-	UN (Unfitted)	no	no	no*	the primary goal of RCA/ERTMS is not to improve the SN/UN/LS performance. **Assumption: VL localisation without map is sufficient for SN/UN*	3
-	LS (Limited Supervision)	yes	yes (L2/L3)	no*	see UN	3

Level	Mode	Movement Authority	Connected to RBC	Benefit of Map	Comment/Rational	Category
-	SN (National System)	no	no	no*	see UN	3
-	IS (Isolation)	no	no	yes	there is no supervision, but train is aware of train position/speed.	3
-	NP (No Power)	no	no	no	see IS	4

Conclusion:

- The system must provide the On-board Map in modes with or without movement authority.
- The system can rely on radio connection between OBU and RBC for the mandatory On-board Map use cases
- Optionally, the system should support modes/levels even without radio connection between OBU and RBC. For this extended support an additional, dedicated safe interface between trackside and on-board is required to provide the On-board Map and maintain the validated/activated state of On-board Map. Otherwise national, non-standardized processes must be implemented (not part of Digital Map).

3.1.2. Derived Use Cases

Based on the identified relevant modes and to analyse all mandatory (category 1 and 2) cases in detail the following operational scenarios need to be evaluated regarding the management of On-board Map:

a) Train runs with Movement Authority (e.g. FS, OS, new SH,…)
b) Start of Mission (SB, SR)
c) Train runs without Movement Authority (SR, SL, RV,…)

As further special operational situation the following use case(s) should be analysed:

d) Train passes trackside control area border (e.g. FS, SR)

All introduced use cases for map management consider an available connection between RBC and OBU as necessary condition. In order to take into account extended support by On-board Map the following optional use case should analysed as well:

e) Train runs in mode without connection to CCS-TS (RBC/MT)

3.2. Required Data and Volume Estimation

The following kind of data shall be transmitted by the On-board Map:

- Representation of track axis following the track centreline with coordinates (2D or 3D) and optional gradient, CANT (superelevation), radius or azimuth. Also, topological information organized as node-edge-model are required to support the safe track determination and supervision of safe distances.
- Positions of elements, which are relevant for initial localization use case, e.g.
    - Permanent obstacles, which have an impact on the on-board localisation and change the environment significantly for the sensors, e.g. tunnels, roofs, bridges, metal masses beside the track for GNSS conditions
    - Trackside reference points such as ERTMS/ETCS balises (virtual or physical)
    - Landmarks: suitable objects serving as landmarks for on-board localisation

Both kind of data (track axis and elements) are analysed in more detail regarding required information and data volume.

While the data representation is based on the RCA domain knowledge model to ensure compatibility, the structure has been adapted in the following ways:

- The data is described as example implementation of a data package, so the class hierarchy of RCA is flattened and adjusted for this specific purpose
- Attributes of RCA classes, that are not required in this context, are not mentioned here
- Attributes of RCA classes, that are additionally required in this context, are added here
- Generic attributes are moved to the header to reduce the data volume

3.2.1. Track axis

In general the track axis/centreline data can be structured in the following ways

- Point based track geometry: Discrete track points with track axis information, so each point is defined by coordinate (at least x and y) and potential further information such as superelevation/CANT, gradient, azimuth. The track points could sample the actual track axis with fixed or variable density (e.g. depending on radius).
- Vector based track geometry: Actual elements of alignment, such as curve, straight or transition curve to describe the radius or similar models to describe gradient or superelevation. Each element must have a start- and end-coordinate as well as element specific information (e.g. radius)

Both representations are supported by the RCA domain knowledge model. The following comparison represents the first result of the discussion, which must be complemented in further studies (e.g. ongoing study by SBB). The actual trade-off analysis and required representation must be developed by the consuming system (here: Vehicle Locator).

3.2.1.1. Preliminary comparison of track-axis representation approaches

In the following some arguments for the *point-based track-geometry* are collected (not complete):

- Since each track point is positioned in the relative topology and the absolute coordinate system, the track points allow a direct and very simple translation from coordinate to relative (edge) distance, which is crucial for ETCS supervision. Since no calculation is required, this approach is considered highly appropriate for the safety-related on-board platform.
  Note: this can also be simple procedure for vector-based approach, but still a calculation is required, see below.
- While other approaches might have continuous information, the level of detail in the discrete point approach must be adjusted depending on the situation (e.g. radius) to allow a sufficient level of detail for intended function. Since the data volume increases linearly with the point density, the density should be as low as possible (depending on accuracy requirements and topographical situation, see also discussion below)
- The approach also offers the flexibility to transmit relevant changes of information only, which might be grouped on layers. For example: if the gradient changes in a significant a way, a new track point with gradient information is required. Between two points with gradient information the gradient is assumed as constant value. The sample principle can be applied for radius, superelevation etc.
  Note: the vector-based approach also offers the same amount of flexibility, see below
- Especially the representation of transition curves for radius, gradient, CANT follows different models depending on national alignment design rules, which complicates the standardization process not only for the airgap but also for the further processing (i.e. in VL)
- If dynamic measurement equipment is used to gather sufficiently accurate and up-to-data infrastructure data in an efficient way, it requires much effort to re-engineer the actual alignment

elements (actual start and end of curves, straights, etc.) compared to the simple description of measured track centrelines by discrete points.

The density of discrete points as well as the amount of the required attributes depend on the requirements of the localisation system (i.e. VL). In general it must be specified:

- What is the minimum amount of On-board Map information for the localisation system?
- Are there different localisation system capabilities and needs, which lead to optional On-board Map information?
    - if yes: how it is ensured, that the on-board units always get a sufficient amount of information from trackside?

  Note: if route information is used to support the track-selective localization (not only for verification), then the sensor requirements might be much lower regarding accuracy, density, and amount of information
- What is the minimum accuracy of the On-board Map data, e.g. regarding coordinates, distances, gradients/heights, superelevation, azimuth?

On the other side there are good arguments to prefer the *vector-based track geometry*, such as:

- The required data size of On-board Map can be reduced by around 20% (average) according to first studies done by SBB (study ongoing, not referrable yet). The actual reduction depends on the track geometry and the density of points that is used for the compared point-based approach.
- The accuracy of localisation can be improved due to the continuous track axis information without the need for interpolation between points and without the caveat of increased data volume for higher point resolution.
- Since the vector segments are defined along the edge a translation from global coordinates to relative distances can be nearly as simple as the track point approach.
  Note: actual complexity must be evaluated by VL
- Since the vector segments can be created with a defined threshold, which defines the accuracy of the data model compared to the actual track geometry, the amount of data and required data volume can be adjusted to the actual accuracy requirements by localization.

Preliminary bottom line: while the track points might be easier to gather from measurement and avoid runtime calculation efforts in safety-critical on-board environment, the vectors allow the highest level of accuracy without increasing the data volume. As pointed out, the final selection of an approach must be based on a complete trade-off analysis by the Vehicle Locator system design process.

3.2.1.2. Track axis data structure and volume

For a first estimation the point-based track geometry is applied, without deciding for this approach. Regarding data volume this seems to be the (not too) restrictive assumption. During the specification phase the final model must be decided based on the results of the already ongoing studies (not referrable yet).

The following Table 6 defines the attributes including data type and volume for each track point, which are positioned and grouped on a defined track edge. Some attributes are optional, if there is no relevant change of information at the specific track point position. However, the optional attributes are not supposed to be left out, but rather included with addition descriptions. If the case of “locally unavailable information” is relevant as well the layers could be marked as “not available” (e.g. Q_CANT as 2 bit variable to allow a 3rd state like “CANT not available”). This avoids complexities during standardization.

Table 6: Variables and Data Types of Map Packet for Track Axis Description

Level	Variable	Type	Length	Description
1	***Header***		*sum<=6 bytes*	*Contains required information to identify and interpret transmitted packet, i.e.:*
1	NID_PACKET	INT	8 bits	ID of packet
1	L_PACKET	INT	13 bits	Length of packet
1	Q_GEOREF	INT	2 bits	Geographic Coordinate System for absolute coordinates, e.g. ETRS89 (default)
1	Q_HEIGHTREF	INT	2 bits	Geographic Coordinate System for heights
1	Q_SCALE_DIST	INT	2 bits	unit for distance, e.g. dm (default)
1	Q_SCALE_CANT	INT	2 bits	unit for CANT, e.g. mm (default)
1	Q_SCALE_RADIUS	INT	2 bits	unit for radius, e.g. m (default
1	Q_...		<=8 bits	Additional header data, such as flags for availability of optional variables,
1	N_ITER_EDGE	INT	5 bits	Number of trackEdges in packet
2	***Data per trackEdge for each N_ITER_EDGE:***		*<=5 bytes*	***Contains all the edges of the topology that are transmitted in the packet***
2	EDGE (TrackEdge.id)	INT (UUID)	32 bits	Unique id of referenced edge, which serves as reference for the relative distances of track points on the edge. Mandatory: minimum data for topological reference *Note: if NID_C is considered (similar to NID_BG) than the size can be reduced to e.g. 14 bit. Also, the amount of information could be reduced by grouping track points per edge*
2	N_ITER_POINT	INT	5 bits	Number of trackEdgePoints on trackEdge
3	***Data per trackEdgePoint for each trackEdge. N_ITER_POINT*** ***Data per track point on edge:***		*Min: 29 bytes* *Max: 33 bytes*	*Contains the data per track point to model the track axis/centreline, incl. some optional attributes which are not required for any track point or in general due to localization sensor setup.*
3	X (trackEdgePoint. geoCoordinates. xCoordinate)	FIXED DECIMAL	64 bits	Defines the x-coordinate of a point on the track centreline in defined reference system mandatory: minimum required data
3	Y (trackEdgePoint. geoCoordinates. yCoordinate)	FIXED DECIMAL	64 bits	Defines the y-coordinate of a point on the track centreline in defined reference system mandatory: minimum required data
3	Z (trackEdgePoint. geoCoordinates. zCoordinate)	FIXED DECIMAL	64 bits	Defines the z-coordinate of a point on the track centreline in defined reference system Mandatory: data might be not required for track selectivity in case of route information

Level	Variable	Type	Length	Description
				support, but can also support the localization system
3	OFFSET (trackEdgePoint. offset)	INT	15 bits	Offset/distance along track centreline to reference point (start track node of referenced edge) to define the relative position of the track point Mandatory: minimum data for topological reference Unit: Q_SCALE_DIST
3	AZIMUTH	INT	15 bits	Unit: 1/100 degree
3	Q_CANT	INT	1 bit	Defines if CANT information (layer) included or not *Note: layer is used for point with relevant changes only*
3	CANT (cant value)	INT	8 bits	If Q_CANT = 1 optional: if required for IMU/sensor support / verification purposes, i.e. if track selectivity not given by route or other means Unit: Q_SCALE_CANT
3	Q_GRADIENT	INT	1 bit	Defines if GRADIENT information (layer) included or not *Note: layer is used for point with relevant changes only*
3	Q_GDIR	INT	1 bit	If Q_GRADIENT = 1 0 = downhill 1= uphill
3	GRADIENT (gradient. gradient)	INT	8 bits	If Q_GRADIENT = 1 to be defined, if required for IMU/sensor support (e.g. verification purposes) it can be calculated from coordinates Unit: Q_SCALE_GRADIENT
3	Q_RADIUS	INT	1 bit	Defines if RADIUS information (layer) included or not *Note: layer is used for point with relevant changes only* *To be defined if curvature is preferred information instead of radius*
3	RDIR	INT	1 Bit	1 curve on the left, 0 curve on the right
3	RADIUS (curveRadius. radius)	INT	15 bits	If Q_RADIUS = 1 to be defined, if required for IMU/sensor support (e.g. verification purposes)

Lev el	Variable	Type	Length	Description
				it can be calculated from coordinates Unit: Q_SCALE_RADIUS Reserved value: 32768 = infinite

Regarding the density of track points the following is assumed:

- The minimum average density of track points is 100 points per track-km, which means an average distance of 10m between two track points
- The maximum average density of track points is 1000 points per track-KM, which means an average distance of 1m between two track points
- The track point density can vary based on topographical (and topological) situation:
    - Lower radii require higher density
    - Slopes (changes in z-axis) require higher density

Conclusion: depending on the final implementation of the map packet data the data volume per track point ranges between 29 up to 33 bytes. The edge information of max. 5 bytes per edge can be neglected (very restrictive estimation: average edge length of 200m and point density of 10m would add only 5/20 = 0,25 byte to each track point). Also, the header information is listed for completeness but has no relevant impact on data volume.

3.2.2. Track Elements

The transmission of track elements (obstacles, reference points, landmarks, …) require the following information:

Table 7: Variables and Data Types of Map Packet for Track Element Description

Level	Variable	Type	Length	Description
1	***Header***		*sum<=5 bytes*	*Contains required information to identify and interpret transmitted packet, i.e.:*
1	NID_PACKET	INT	8 bits	ID of packet
1	L_PACKET	INT	13 bits	Length of packet
1	Q_GEOREF	INT	2 bits	Geographic Coordinate System for absolute coordinates, e.g. ETRS89 (default)
1	Q_SCALE_OFFSET	INT	2 bits	unit for distance/offset, e.g. cm (default)
1	Q_SCALE_LEN	INT	2 bits	unit for length, e.g. cm (default)
1	Q_...		<=8 bit	Additional header data, such as flags for availability of optional variables…
1	N_ITER_EDGE	INT	5 bits	Number of trackEdges in packet
2	***Data per trackEdge for each N_ITER_EDGE:***		*<=5 bytes*	*Contains all the edges of the topology that are transmitted in the packet*

Level	Variable	Type	Length	Description
2	EDGE (TrackEdge.id)	INT (UUID)	32 bits	Unique id of referenced edge, which serves as reference for the relative distance. Mandatory: minimum data for topological reference *Note: if NID_C is considered (similar to NID_BG) than the size can be reduced to e.g. 14 bits. Also, the amount of information could be reduced by grouping track points per edge*
2	N_ITER_ELEMENT	INT	5 bits	Number of elements on trackEdge
3	***Data per element***		*Min: 11 bytes* *withXYZ: 35 bytes* *virtual Balise: 163 bytes*	*Contains the data per element*
3	OFFSET_START (startTrackEdgePoint. offset)	INT	15 bits	Offset/distance along track centreline to reference point (start track node of referenced edge) to define the relative start position of the element Mandatory: minimum data for topological reference Unit: Q_SCALE_DIST
3	OFFSET_END (endTrackEdgePoint. offset)	INT	15 bits	Offset/distance along track centreline to reference point (start track node of referenced edge) to define the relative end position of the element Mandatory: minimum data for topological reference Unit: Q_SCALE_DIST
3	LENGTH	INT	15 bits	Complete and real length of element along track centreline (not only track edge section) Unit: Q_SCALE_LEN
3	TYPE	INT	5 bits	Type of element (e.g. tunnel)
	ID	INT	32 bits	Unique id of element Mandatory: minimum data, allows referencing

Level	Variable	Type	Length	Description
				Note: if NID_C is considered (similar to NID_BG) than the size can be reduced to e.g. 14 bits.
3	Q_COORD	INT	1 bit	Defines if coordinate information (layer) included or not *Note: not all element types require coordinates, since their locations are already sufficiently described by relative positions (e.g. tunnel)*
3	X (trackEdgePoint. geoCoordinates. xCoordinate)	FIXED DECIMAL	64 bits	Defines the x-coordinate of a point on the track centreline in defined reference system optional: for elements with absolute coordinates
3	Y (trackEdgePoint. geoCoordinates. yCoordinate)	FIXED DECIMAL	64 bits	Defines the y-coordinate of a point on the track centreline in defined reference system optional: for elements with absolute coordinates
3	Z (trackEdgePoint. geoCoordinates. zCoordinate)	FIXED DECIMAL	64 bits	Defines the z-coordinate of a point on the track centreline in defined reference system optional: for elements with absolute coordinates
3	Q_TELEGRAM	INT	1 bit	Defines if telegram information (layer) included or not 0 = physical balise, 1 = virtual balise
3	TELEGRAM	INT	1023 bits	Contains the coded telegram of a balise

Regarding the density of elements the following is assumed:

- The minimum average density is 5 elements per track-km, which means an average distance of 200 m between two elements
- The maximum average density is 10 elements per track-KM, which means an average distance of 100 m between two elements

Conclusion: Compared to the amount of information for track axis the element density is much lower (at least factor 10). The data volume per element varies a lot by the element type, while the balise with telegram requires the most data (simplification: header and edge defined individually for each element):

- Relative positioned element types: <=21 bytes (including header and edge)
- Elements with addition absolute coordinates: <=45 bytes (including header and edge)
- Balises with telegram data (i.e. virtual balises): <=173 bytes (including header and edge)

However, the track axis description dominates in terms of required data volume due to the expected much higher density.

4. Approaches

Based on the ongoing discussions the following two basic approaches can be divided (Figure 2):

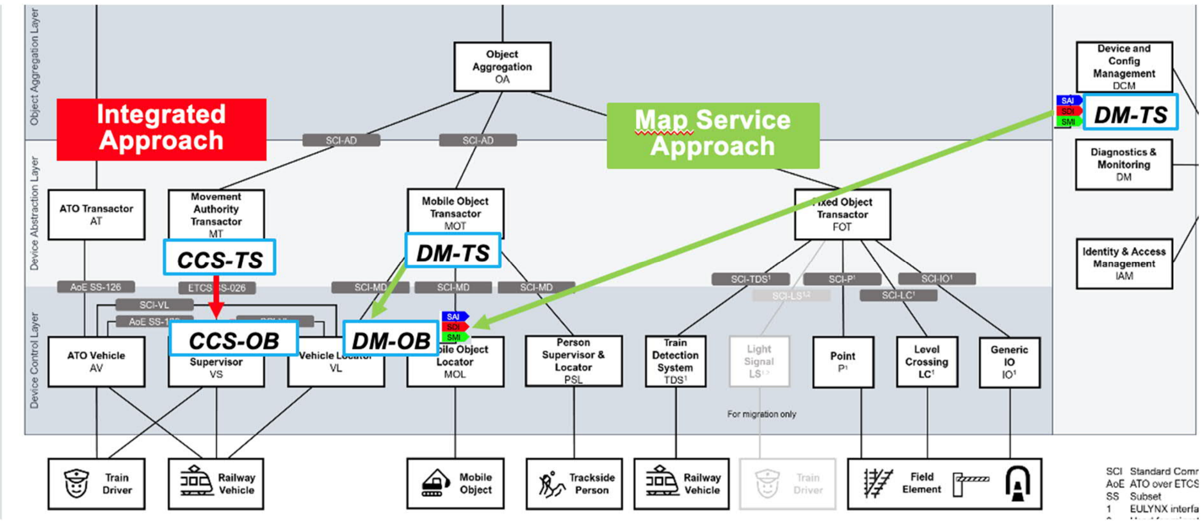

Figure 2: Approaches

- Integrated Approach (chapter 4.1.1):
  - On-board Map is delivered to the train within operational message data stream (extension of Subset 026). There is no need for dedicated map management systems since the approach is fully integrated into already defined systems and channels.
  - System/Interface Candidates: CCS-TS – CCS-OB, i.e. MT (RBC) -VS(/VL)

    (existing air-gap interface, standardized by UNISIG Subset 026)

    Note 1: technically the synchronous, integrated approach could also be applied via the new RCA interface MOT - VL (ONBOARD). However, it's not directly integrated into the existing message stream and uses a dedicated interface. Therefore, this interface is excluded here.

    Note 2: ATO TS - ATO OB is another interface candidate, but it is excluded, since it is not safe and not always available [PPA6]
- Map Service Approach (chapter 4.3):
  - On-board Map is delivered by dedicated map service systems and channels, so for the plain approach no adaption of Subset 026 / Airgap is required but a new airgap interface between DM-TS and DM-OB is defined. The interaction with CCS-OB as localisation system is required for requesting and providing the On-board Map.
    Note: In an approach variant (chapter 4.3.2) validation data (On-board Map Reference) is transmitted via Subset 026 interface, so that no safety-related Digital Map functions remain for DM-TS and at least partially also for DM-OB (see decryption in next chapter)
  - System/Interface Candidates: DM-TS – DM-OB, i.e.
    - DCM – VL (OBU) → new RCA interface for delivering configuration data
    - MOT - VL (OBU) → new RCA interface between trackside and on-board systems (e.g. for On-board Map transmission)

In the following the introduced approaches are described in more detail. According to the requirements of versatile map support, the approaches are sketched for several operational use cases as defined in chapter 3.1.2.

4.1.1. Estimation of required Transmission Capacity

As pointed out, the transmission of track axis data is more relevant than the element data for the considered initial use case. Therefore, only the track axis is taken into account for a first and rough estimation of required transmission capacity.

Depending on the density of discrete track points (range of 1m…10m resolution, according to radius and required accuracy during localisation) and the amount of data per track point the following data rate as byte per track-km results:

Table 8: Track Axis Map Packet Data Volume

distance between track points [m]	**10**	**1**	**Unit**
Min. information per track point	2.900	29.000	bytes/track-KM
Max. information per track point	**3.300**	**33.000**	bytes/track-KM

If GSM-R (not packet based) is used this leads to the following transmission times in seconds (GPRS: factor 0,5):

Table 9: Track Axis Map Data Packet Transmission Times

Average distance between track points [m]	**10**	**1**	**Unit**
Min. information per track point	4,72	47,20	s (GSM)
Max. information per track point	**5,37**	**53,71**	s (GSM)

Considering the minimum average point density of 10m/track-km at least 3,3 kilobytes per track-km are required as channel capacity, which leads to around 6s transmission time for GSM-R (respectively 3s with GPRS). A higher average point density than 10m will not be compatible with the available GSM-R/GPRS transmission speeds (e.g. at 100 km/h a track-km is passed in 36s, while the transmission of Map Data with 1m point density would take around 60s according to table above) and available capacities. For high-speed lines GSM-R is assumed to be insufficient even at 10m point density.

For plausibility check the numbers are evaluated in the context if typical data rates per track-km for ETCS and ATO applications:

Table 10: Reference Data Volume ETCS and ATO

System	**Data Rate**	**bytes/s**	**kbits/s**	**Average speed 70 km/h**
ETCS	Ca. 1,0kByte in 30s	33,3	0,3	**1.714 byte/track-km**
ATO (without Segment Prof.)	Ca. 7,5kByte in 30s	250,0	2,0	**12.857 bytes/track-km**

The data consumption for a density of 10m is in the same order of magnitude as ETCS itself, while ATO comes close to the volume that would be required by map data with 1m density. For this reason, a maximum average point density in the range of 10m is recommended for GSM-R/GPRS transmission. Higher point densities or high-speed lines require advanced communication systems (3G, 4G, 5G). The inclusion of element data for localisation purposes as well as additional On-board Map data for other purposes (e.g. perception systems) will not be compatible with GSM-R (even with GPRS). Besides the scalability aspects the limited available capacities of GSM-R due to existing applications (such as ETCS) must be considered during approach development. Due to the limited bandwidth this cannot be compensated by pre-loading of data over GSM-R for a specific journey.

4.2. Integrated Approach

4.2.1. Process

4.2.1.1. Provisioning of On-board Map

The generic process of the Integrated Approach is embedded into the message stream between CCS-TS and CCS-OB by extending the message structure defined by Subset 026.

In addition to the situation of today, the Map Data loaded in the CCS-TS system must contain the required information for localisation support (i.e. track axis details). If the approach is also applied for future use cases with extended On-board Map, then it requires even more Map Data as part of CCS-TS configuration.

Due to limited real-time transmission capacities (see chapter 1) the On-board Map should be delivered for the route of train mission only, which is defined by movement permission/authority. This is not achievable in modes without Movement Authority, so in order to cover all relevant use cases sufficiently, the process for Integrated Approach is divided into the following two alternative sequences:

- Process for modes with Movement Authority:
  - The On-board Map packet is generated and provided for a specific Movement Authority (MA).
  - The data volume is minimized, since only data of the actual route is provided.
- Process for modes without Movement Authority (incl. Start of Mission):
  - The On-board Map packet is generated around the position provided by CCS-OB with the Position Report.
  - This position does not need to be validated in terms of ETCS but must fulfil the requirements as defined in PPA11 (safe, current, with estimated accuracy). In order to allow not only distances to LRBG but also absolute coordinates as initial transmitted position, a modified packet 0 or 1 for coordinates is required.
  - Due to the lack of a MA, the On-board Map packet is generated for all possible track segments around the provided position of the vehicle, which intersect the area around vehicle position and its accuracy estimated by CCS-OB. Therefore, a lot more data volume is required compared to the modes with MA, which must be considered especially if the train is not at standstill and limitations from GSM-R still exist.
  - The On-board Map packet is provided to CCS-OB (new Subset 026 packet).
  - If the next Position Report is received, the need for further On-board Map data is checked according to the updated position of the vehicle.

After that, the CCS-OB is able to use the provided On-board Map for localization support.

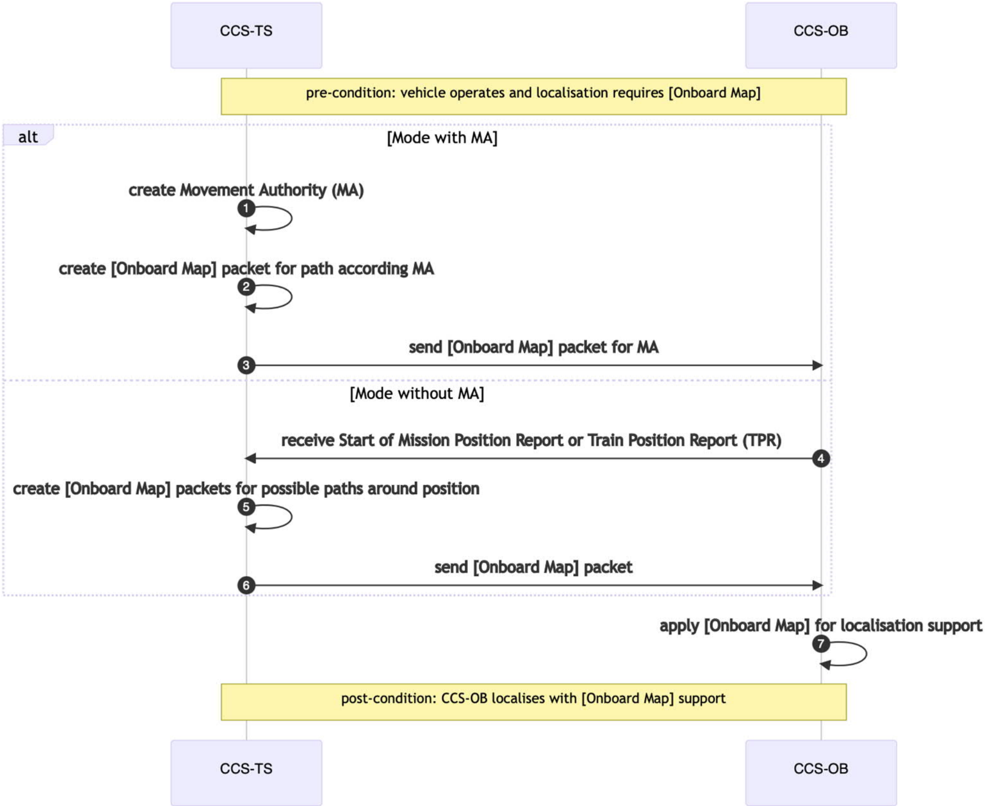

Figure 3: Integrated Approach – Provisioning of On-board Map

In the simplest implementation of the Integrated Approach the transmitted On-board Map data is transient and overwritten by the next message containing On-board Map (as shown above). To (partially) compensate the limitations of GSM-R and avoid redundant data transfers an on-board storage for caching of received On-board Map could be foreseen. In this case, additional messages are required to introduce an On-board Map version check. The version check is performed based on On-board Map Reference (Ref) information, that includes the active version of the relevant On-board Map region. The On-board Map Reference is provided as replacement of the On-board Map in the first stage.

Only if the version check fails because of an asynchronous state between CCS-TS and CCS-OB Map Reference the actual download of On-board Map is initiated. The successful and complete downloading is confirmed by the following validation procedure. Otherwise, the download of On-board Map could be repeated (to be defined).

The following sequence chart shows the adapted process with on-board cache.

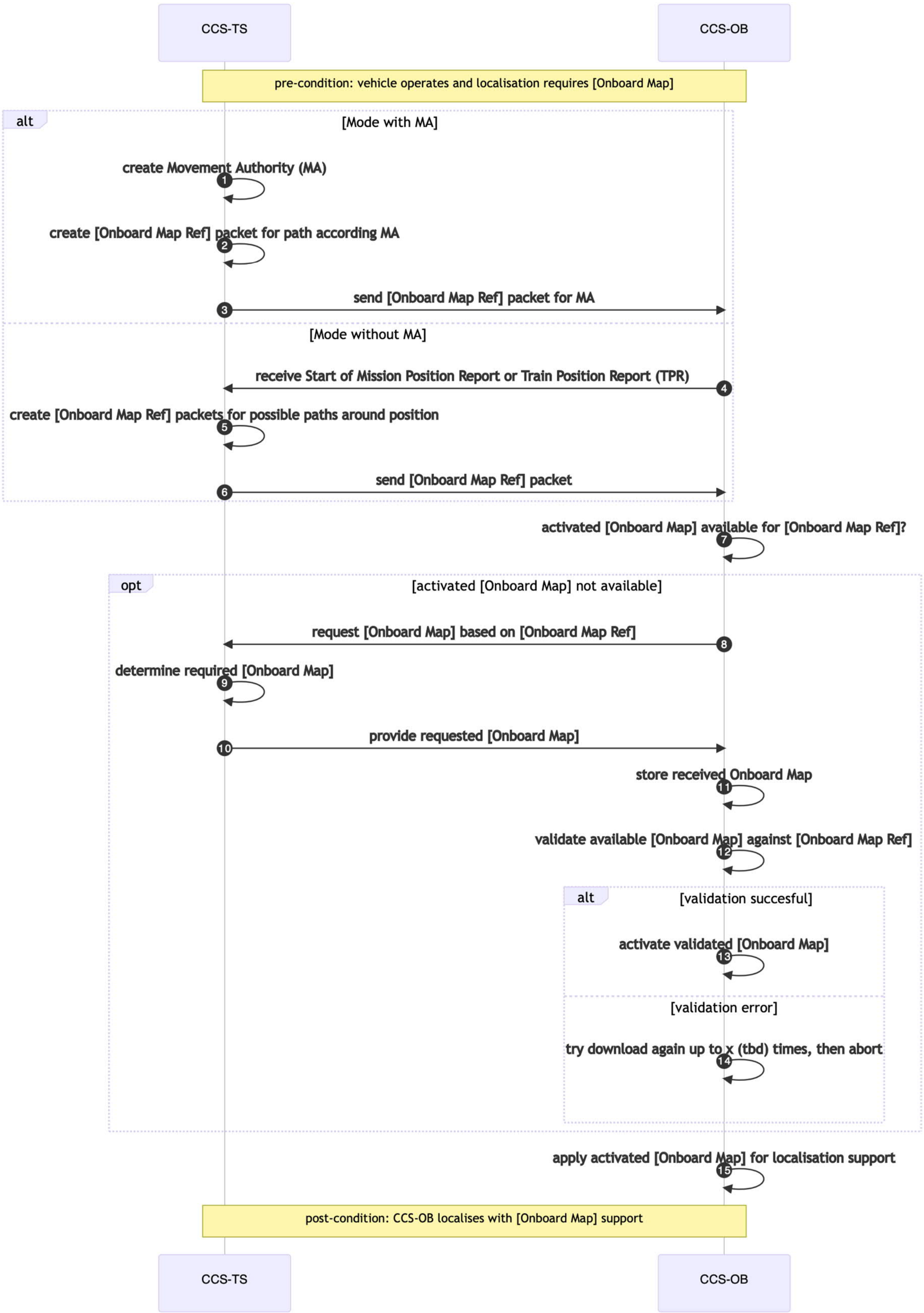

Figure 4: Integrated Approach Variant with Cache – Provisioning of On-board Map

4.2.1.2. Deactivation of On-board Map

With or without caching, the received On-board Map must be deactivated on-board for safety reasons after each disconnect to CCS-TS or during each start of the vehicle within the initial handshake with CCS-TS at the latest. At least for the process without cache, the remaining On-board Map data should be instantly deleted during deactivation (if not already done).

In general, the two following cases are divided:

- *Trackside triggered deactivation of On-board Map*: If the CCS-TS system requires a shut-down (e.g. due to updated On-board Map) the connection to all connected vehicles is removed. If RCA manages to update On-board Map without system shut down, then the connected vehicles must be informed about the updated data with highest priority. Both situations must cause the deactivation of the On-board Map delivered by the CCS-TS instance at least.
  Note: While in RCA a partial Map Data update without complete system shut-down is envisaged, at least in legacy architectures a shut-down and disconnect to controlled on-board systems is expected.

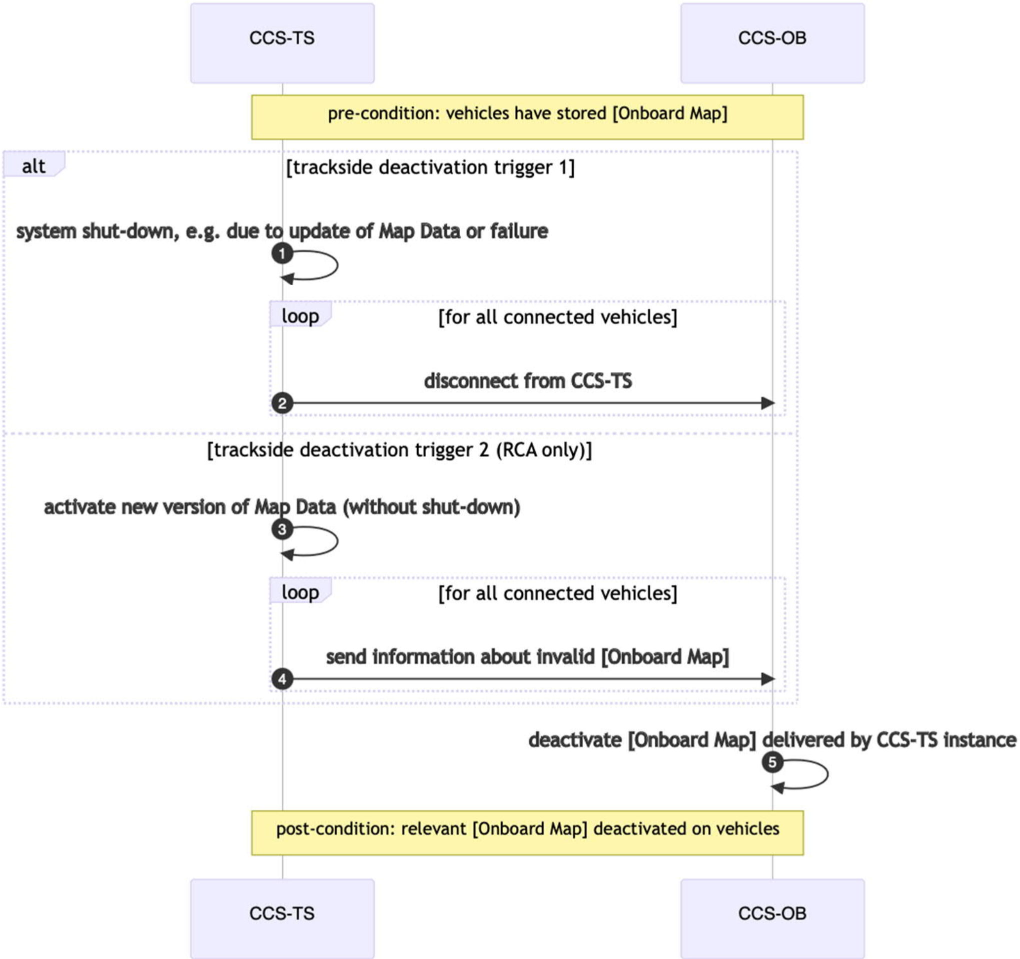

Figure 5: Integrated Approach – Trackside triggered deactivation of On-board Map

- *On-board triggered deactivation of On-board Map:* If the vehicle is shut-down or re-booted the complete On-board Map stored on the train must be deactivated. In addition, if the vehicle disconnects to a specific CCS-TS instance, the On-board Map received by this instance must be deactivated. This situation is not only relevant in modes like IS (isolation), but also if the vehicle leaves the control area of a trackside system instance, which also causes a disconnect.

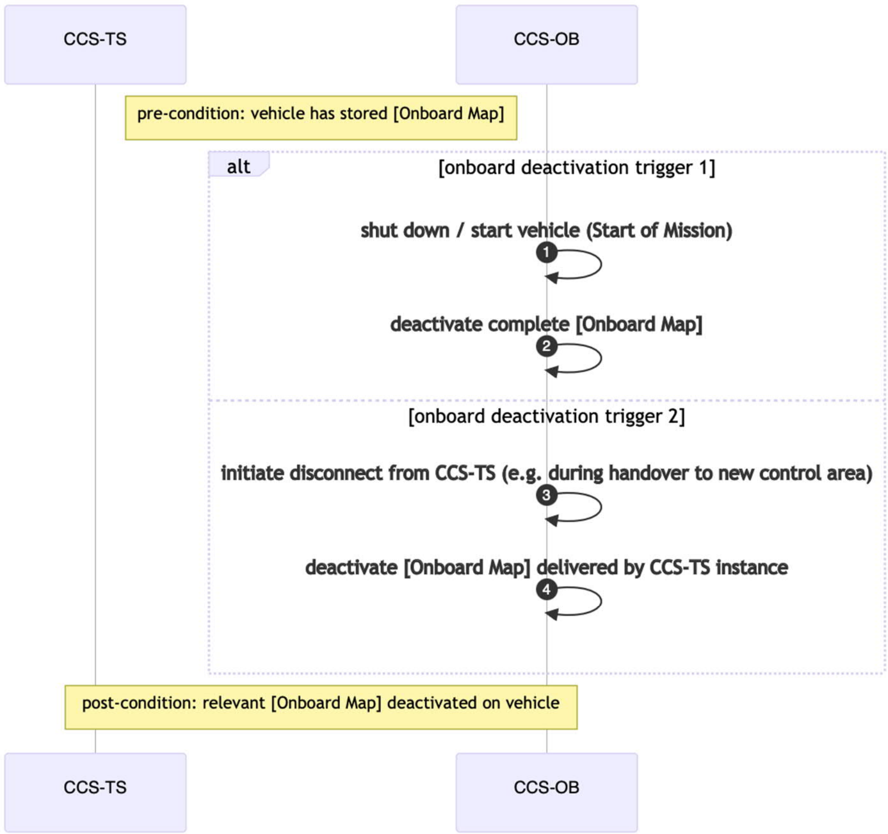

Figure 6: Integrated Approach – On-board triggered deactivation of On-board Map

4.2.2. Use Case Analysis

4.2.2.1. Train runs with Movement Authority

In this use case the generic process for “Mode with MA” can be applied without any modifications.

Since the On-board Map is transmitted as path according to the Movement Authority only, the track-selective localisation (track determination) could be achievable with much less sensor requirements. For safety reasons, the initial positioning for the first Movement Authority during a mission must be applied without limitation to an (estimated) path. This is realized by the Start of Mission procedure, which uses On-board Map including all possible track segments within the assumed area of the vehicle position (chapter 4.2.2.2).

4.2.2.2. Start of Mission

In this use case the generic process for “Mode with MA” can be applied without any modifications.

The On-board Map is provided for all possible track segments intersecting the area resulting from the initial position and the estimated accuracy. Since the initial position for the first request of On-board Map must be determined without On-board Map support, the accuracy might be

a) very rough, which leads to bigger areas of provided On-board Map
   or
b) precise and track-selective due to a stored position which is even trustworthy in terms of ETCS.

Depending on the quality of localisation this might stand in conflict with the limited bandwidth/capacity of GSM-R. However, the initial localisation benefits from the SoM (Start of Mission) specific conditions with sufficient time for On-board Map transmission and initial positioning during standstill. In addition, the locomotive is considered standing not on a switch, which supports the track-selective localisation.

Even after the first provisioning of On-board Map, the localisation of CCS-OB must allow a track selective map matching with support by On-board Map, which is not limited to the actual path of the vehicle.

The information provided by On-board Map during the Start of Mission shall be taken into account to validate the estimated train position by CCS-OB. If the position is safely validated, the vehicle should be able to request a MA without waiting for the first passed balise group.

4.2.2.3. Train runs without Movement Authority

In this use case the generic process for "Mode without MA" can be applied without any modifications.

The route might not be safely allocated to the train unit (interlocking). In this case, the route information cannot be provided to the train and the On-board Map must be provided for all possible track segments intersecting the required map area.

In contrast to Start of Mission the vehicle is running, so the additionally required capacity of radio network compared to modes with MA is critical for GSM-R. This can be partially compensated by storing the received On-board Map data in a cache to avoid redundant data transfers. Nevertheless, the application of the Integrated Approach in modes without Movement Authority is not recommended for GSM-R based transmission.

4.2.2.4. Train passes trackside control area border

If a border between two CCS-TS (meaning RBC or APS) control areas is passed, a seamless handover must be guaranteed in order to allow uninterrupted operation.

Since the Integrated Approach relies on existing systems and channels only, this handover procedure is already solved in a generic way by CCS-TS and CCS-OB.

4.2.2.5. Train runs in mode without connection to CCS-TS

Since the Integrated Approach relies on the connection between CCS-OB and CCS-TS (i.e. Subset 026 interface), it cannot be applied in these modes without connection to CCS-TS. So this optional use case is not supported by the Integrated Approach.

4.3. Map Service Approach

4.3.1. Process

4.3.1.1. Provisioning of On-board Map

For the Map Service approach, additional dedicated map service systems on trackside ("DM-TS") and on-board ("DM-OB") are required. This allows a decoupling of the download procedure from the actual application of the On-board Map, which increases the flexibility and allows better usage of network capacity.

In addition, the splitting of On-board Map download and usage allows, that the transmission of On-board Map with large data volumes could be realized by non-safety-related systems and channels, if the data is validated by safe functions before actual usage. In addition, if all safety-related functions and data are allocated to safe parts of CCS-TS/OB instead of DM-TS/OB a wider market for Digital Map (DM-TS/OB) products could be potentially addressed (incl. integration of COTS). This variant with CCS-TS is described in detail in chapter 4.3.2.

Independently of the involved actors, the Map Service Approach is able to rely on public radio instead of GSM-R or FRMCS, if

- DM-TS and DM-OB are implemented as safe systems (including cyber security measures such as safe authentication, encryption, …)
  or
- No safety-related data is transmitted between DM-TS and DM-OB (this variant is described in detail in chapter 4.3.2.)

The reason is that the On-board Map is not considered to be time-critical due to the capability of the Map Service Approach to provide very big areas of On-board Map in advance and independently of actual usage (decoupling of processes).

In Figure 7 the generic (use-case independent) process is described, together with the following notes:

- In this variant the main actors are the dedicated Digital Map trackside (DM-TS) and on-board (DM-OB) systems. CCS-OB is required for localisation and communication with DM-OB only.
- In general there is no binding of data or functions to the Movement Authority in order to allow the highest amount of flexibility and applications even in modes without Movement Authority (see also below in use case analysis). Consequently, the On-board Map is typically transmitted as regions (not paths), which can scale from a few square meters up to several square kilometres, depending on the download time and available channel capacity. However, the requested On-board Map could be restricted to the actual route in modes with MA (not modelled here), in case of limited bandwidths or to support the track-selective localisation (the latter can also be achieved by route information provided outside of Digital Map, e.g. by ETCS Movement Authority itself).
- Following assumption PPA11 the process must be based on the “required map area” (derived from the current position, estimated inaccuracy, etc.) provided by CCS-OB. This “required map area” information is used by CCS-OB (VL) internally to prove the completeness of On-board Map (exported requirement). This prove and the input information (required map area) is considered safety-related.
  In addition, Digital Map uses this information for availability check of activated On-board Map (next step).Therefore, this step and its input data is considered safety related.
  Note: The initial request of On-board Map with the provided “required map area” is based on a localisation without On-board Map support since the On-board Map is not available on the vehicle or deactivated at least. While the localisation still must be safe, the provided accuracy can be very rough (e.g. several square km area), which leads to bigger areas of transmitted On-board Map data but avoids safety issues (in CCS-OB) due to incompleteness of On-board Map. As pointed out, the correntness and safety integrity of the position is more important than its accuracy (i.e. the position does not need to be track-selective during this step).
  A safety analysis has to be done to find out the needed SIL for that initial position estimate as input for the VL requirement specification.
- Based on the safe information of “required map area”, the availability of activated (validated) On-board Map is evaluated by DM-OB. This function is not considered as safety related, since CCS-OB (VL) finally proves the completeness based on the required map area in a safe way and the integrity of stored On-board Map is ensured by other functions of DM-OB.
- If the “required map area” is not sufficiently covered by available On-board Map data in DM-OB the active version of On-board Map is requested by DM-OB from DM-TS. The version information for the “required map area” is provided as On-board Map Reference data and

contains additional integrity data for validation.

Note: The On-board Map Reference must contain all the information that is required to safely confirm the completeness of On-board Map and reveal potential transmission or processing errors during the On-board Map download process. Therefore, the On-board Map Reference information includes an unambiguous definition of the required map parts with the valid version number and the assigned protection data.

- The following version-check of potentially available but deactivated On-board Map is based on the On-board Map Reference (Ref) information provided by DM-TS.
- The area highlighted in green describes the actual download process for On-board Map, which might be realized by systems and channels with basic safety integrity level.

  Note: Even if the On-board Map is transferred by safe systems and channels, the previous version check by On-board Map Reference should be handled separately to allow efficient communication for synchronization checks between trackside and on-board. Also, the correct transmission must be checked before actual activation for safe transmission in any case.
- The safety-related validation function compares the received On-board Map against the On-board Map Reference (safe) data. Only if the validation is successful, the updated On-board Map is activated. Otherwise the download procedure is repeated (number of repetitions: to be defined)

  Note: this step ensures the integrity of On-board Map, which must be implemented as safe function.
- Finally, the activated (validated) On-board Map is provided in CCS-OB system for further consumption.

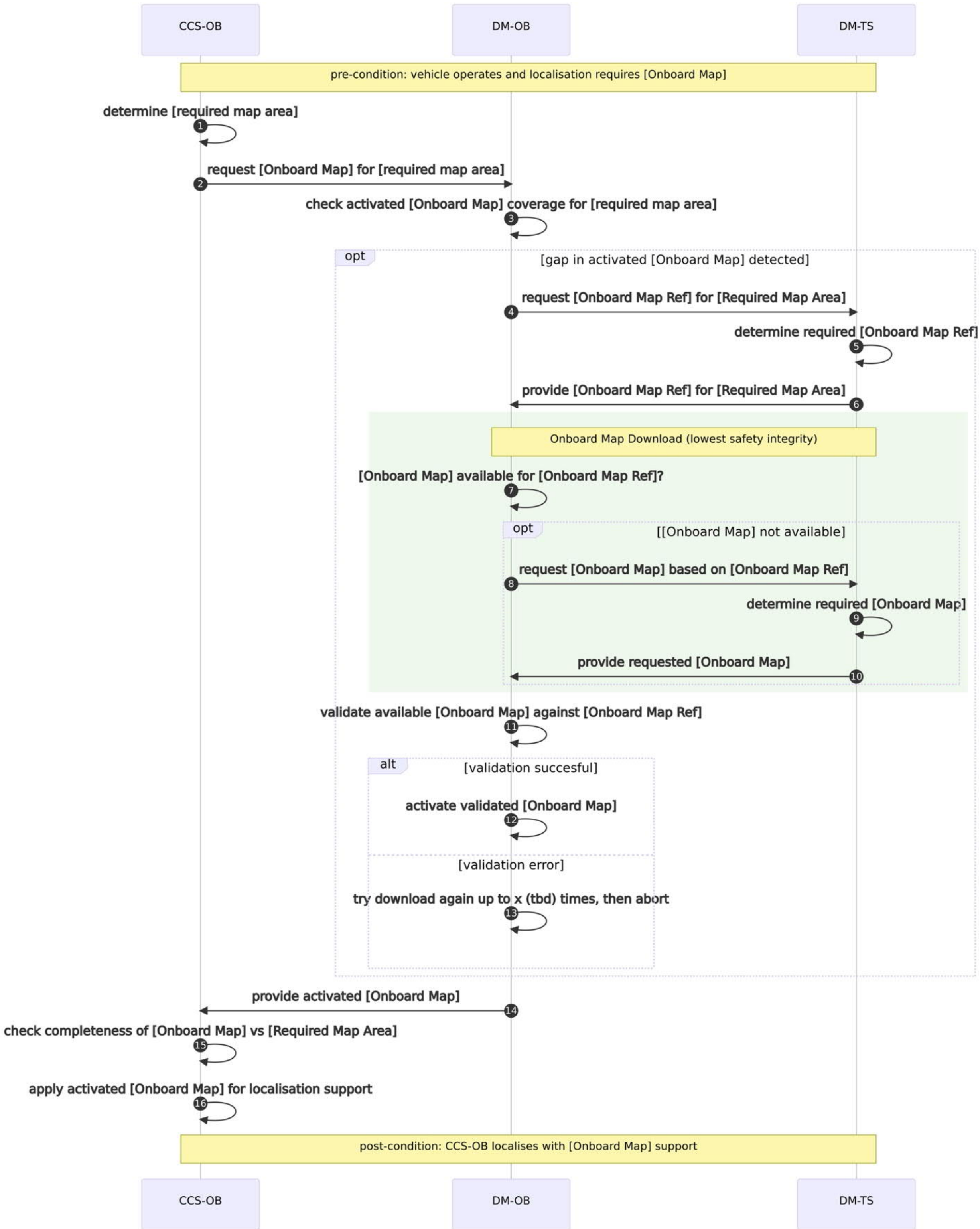

Figure 7: Map Service Approach – Provisioning of On-board Map

4.3.1.2. Deactivation of On-board Map

While the provisioning process already describes the transmission and safe activation of On-board Map, it needs to be ensured that the On-board Map stored by the vehicle is also safely deactivated if Map Data updates in the trackside systems are executed or cannot be safely excluded. To fulfil this condition, the same process as defined for the deactivation of On-board Map in the Integrated Approach is applied. The only major difference are the involved actors (DM instead of CCS).

After the deactivation, the On-board Map Reference data must be requested again at trackside for the current location as soon as the connection is established again. According to the already described generic process the available On-board Map (in deactivated state) is checked to be compliant with the active version (On-board Map Reference) of the trackside systems. Otherwise, the On-board Map must be replaced by the latest version of DM-TS.

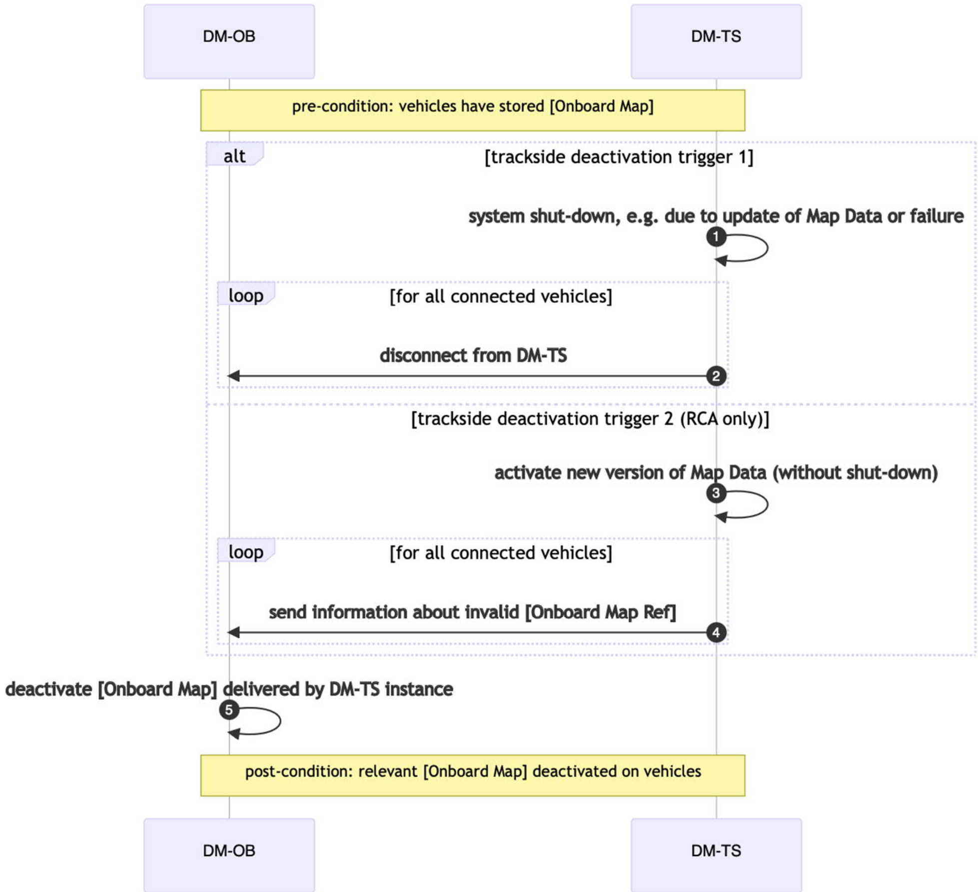

Figure 8: Map Service Approach - Trackside triggered deactivation of On-board Map

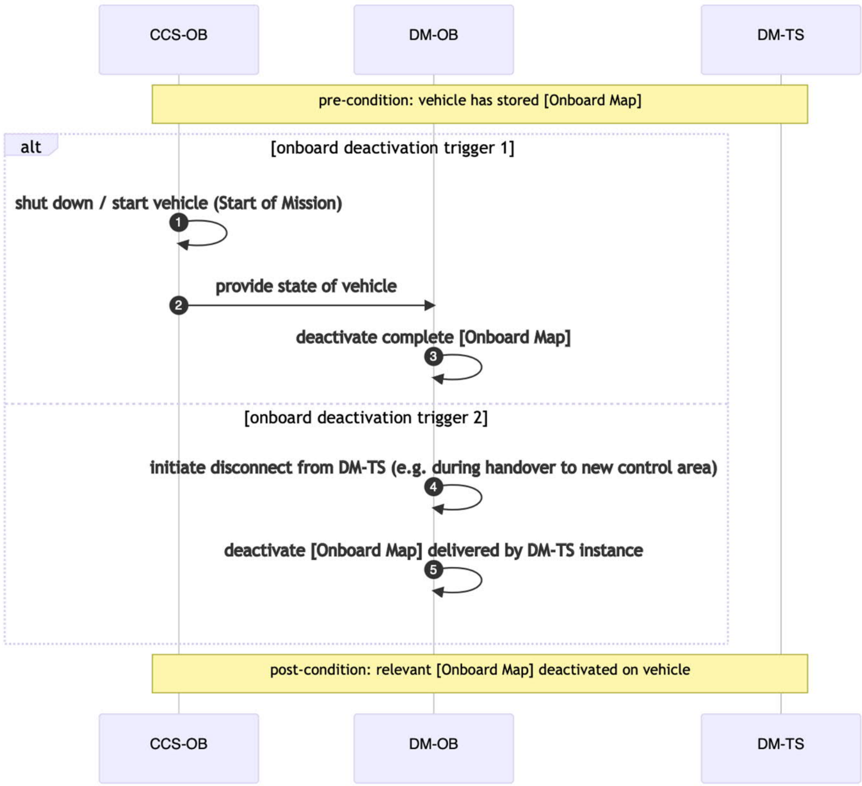

Figure 9: Map Service Approach - On-board triggered deactivation of On-board Map

4.3.2. Process Variant with CCS-TS

4.3.2.1. Provisioning of On-board Map

As pointed out earlier, an alternative regarding the involved actors is developed, which avoids safe functions and reliable data for DM-TS, DM-OB and the interface between both. By this adaption, no safety-related Digital Map functions remain for DM-TS and at least partially also for DM-OB. The publishing of safety-related On-board Map is completely managed by the CCS-OB system and DM-OB is reduced to a communication interface for downloading On-board Map. This could help to integrate existing map management solutions and open the market for additional vendors. Therefore, the safe functions are allocated to CCS-TS and CCS-OB systems only. The safety-related On-board Map Reference data for map coverage check and final validation is transmitted by a new Subset 026 packet. The DM-TS and DM-OB handle the On-board Map download process only, which is not safety-related.

The following diagram shows the adapted generic process including the new actor CCS-TS.

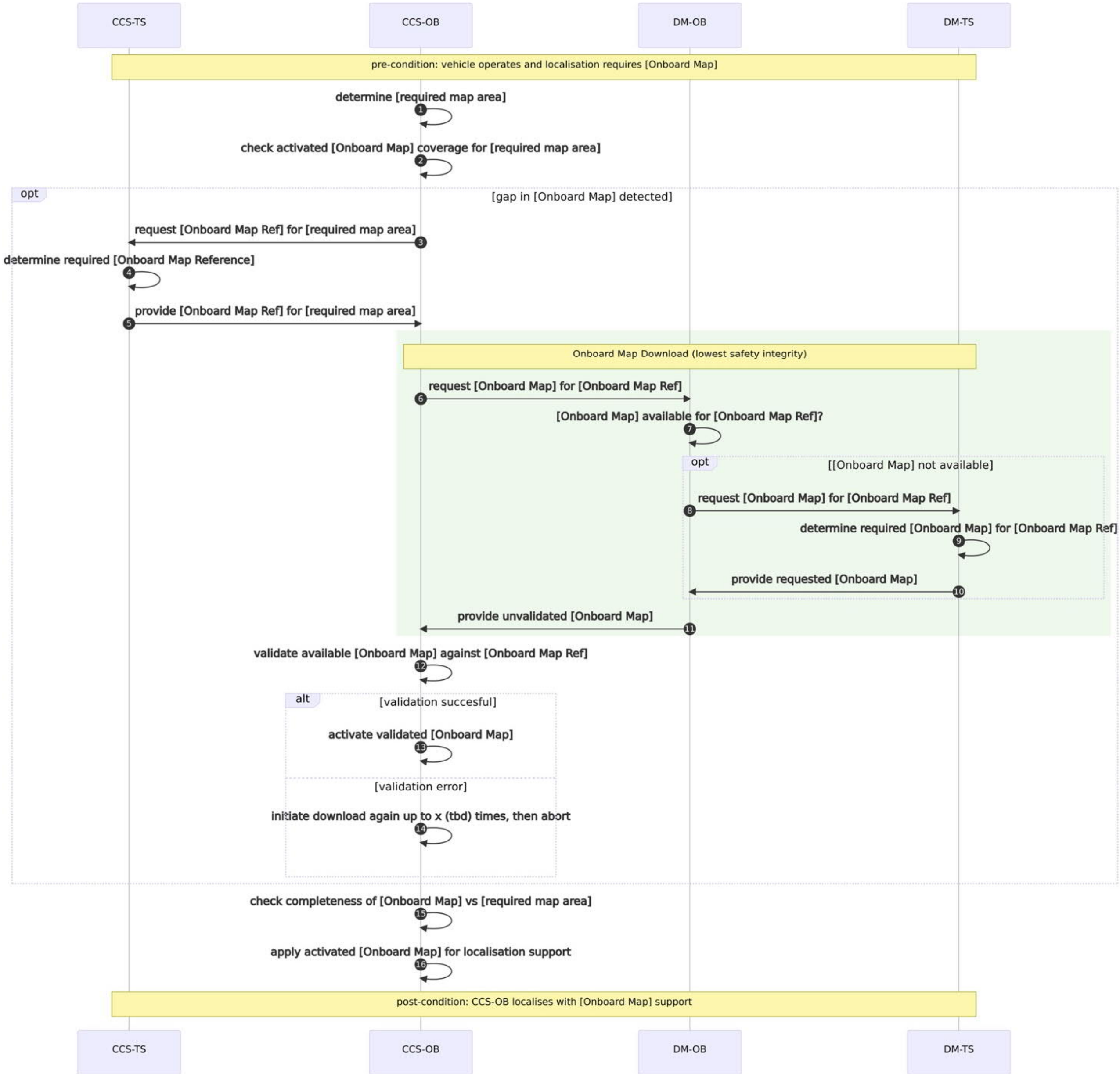

Figure 10: Map Service Approach Variant with CCS-TS – Generic Process

If the CCS-OB shall not perform safety-related functions of Digital Map management, these functions could also be allocated to a safe part of DM-OB. Still, the download functionality remains in the non-safety-related part of DM-OB. In this case CCS-TS and CCS-OB handle the transmission of On-board Map Reference only.

4.3.2.2. Deactivation of On-board Map

For the deactivation procedure of this process variant with CCS-TS and CCS-OB it is referred to the Integrated Approach in chapter 4.2.1.2.

4.3.3. Use Case Analysis

Based on the generic sequence the specialities of the different use cases are analysed in the following chapters.

4.3.3.1. Train runs with Movement Authority

In this use case the generic process can be applied without any modifications.

If required for bandwidth or localisation reasons, the request of On-board Map at DM-TS can be restricted to the actual route. This can be achieved by considering MA information in CCS-OB. In the process variant with CCS-TS the On-board Map Reference could be already limited to the route.

4.3.3.2. Start of Mission

In this use case the generic process can be applied without any modifications.

During the Start of Mission (SoM) procedure, the vehicle usually has an estimated position, which is not trust-worthy in terms of ETCS. The usage of On-board Map shall support the validation of the estimated position.

4.3.3.3. Train runs without Movement Authority

In this use case the generic process can be applied without any modifications. The approach does not depend on Movement Authorities.

Note regarding Shunting without Movement Authority (legacy architecture only): Since the Map Service approach is able to transmit whole regions of On-board Map data, the required region for the shunting area must be provided in advance (e.g. during shunting request or earlier). If the process variant with CCS-TS is applied, the validation of On-board Map must be finished before the connection is terminated between trackside and on-board. However, as pointed out in chapter 3.1.1 the usage of On-board Map for Shunting without Movement Authority is not considered as an effective technical solution.

4.3.3.4. Train passes trackside control area border

If a border between two CCS-TS control areas is passed, the validation process is affected, if CCS-TS is used as an actor (see 4.3). The generic handover procedure of CCS-TS (RBC/MT) and CCS-OB ensures that the connection to the next control area is established. There are no special requirements for the CCS-TS handover coming from the Digital Map management processes.

If a border between two DM-TS control areas is passed, the Map Management functions of Digital Map must ensure a seamless transition, i.e. by

- sufficiently large overlap of the control areas from the actual and next DM-TS in the handover section
- sufficiently early transmission of connection data for the DM-TS of the next control area
- simultaneous connection to DM-TS instances of the actual and next control area

In general, the principles of CCS-TS/OB handover can be applied in a similar way. The further details of the handover management are not subject of this document.

4.3.3.5. Train runs in mode without connection to CCS-TS

If the Map Service Approach is applied without relying on CCS-TS (plain approach) then this optional use case (without connection to CCS-TS) can be supported under the condition, that the connection between DM-TS and DM-OB is established. The variant with CCS-TS is not applicable for this use case. *Note: according PPA7 IM specific procedures can be applied alternatively to allow operation with On-board Map even if the on-board is not connected to trackside.*

5. Evaluation

The introduced approaches are compared regarding coverage of requirements. The following simplified scale is used:

both approaches fulfil requirement

one approach (green) fulfils the requirement better than the other approach (yellow)

Based on the overall requirement coverage the result is summarized as base for the following conclusion.

Table 11: Evaluation of approaches

Requirement	Integrated Approach	Map Service Approach
PPR1: Flexible	Typically, the On-board Map required for running path only is provided. Bigger areas or even complete maps require offline provisioning, unless FRMCS is available (usage of public radio network is not an option).	The approach can be applied with different region sizes depending on the available radio capacity. With the possible application of public radio network very large (or even complete) On-board Map areas can be delivered online before the actual usage (e.g. complete initial data load, especially in urban area or regional line).
PPR2: Efficient	only required data is transmitted to the train (especially in modes with MA), which guarantees a high efficiency. In addition, the repeated transmission of On-board Map with each Movement Authority can be avoided by implementing an on-board cache with version check, although the approach gets more complex (similar to Map Service Approach).	no redundant transmission, but a lot of data within the provided On-board Map region potentially not applied by train localisation. *Note: Since the transmission could be done via public radio with less restrictions, the efficiency criteria might weight less.* *Also, in theory, the transmission could be limited to the route in modes with MA as well, if required for any reason.*
fPPR3: Versatile	technically, all required use cases are supported with only one limitation for modes without MA and speeds higher than zero: the Integrated Approach is not recommended if the transmission needs to rely on GSM-R only. In addition, the optional use case is *not supported* due to required radio	all required use cases are supported. Even the optional use case can be supported, if no CCS-TS is involved and a completely independent channel is used between DM-TS and DM-OB

Requirement	Integrated Approach	Map Service Approach
	connection between CCS-TS and CCS-OB.	*Variant with CCS-TS:* all use cases except the optional use case are supported
PPR4: Comprehensive	In general, all required track axis data as well as element information can be transmitted. However, depending on the local situation the reduced capacity of GSM-R will lead to relevant limitations in case of providing highly accurate track axis data or virtual balise information (i.e. balise telegram)	All required track axis data as well as element information can be transmitted. There are no relevant limitations due to possible involvement of public radio network.
PPR5: Robust	no delays of operation expected since the On-board Map is transmitted together with the data that leads to train movement as part of message sequence. If caching is implied, then the approach is even more robust.	to reduce the probability of operational delays the On-board Map update must be triggered early enough, i.e. when the vehicle is localized at border of actual region. Optionally, additional triggers with sufficient foresight can be considered for pre-loading On-board Map in advance, e.g. Journey Profiles provided by other trackside systems. Since public radio network can be used before FRMCS is available, the bandwidth allows preloading of very big areas (e.g. whole country) around the actual location. Redundant transmissions and impacts of radio holes are avoided by On-board storage/cache. Therefore, it is possible to reach a level of robustness comparable to the Integrated Approach, even if more systems and interactions are involved.
PPR6: Safe	new On-board Map versions are automatically considered on trackside and on-board due to coupling with operational message stream (safety is already	Digital Map systems (DM-TS/OB) are implemented as safety-related systems (SIL>0), which reduces the possibility of integrating COTS or existing solutions from other domains but

Requirement	Integrated Approach	Map Service Approach
	embedded independently of Digital Map). If cache is used: With each disconnect the deactivation/deletion of On-board Map is triggered for safety reasons.	ensures safety. This includes not only the transmission and validation, but also the deactivation of On-board Map if required. *Variant with CCS-TS:* the safety-related data is transmitted via existing safe channel only (Subset 026). In addition, the safety-related Digital Map functions could be allocated to CCS systems only, so COTS/existing solutions might be used for Digital Map management. In any variant or allocation scenario the safety is ensured.
PPR7: Secure	Security is ensured by the design of the ETCS and Euroradio transmission	Security will be ensured by generic RCA measures/concepts and must be considered during system/interface design
PPR8: Migratable	integration into legacy architecture as well as RCA easily possible for trackside systems, since it can be realized completely with interfaces/systems, that are already part of standardization work. However, besides the functional extensions for trackside and on-board the engineering data of existing RBC must be added by On-board Map information.	Integration into legacy architecture as well as RCA possible, but additional map systems required on trackside and on-board to realize the map management service in parallel to existing systems. These additional systems and interfaces might lead to higher migration efforts in legacy architectures. However, the investments of existing systems are protected, and the costs of additional systems could be (partially) compensated by the fact, that CCS-TS must not be changed at all (for plain approach).

Requirement	Integrated Approach	Map Service Approach
PPR9: Interoperable	In order to ensure interoperability existing standardized systems/interfaces must be extended by localisation functions and data (more information about adapted specification: see evaluation of PPR13 Modular).	The DM-TS and DM-OB systems can be mapped to RCA standardization work, which must be also applied for legacy architectures to ensure cross-border compatibility (more information about adapted specification: see evaluation of PPR13 Modular).
PPR10: Adaptable	Extended On-board Map use cases require FRMCS due to increased amount of data. This dependency limits the ability for the support of extended use cases.	Due to the decoupling of On-board Map download and validation and the possible usage of public radio extended data needs can be fulfilled easily by extension of the On-board Map.
PPR11: Low LCC	Lower number of standardized system component supports are used, which helps to keep initial costs low. *Note: On the other side, the adaption of exisiting CCS systems is considered expensive, i.e. over the life cycle for each update/functional extensions (covered by PPR12 Modifiable)*	Additional, dedicated Digital Map systems required, which might increase the initial implementation costs. *Variant with CCS-TS:* higher number of involved compoments, which might be compensated partially by the possible usage of COTS for remaining Digital Map system functions.
PPR12: Modifiable	Updates are expensive, since CCS-TS (i.e. RBC/MT) and CCS-OB (i.e. OBU/VS) must be adapted for Digital Map functions (including proof, that there are no side effects for other functions of these systems)	Due to the independent, dedicated systems and interfaces the (plain) Map Service approach can be modified with low costs. see plain approach plus cost for adaption of CCS-TS (i.e. RBC/MT) engineering for updated On-board Map Reference
PPR13: Modular / Extensible	The functions and data are implemented into existing CCS systems only, which requires an adaption of specifications such as: - SUBSET 026: required, i.e. message/packet for providing actual On-board Map data	The functions are implemented in independent, dedicated systems, which offers the highest grade of modularity. The main impact to other systems is reduced to the on-board specifications to cover the

Requirement	Integrated Approach	Map Service Approach
	- SUBSET 091: required, i.e. safety requirements of new trackside and on-board functions - Potentially further on-board specifications (not in scope of RCA/this evaluation → OCORA). Due to the integration of the new On-board Map management into CCS systems, which fulfil other purposes, the modularity is limited.	communication needs for requesting and receiving On-board Map data from DM-OB to CCS-OB system (not in scope). *Variant with CCS-TS:* Similar to the Integrated approach, the Subset 026 needs to be adapted in addition to allow the transfer of On-board Map Reference (no On-board Map).
Result	this solution offers *less* advantages for the intended use case of providing On-board Map data for the support of localisation in the ETCS context	this solution offers *more* advantages for the intended use case of providing On-board Map data for the support of localisation in the ERTMS context. The plain process without CCS-TS involvement additionally benefits from the higher grade of independency and less impact on existing standardization.

The evaluation leads to the following conclusions:

- **Integrated Approach**: This approach (without cache) is the less complex solution which offers intrinsic safety and less integration/migration efforts. The biggest disadvantage is the expected high consumption of transmission capacity, which cannot be provided by GSM-R, and the dependency to ERTMS, which limits the coverage of use cases of today and in the future (scalability).
- **Map Service Approach:** While this solution requires new, dedicated map management systems including the potentially higher integration efforts on trackside and on-board, it allows better decoupling from the actual usage of On-board Map. Therefore, the available bandwidth can be used more efficiently and even increased by usage of public radio. The variant with CCS-TS as actor comes with the cost of higher dependency and has an impact on Subset 026, therefore it is less preferable.
  In general this approach is the more most scalable approach for further applications requiring On-board Map, i.e. since new Map Data layers do not required changes of Subset 026.

Finally, the Map Service Approach is the preferred solution. It needs to be decided if the variant with CCS-TS should be applied or not. Based on the evaluation the process *without CCS-TS* has more advantages and *is the recommended variant of Map Service Approach*.

6. Conclusion

As shown by the analysis, the *Map Service Approach* seems to be the more suitable and scalable solution for publishing safety-related On-board Map data from trackside to On-board systems for the purpose of localisation (odometry enhancement).

It needs to be decided if the variant with CCS-TS should be applied or not. The most important question is the weight of the criteria:

- Potential involvement of commercial products in a non-safety related Digital Map environment (and therefore addressing a wider market) → approach with CCS-TS
  vs.
- Stability of Subset 026 and grade of independency/modularity for Digital Map → approach without CCS-TS

While the final decision is subject of the further development phases, the *plain Map Service approach without CCS-TS is the recommended solution* based on the evaluation.

Next Steps/Open Points:

- Identification of functions based on the aligned approach and sequence
- Use this decision and input for System Definition, Preliminary Hazard Analysis, specification incl. exported requirements to other systems. As part of the mentioned phases the map management process should be further refined, i.e.
  - complete function list,
  - complete non-functional requirements (i.e. RAM)
  - SIL-allocation to functions based on hazard analysis,
  - consider also map management of degraded modes (error management)
  - final allocation of functions to the systems
- Study regarding point vs. vector-based track geometry
- Update of this evaluation according to progress of RCA modelling & specification work (including definition of actual data structure, messages...)
- Overall migration strategy, which defines the different scenarios for the implementation of VL and the Digital Map. This should be done from the perspective of the consumer, i.e. VL

7. Allocation of Systems and Interfaces

Based on the resulting approach, the potential function allocations to the systems of the RCA are discussed. The legacy architecture is included in the discussion as well.

Since it is not finally decided yet, if the variant with CCS-TS is applied or not, both approach variants are considered here.

The following interacting systems are recommended to realize the functions of the abstract system terms introduced in Table 1:

7.1. Map Service Approach (without CCS-TS)

In this case, all Digital Map functions are allocated to dedicated Digital Map systems only. For better clarity on the subsystems involved in the approach refer to Figure 2.

- DM-OB:
  - RCA/OCORA:
    - the on-board system of Digital Map in RCA is represented by VL.
    - In OCORA the subsystem breakdown already divides between DM-OB as on-board map management system and VL as localisation system, so the Digital Map functions are allocated to DM-OB of OCORA.
  - Legacy: In legacy architecture the DM-OB is a new on-board system that is not standardized yet, so it must be implemented following RCA/OCORA standardization work.
  - (Almost) all functions are considered safety related.
- DM-TS:
  - RCA: The trackside system of Digital Map in RCA as operational system with direct communication interface (SCI-MD) to VL is the MOT. ~~DCM is connected via maintenance interface only, which is not recommended for a robust Digital Map service~~.
  - Legacy: In legacy architecture the DM-TS is a new trackside system that is not standardized yet, so it must be implemented following RCA standardization work for MOT.
  - (Almost) all functions are considered safety related.
- Interface DM-OB - DM-TS:
  - RCA/OCORA: The applied interface is the already defined SCI-MD
  - Legacy: The applied interface is not available yet, so it must be implemented according to RCA SCI-MD
  - The transferred data and messages are considered safety-related for the On-board Map Reference.
- Interface CCS-OB – DM-OB (OCORA):
  - The standardization is not part of RCA, since it is a vehicle platform internal interface of OCORA.
    Note: In RCA it is not to be foreseen between VL and DM-OB. This interface is specified as a part of OCORA only.
  - the transferred data and messages are safety-related since it includes the validated/activated On-board Map.

7.2. Map Service Approach variant with CCS-TS

In this approach variant some safety-related Digital Map functions are transferred to CCS system:

- Allocation scenario 1 (minimum): request On-board Map Reference only allocated to CCS-OB
- Allocation scenario 2 (maximum): Scenario 1 plus all other safety-related functions of DM-OB allocated to CCS-OB

Depending on the number of functions transferred to CCS the DM-OB can be implemented with reduced safety integrity level or even basic safety integrity. DM-TS as well as the interface between DM-TS and DM-OB is not safety-related at all in this variant.

The additional CCS systems and required interfaces are allocated as follows:

- DM-TS: see chapter 7.1
- DM-OB: see chapter 7.1
- Interface DM-OB - DM-TS: see chapter 7.1
- CCS-TS:
    - The MT (RCA) / RBC (legacy) should be allocated to this, since it exists in both RCA and legacy architecture as CCS-TS system.
    - All allocated functions are considered safety related.
- CCS-OB:
    - If MT (RCA) / RBC (legacy) is used on trackside, the direct interacting partner will be VS, which must communicate with VL to forward the On-board Map Reference data.
    - All allocated functions are considered safety related.
- Interface CCS-OB – CCS-TS:
    - Must be standardized by extension of Subset 026, which is reused by RCA/OCORA
    - The transferred data and messages are safety-related since it includes the On-board Map Reference data.
- Interface CCS-OB – DM-OB (OCORA):
    - see chapter 7.1, except for assumed safety integrity of the transmitted data:
    - Allocation Scenario 1: The transferred data and messages are safety-related since the On-board Map Reference is included.
    - Allocation Scenario 2: The transferred data and messages are not safety-related since the transmitted On-board Map is validated by CCS-OB with information provided by CCS-TS

7.3. Result

In general, the systems and interfaces can be clearly allocated without variants or the need for deeper trade-off-analysis. For the final definition it needs to be decided:

- If CCS-TS should be involved or not (see discussion in previous chapters)
    - If CCS-TS is involved: which safety-related functions of DM-OB are allocated to CCS-OB (allocation scenarios above)

The allocation is summarized as follows:

Table 12: Allocation of systems and Interfaces

Nr	Group	Allocated System or Interface	Map Service Approach (recommended)	Map Service Approach with CCS-TS
1	DM-TS	RCA: MOT Legacy: new system as standardized by RCA	Required for Digital Map Safety Integrity: highest	Required for Digital Map Safety Integrity: basic
2	Interface DM-TS ←→ DM-OB	RCA(/OCORA): SCI-DM Legacy: new interface as standardized by RCA	Required for Digital Map Safety Integrity: highest	Required for Digital Map Safety Integrity: basic

Nr	Group	Allocated System or Interface	Map Service Approach (recommended)	Map Service Approach with CCS-TS
3.1	DM-OB	OCORA: DM-OB RCA: VL Legacy: new system as standardized by OCORA	Required for Digital Map Safety Integrity: highest	Required for Digital Map Safety Integrity: basic or highest (depending on function allocation)
3.2	Interface DM-OB ←→ CCS-OB	OCORA: DM-OB–LOC-OB RCA: VL internal Legacy: new interface as standardized by OCORA	Required for Digital Map Safety Integrity: highest	Required for Digital Map Safety Integrity: basic or highest (depending on function allocation)
3.3	CCS-OB	OCORA: not defined here (black box), e.g. LOC-OB,… RCA: VL & VS & interface VL←→VS Legacy: adaption of OBU	Not required for Digital Map (for localisation and application of On-board Map only)	Required for Digital Map Safety Integrity: highest
4	Interface CCS-OB ←→ CCS-CCS	ETCS-SS026 (adapted)	Not required for Digital Map	Required for Digital Map Safety Integrity: highest
5	CCS-TS	RCA(/OCORA): MT Legacy: RBC (adapted)	Not required for Digital Map	Required for Digital Map Safety Integrity: highest

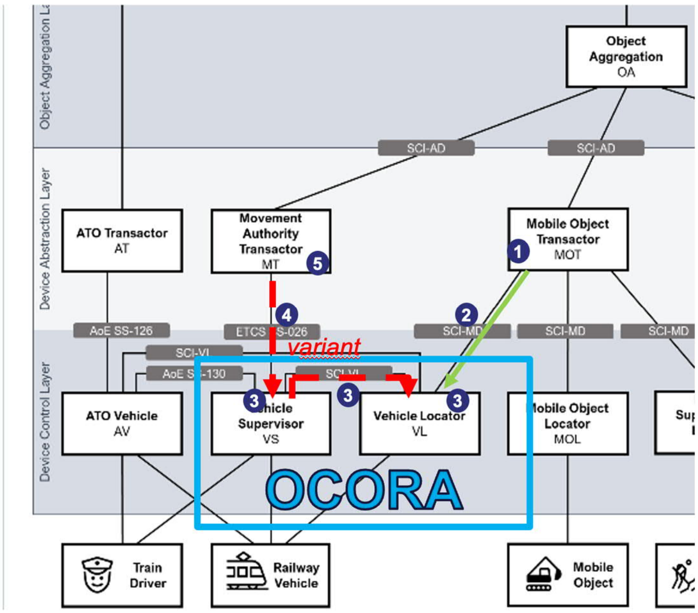

Figure 11: Allocation to Systems and Interfaces