CLUG Demonstration of Readiness for Rail – CLUG 2.0

D2.3 LOCALISATION ON-BOARD SYSTEM DEFINITION AND OPERATIONAL CONTEXT

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EXECUTIVE SUMMARY

This document is a deliverable of the “Work package 2 - LOC-OB System Definition and Requirement Specification” of the CLUG 2.0 project which stands for Certifiable Localisation Unit using Global Navigation Satellite System (GNSS) in the railway environment. The project is one more milestone in transforming the way of train localisation using technologies such as GNSS and European Geostationary Navigation Overlay Service (EGNOS) which are among the “game-changing” technologies for future digital and automated railway operations.

Work package 2 analyses operational user needs and the operational context of a train on-board localisation system. Based on this analysis, system capabilities are defined. An observation of nominal and degraded operational scenarios focussing on Start of Mission and Track Selectivity allows to derive further constraints against the system. The consolidation of existing approaches (e.g., OCORA) results in the definition of a system architecture including system boundaries, interfaces, and functions. Finally, a set of requirements for the on-board localisation system is specified.

Deliverable D2.3 focuses on the system architecture and the operational context of the LOC-OB component. The complexity of the on-board CCS strongly influences design decisions for a common architecture. CLUG promotes a modular approach that enables functional isolation of all subsystems. A common communication bus allows the blocks to exchange information. To provide the operational context, the proposed CLUG architecture is compared with the existing ETCS solution and the proposals of preceding projects. A system under consideration is then defined to identify the functional interfaces between the LOC-OB component and its users and supporting systems.

For the architecture, the assumed black box from D2.1 is filled with functional blocks in this deliverable, by following a model-based system engineering process. The system requirements defined in D2.1 are assigned to functional blocks, and the functional interfaces to user and input system of LOC-OB are defined in D2.3. Care has been taken not to pre-empt a technical solution for how LOC-OB should be implemented, but to provide a shell with defined functions and interfaces from which the solution designers can build.

One main input to the LOC-OB in its current architecture is a digital map with very specific information about the railway net. D2.3 exports a minimal set of relevant requirements to the digital map, and gives a ratio of why these are important for LOC-OB. Besides these requirements, the Digital Map model developed within the Reference CCS Architecture (RCA) is picked up, and the model as well as its components are evaluated for the use of safe on-board localisation.

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Applicable documents

The following documents define the contractual requirements that all project partners are required to comply with:

- Grant Agreement N°101082624 (which includes description of work, Grant Preparation Forms and annexes): This is the contract with the European Commission which defines what has to be done, how and the relevant efforts.
- Consortium Agreement (Signature Date: 2023-04-13): This defines our obligations towards each other.

Each of the above documents was established at the start of the project, and copies were supplied to each partner. Each document could potentially be updated independently of the others during the course of the project following a prescribed process. In the event of any such update, the latest formal issued version shall apply.

In the event of a conflict between this document and any of the contractual documents referenced above, the contractual document(s) shall take precedence.

1 Scope and Assumptions

This deliverable defines an interoperable, interchangeable and upgradeable architecture of LOC-OB and the interfaces to the CCS-OB system. This architecture is an input for D2.4 (Ref [4]) and the downstream work packages, in particular for the design and development phase in WP4.

First the document presents an overview of the architectures of other initiatives, projects and the existing European Train Control System (ETCS). It then defines the Operational Context of the Localisation On-Board (LOC-OB). Thereafter, the external interfaces and the high-level architecture are introduced. The deliverable closes with a brief re-assessment of the digital map approach of RCA.

A few assumptions are important to understand the context and decisions taken on this deliverable. Those are explained below:

- The architecture targets the LOC-OB system in general and focuses on the perspective and needs of the Railway operators. The architecture does not explicitly consider the selected and promoted sensor setup of GNSS, EGNOS and Inertial Measurement Unit (IMU) as stated in CLUG 2.0. The architecture and interface definition aims to contribute to the specification of the localisation unit of ETCS overall.
- The architecture covers the following:
    - The interfaces describe a logical relationship between subsystems. A logical relationship defines what kind of information is exchanged and how the subsequent steps define the interaction process.
    - The architecture provides a structured overview of the anticipated functions of the system. Note: The categorization and clustering of these functions is not a required framework or definition of components.
- The following is not defined in this deliverable and is out of the scope:
    - The LOC-OB subsystem is just one part of the overall Control Command and Signalling On-Board (CCS-OB) architecture, and it does not provide specific details about the interfaces and subsystems of the complete on-board architecture, or the common bus used for data exchange.
    - A physical description with all Open Systems Interconnection (OSI) layers for each interface as the common bus is assumed to be established by OCORA.
    - The responsibility for the design of internal functional components as well as the selection of sensors of LOC-OB lies with the supplier.
    - The selected sensors including their components and software (e.g., antennas, receivers, systems, signals, etc.) are considered to be an integral part of LOC-OB and are not further specified.

2 Existing LOC-OB Architectures

2.1 Current ERTMS / ETCS Architecture

2.1.1 Current ERTMS/ETCS

As defined on the European Union Agency for Railways (ERA) website (cf. Ref [13]), the European Rail Traffic Management System (ERTMS) is a single European signalling and speed control system that ensures interoperability of the national railway systems, with the final goal of developing an efficient and competitive EU-wide railway network, the single European railway area SERA (cf. Ref [44]), reducing the purchasing and maintenance costs of the signalling systems as well as increasing the speed and availability of trains, the capacity of infrastructure and the level of safety in rail transport.

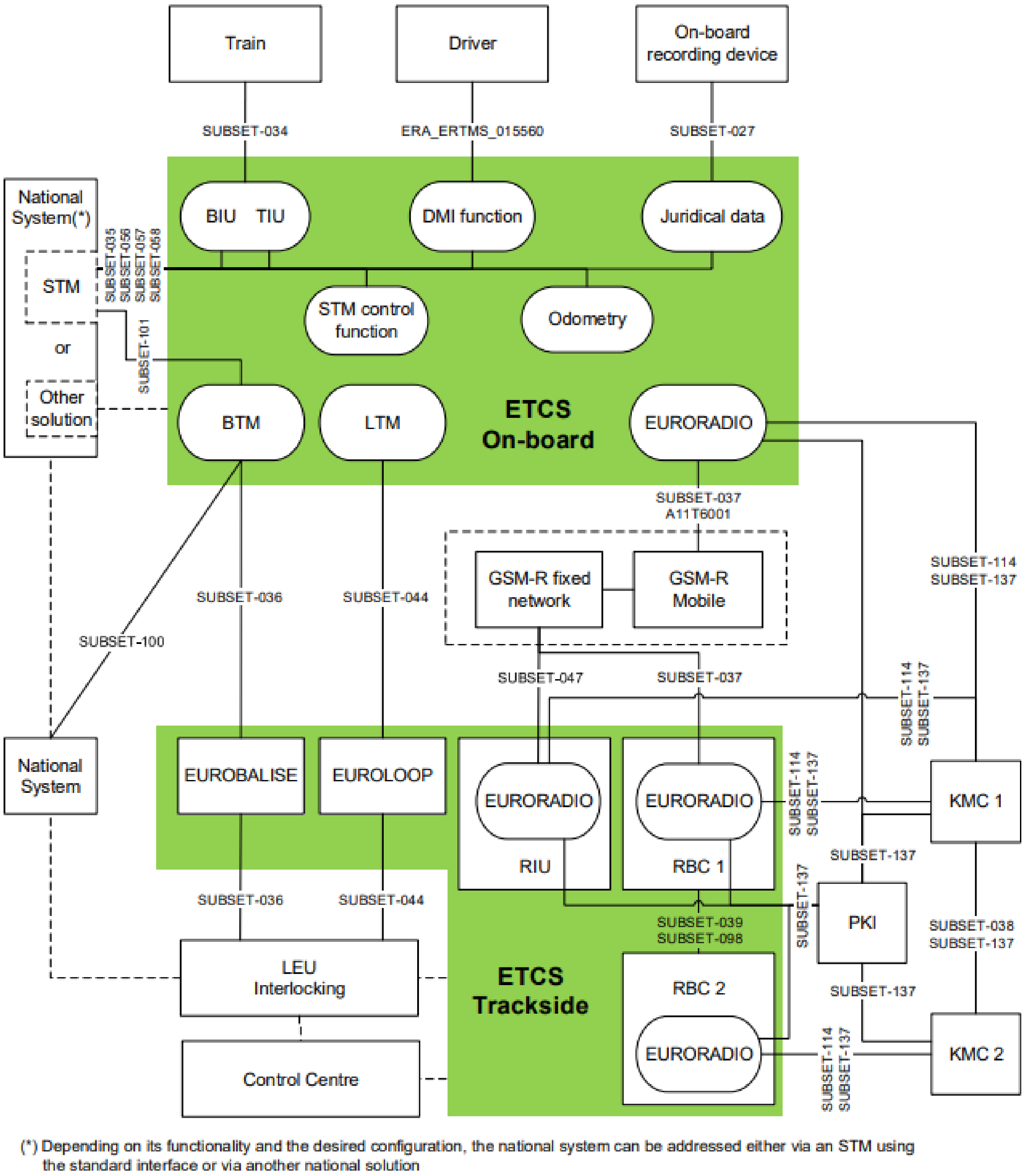


Figure 1 - ERTMS/ETCS reference architecture – SUBSET-026-2 Ref [28]

In today´s ETCS implementation, the LOC-OB functionality is part of the ETCS On-Board Unit (OBU).

As Ref [17] states, in order to ensure the modularity, interchangeability and upgradeability requirements (cf. Ref [1]) it is essential that the future LOC-OB is a separate logical component (including current odometry sensors and new sensor data).

The LOC-OB system has the dedicated functionality of locating safely and reliably the train and its orientation on the track and determining associated kinematic parameters of the vehicle.

Defining LOC-OB as a separate logical component and standardising its external interfaces allows the development and implementation of new localisation technologies inducing updates of the internal LOC-OB logic such as:

- Including new types or new generations of sensors,
- Improving fusion algorithms output quality,
- Including additional standardised data sources in the fusion algorithms (as for example routing information, augmentation information…),
- with a minimum required effort for re-certification and homologation of the whole ETCS OBU unless the standardised interfaces are impacted by the updates.

2.1.2 Future standardised CCS-OB architecture

The definition of the future standardised CCS-OB architecture is ongoing and not yet finalised. All the assumptions made in this document are subject to modification when the standardised CCS-OB architecture will be released. Nonetheless, to have a better understanding which ETCS functions covering localisation, a list of relevant functions has been distilled and is introduced hereafter.

2.1.3 Scope of LOC-OB vs ETCS BL3R2

Odometry as defined in ETCS BL3R2 (cf. Ref [28]) focus on the 1D safe localisation dataset and is part of the monolithic ETCS-OB. Interfaces related to the odometry are considered as the ETCS-OB internal interfaces and are not subject to standardisation. The odometry interfaces are under the responsibility of the ETCS-OB supplier.

In opposition, LOC-OB:

1. Is a standalone component part of a future standardised CCS-OB.
2. Does not only focus only on the 1D safe localisation dataset.
3. Has several users.

The mapping of the relevant ETCS functions to LOC-OB is laid out in Section 3.2.

2.2 On-board localisation architecture defined in previous initiatives and projects

2.2.1 UNISIG concept for on-board CCS (Control Command and Signalling) architecture evolution

UNISIG develops, together with ERA and EUG, the ERTMS/ETCS technical specifications. Ref [43] defines the evolution (short, medium and long-term plans) for the on-board CCS architecture, focusing on a system level (functional building blocks) but not below (e.g., component level: safe computing platforms, middleware, antennas…).

The short-term proposal constitutes the definition of the on-board CCS subsystem for the CCS TSI 2022. This proposal is based on the current design and does not introduce any fundamental change but for the game changer ATO GoA 2. The proposal also involves preparation of existing specifications for the future on-board CCS architecture as for example: Ref [32] for the interface of the ETCS on-board to the train or Ref [33] for the CCS display interface.

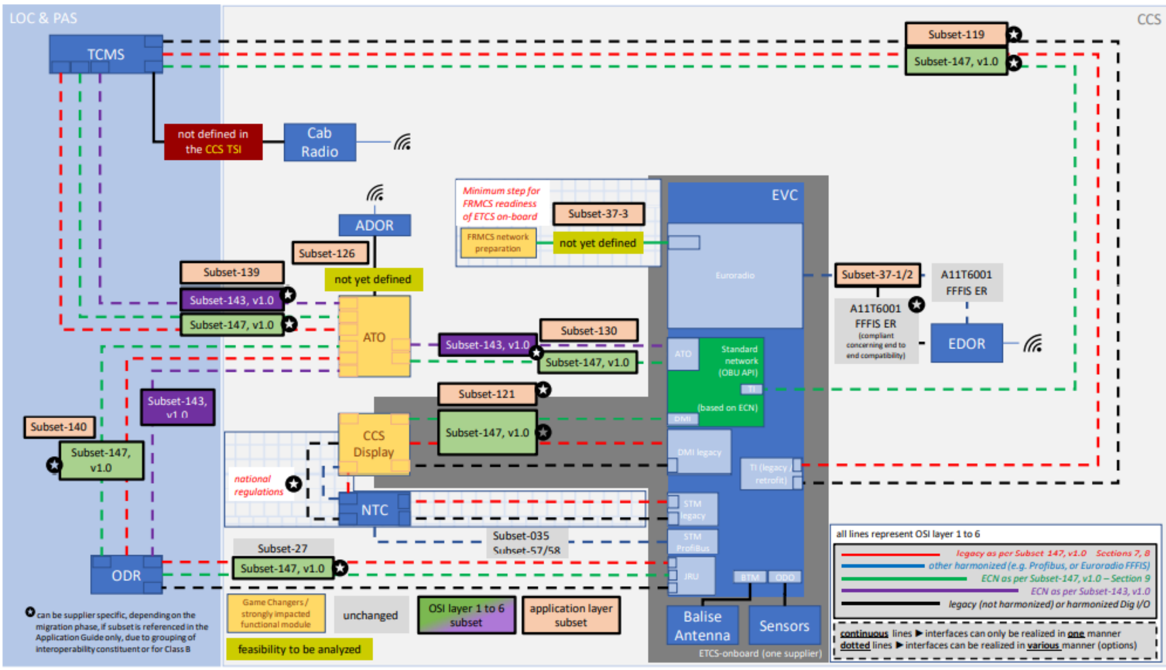


Figure 2 - Stage 1: Short-term (Ref [43]).

The mid-term proposal constitutes the definition of the on-board CCS subsystem for CCS TSI following the CCS TSI 2022. This proposal is also based on the current design and will be mainly aimed at closing unsolved open points during CCS TSI 2022 and introducing FRMCS as the radio baseline 2.

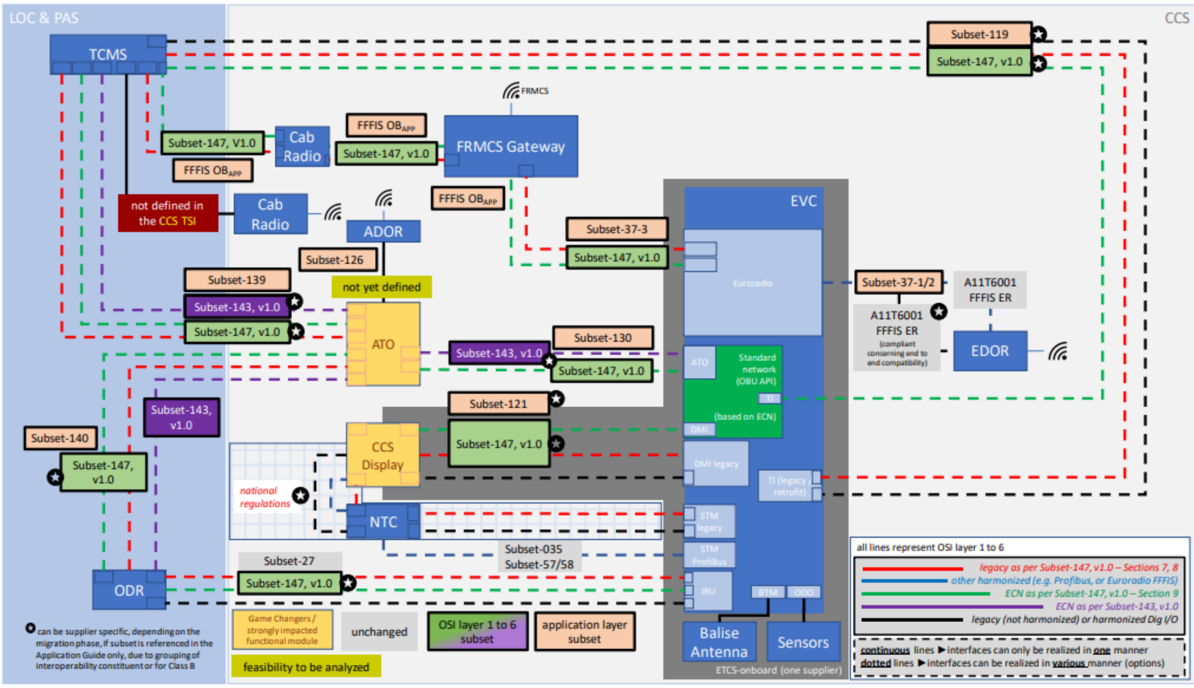


Figure 3 - Stage 2: Mid-term (Ref [43]).

The long-term proposal constitutes the definition of the on-board CCS subsystem for a future CCS TSI. It fully standardizes all interface between CCS and TCMS (train interface between the on-board CCS and the rolling stock) among the interchangeable elements (excluding legacy NTCs) based on the CCS one common bus.

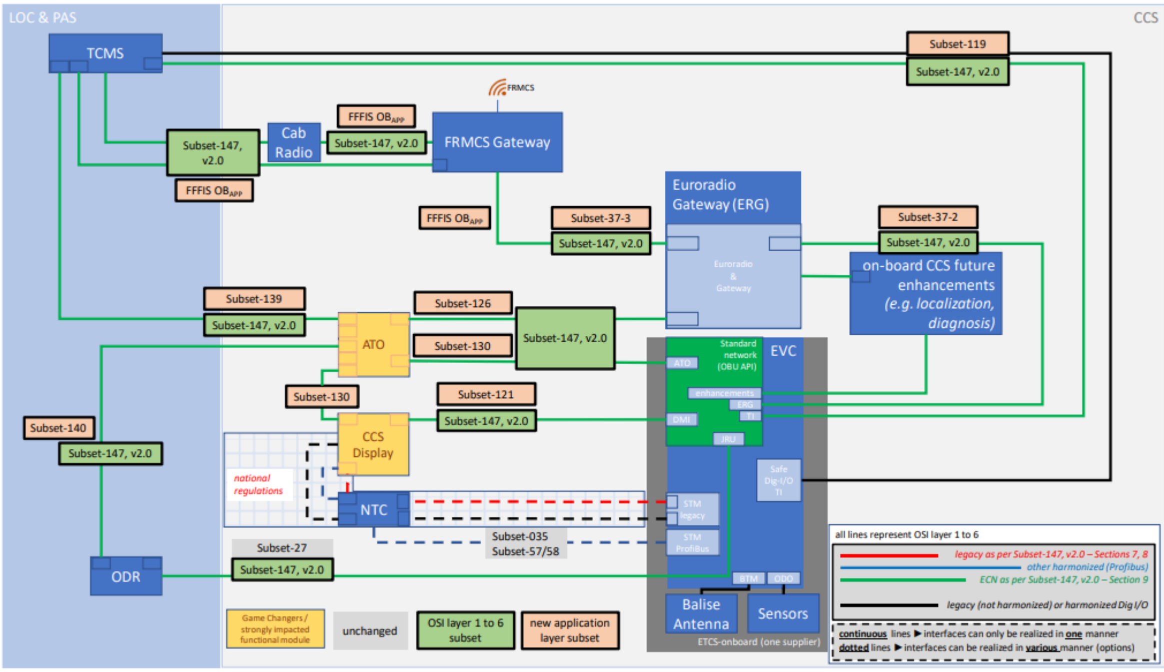


Figure 4 - Stage 3: Long-term (Ref [43]).

UNISIG approach (even long-term) is considering the sensors and balise reader in the ETCS-OB (Ref [43] – Chapter 7.4) while the LOC-OB would be an independent module. This is not aligned with most of the research and development projects where the sensor equipment and data acquisition (balise reader under discussion) is part of LOC-OB (cf. Section 3.2: CLUG (1), X2RAIL-5…) and hence it would affect the interfaces definition. UNISIG is, so far, not foreseeing the inclusion of the odometry sensors within the localisation on-board module neither the standardisation of the interface between the localisation on-board unit and the balise antenna.

Stage	Main affected subsets	Description
Short-term	SUBSET-026	Check against compatibility to FRMCS.
	SUBSET-037	Prepare the connection for the FRMCS on-board gateway to the ETCS on-board through the Euroradio protocol.
	SUBSET-119	Prepare the interface of the ETCS on-board to the train for future on-board CCS architecture.
	SUBSET-121	Prepare the interface between EVC and the train display systems (TDS) in order to enhance replacement of the elements within ETCS on-board (mainly EVC) and simplification of system integration.
	SUBSET-130	Modify the interface between the ATO on-board and the ETCS on-board.
	SUBSET-139	Modify the interface of the ATO on-board to the train.
	SUBSET-140	Modify the interface between ATO on-board and the juridical reporting.
	SUBSET-143	Prepare the communication layer (with relation to SUBSET-130 and potentially SUBSET-139).
	SUBSET-147	Specification for the communication layer (with relation to SUBSET-119, SUBSET-121, SUBSET-139 and SUBSET-140). Can be updated in later stages, overseeing SUBSET-143).
Mid-term	SUBSET-037	Realize the connection for the FRMCS on-board gateway to the ETCS on-board through the Euroradio protocol.
Long-term	SUBSET-121	Envisions the target system with the ETCS on-board as the focal point of the on-board CCS subsystem, comprising all SIL4 components and including the EVC with its odometry sensors (typically non-SIL) and the Eurobalise antenna. The ETCS indication on a DMI is an independent certifiable function provided by a train display system, not being part anymore of the ETCS on-board interoperability constituent.

Table 1 - Affected subsets through evolution stages of on-board CCS architecture.

2.2.2 RCA

RCA is an initiative, driven by EUG and EULYNX, which stands for Reference CCS Architecture and focus on the architecture of the CCS trackside, while OCORA (cf. Section 2.2.3) focus on the CCS on-board side.

RCA allocates localisation functionalities to the LOC-OB component, which has, as per Ref [3]:

- a non-defined interface with the Physical Train Unit,
- a defined input interface (SCI-REP) to receive the digital map data from the on-board repository,
- a defined output interface (SCI-VL) to provide the localisation information,
- a non-defined interface with the Movement Permission.

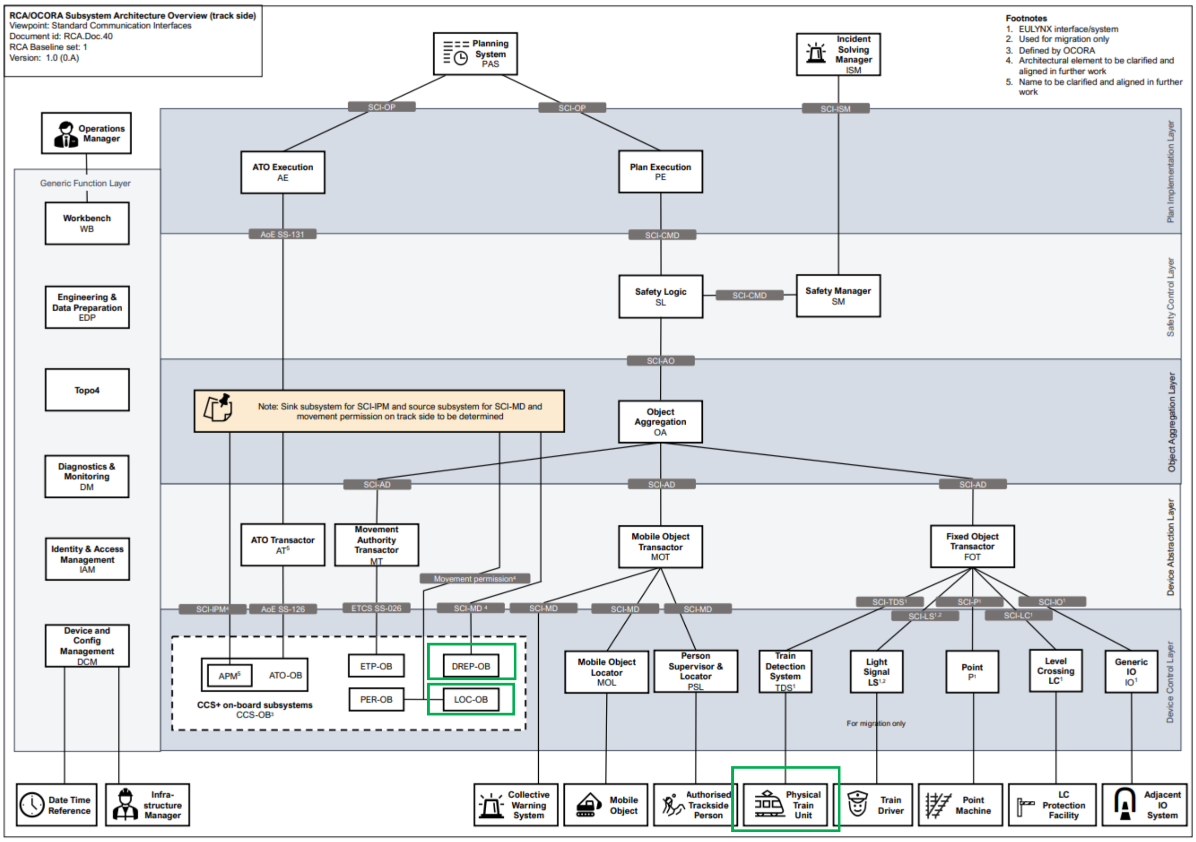


Figure 5 - Reference CCS Architecture (CCS) in Ref [8]. The components considered in the projects CLUG (1) and CLUG 2.0 are marked with green boxes (PTU, LOC-OB and DREP-OB)).

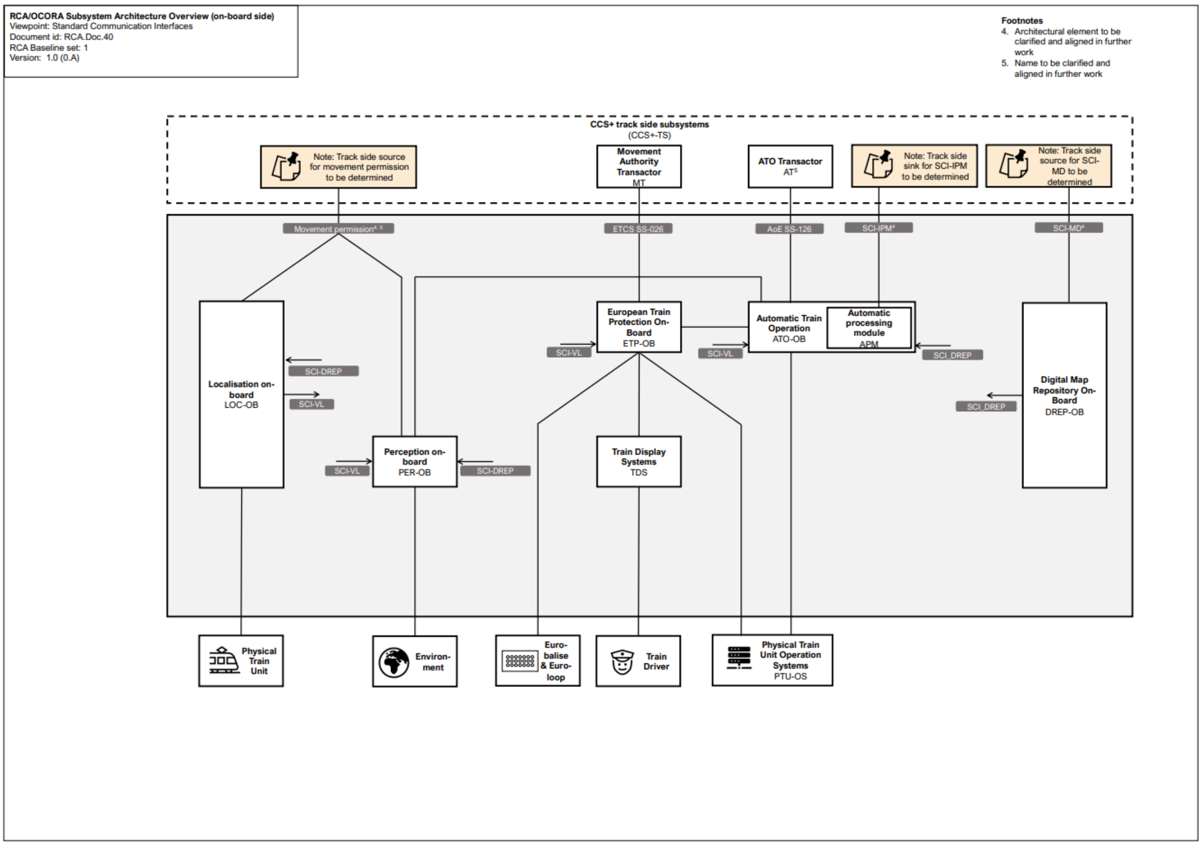


Figure 6 - View of the CCS on-board architecture to link RCA and OCORA in Ref [8]. The components considered in the projects CLUG (1) and CLUG 2.0 are marked with green boxes (PTU, LOC-OB and DREP-OB)).

2.2.3 OCORA

As per Section 2.2.2, OCORA is also a joint initiative by national railway companies which focuses on defining the reference architecture and interfaces for the next generation of CCS-OB (cf. Ref [14]).

LOC-OB subsystem defined in OCORA includes the locator sensors functionality (including GNSS receivers, inertial sensors, rotational sensors, radar-based sensors, optical sensors or other sources). As LOC-OB building block in OCORA is composed of VL and Vehicle Locator Sensors (VLS), no interface between VL and VLS functionalities is specified.

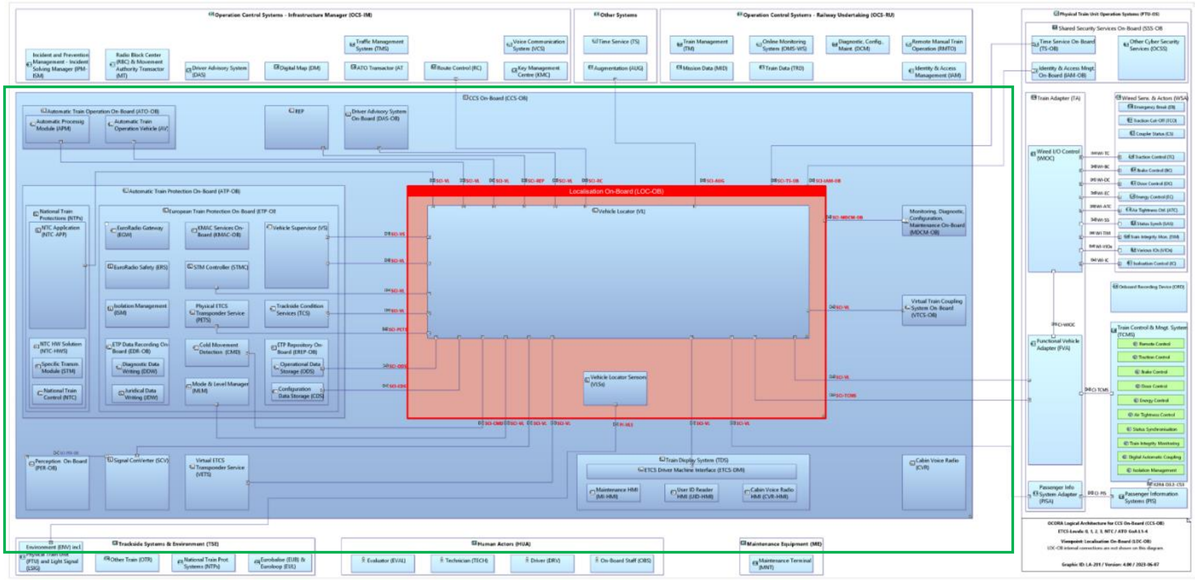


Figure 7 - OCORA CCS-OB logical architecture framed in green. OCORA localisation on-board (LOC-OB) framed in red (Ref [15]). For a better readable figure, please see end of referenced document.

2.2.4 CLUG (1)

The CLUG European consortium comprises major railway companies, railway signalling industries navigation specialists, a research institute and a certification expert.

CLUG (1) project main goal was performing the specification and preliminary feasibility study of an on-board localisation system providing safe location, speed and other dynamics of the train. The system had to be constituted by a failsafe on-board multi-sensor localisation unit consisting of a navigation core (GNSS safely augmented by EGNOS, IMU, tachometer, etc.) brought in reference using track map and a minimal number of reference points. The specified system had to be operational and interoperable across the entire European rail network and compatible with the current ERTMS TSI and its future evolutions.

CLUG (1) defines TLOBU architecture (cf. Ref [26]) based on the RCA and OCORA concepts and constituted by:

- Sensors
- Navigation engine and integration engine
- On-board Digital Map

Balise reader was considered outside TLOBU in CLUG (1) (cf. Ref [26]) but envisaged in the functional architecture below in the denied GNSS area where IMU and tacho won't be able to offer safe localisation within the specified confidence intervals.

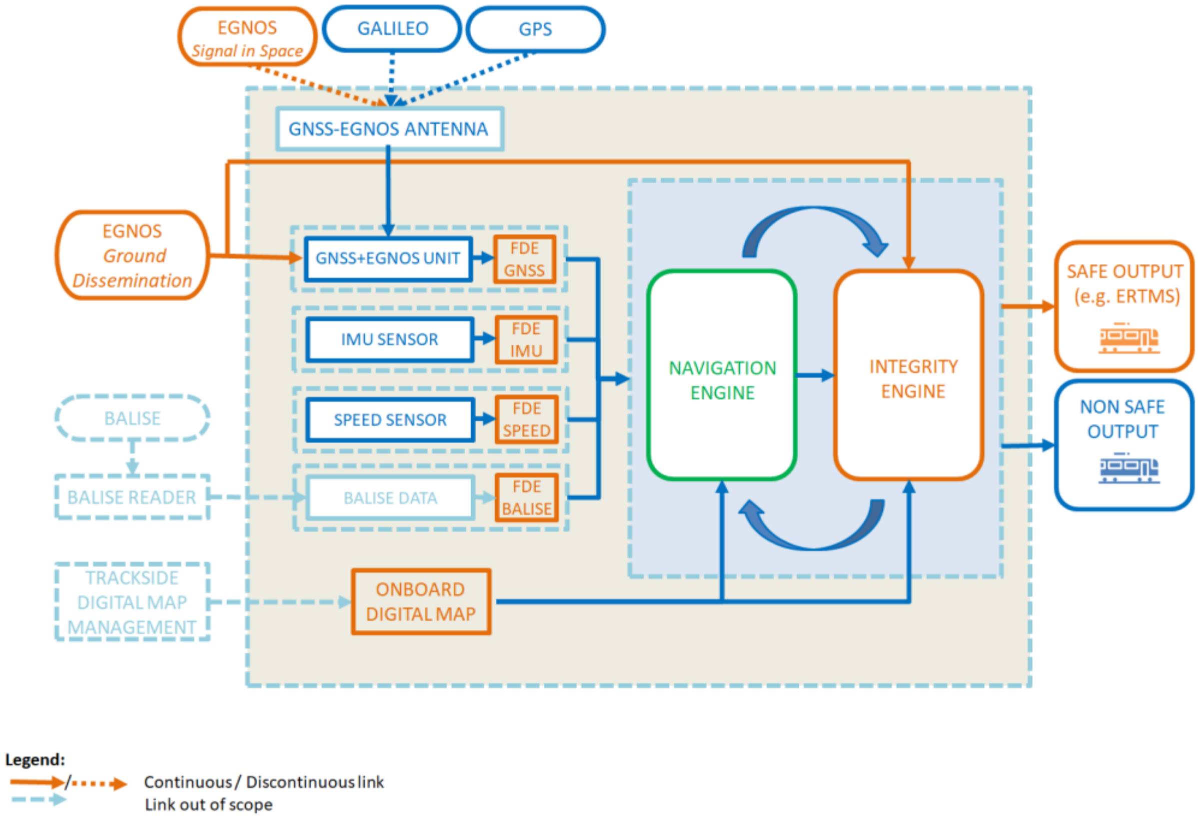


Figure 8 - CLUG (1) Train Localisation Unit functional diagram (cf. Ref [26]).

2.2.5 Shift2Rail

ERA identified and analysed different mid- and long-term strategic challenges related to the ERTMS specifications roadmap (Ref [35] – ERA, Report ERTMS Longer Term Perspective, 18/12/2015). Main goal was ensuring stability of the ERTMS Specification and its evolution while fulfilling the interoperability, capacity and costs expectations. Related to this purpose, ERA pointed to satellite positioning as a key element for the future signalling system aimed at reducing deployment and maintenance of balises and improve performance by usage of more accurate odometry. Shift2Rail initiative aims at fulfilling ERA objectives analysing two complementary approaches leading to two high-level architecture streams (cf. Ref [19]):

- Introduction of the Virtual Balise concept (Stream 1)
- Improving the odometry (Stream 2)

<u>Stream 1</u>

Shift2Rail Stream 1 (cf. Ref [19]) introduces an additional transmission system named Virtual Balise Transmission System (VBTS) as an analogy to the ERTMS Balise Transmission system defined in Subset-036 (Ref [29]) to compute the ASTP.

The VBTS is a safe spot information-based system, as for the EUB Transmission System (cf. Ref [29]). The VBTS provides the ERTMS/ETCS kernel with Virtual Balises (VB) information, which should be used by the kernel to compute the train position and train confidence interval.

The VBTS estimates the current train position using GNSS technology, sending the corresponding VB information to the kernel whenever the estimated position passes over a VB on the track (using information in Digital Map and Dynamic Route Information). This way VB preserves the same approach as physical balises, providing the same information as Balise Transmission Module (BTM) to ETCS kernel and remaining in ETCS kernel the implementation of ERTMS functions related to balises (e.g., Last Relevant Balise Group (LRBG), Linking, Expectation window, Train Position confidence interval, etc.)

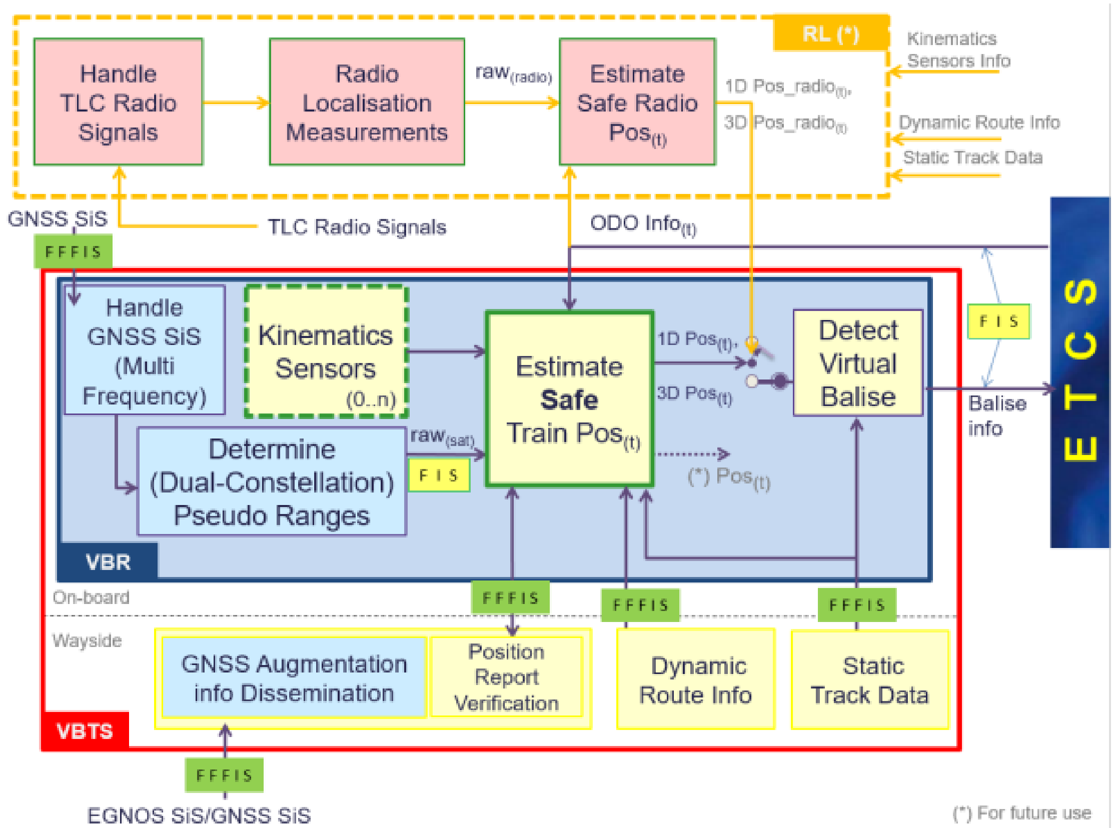


Figure 9 - VBTS Functional Architecture Layout (Ref [19]).

<u>Stream 2</u>

X2RAIL-2 defines the Enhanced Odometry system (E_ODO) in Ref [21] (X2R2 D3.9 System Architecture Specification and System Functional Hazard Analysis of the Fail-Safe Train Positioning subsystem V05), dividing it into Trackside (E_ODO-TS) and On-Board (E_ODO-OB).

E_ODO-TS main task is providing all the required supporting data to E_ODO-OB.

E_ODO-OB main task is estimating the position, speed and acceleration values of the train´s front end by using sensor data plus the data from Data Client Manager plus some other additional information provided by the ETCS-OB.

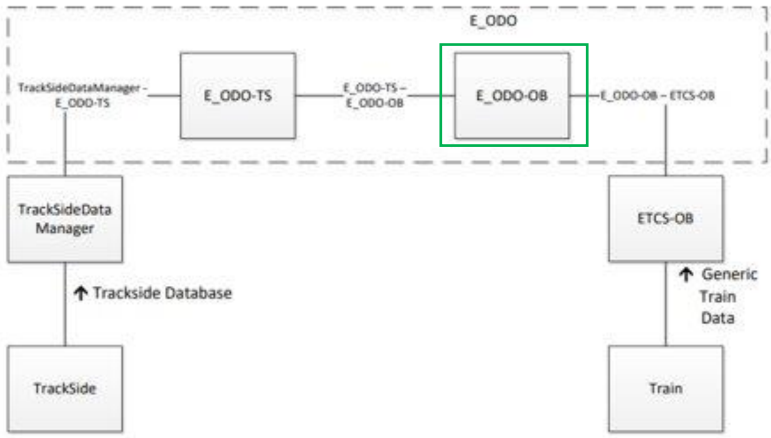


Figure 7-1 Architecture for Stand-Alone Fail Safe Train Positioning

Figure 10 - X2R2 Architecture for Stand-Alone Fail Safe Train Positioning. The component considered in the projects CLUG (1) and CLUG 2.0 (E_ODO-OB) is marked with a green box (cf. Ref [21]).

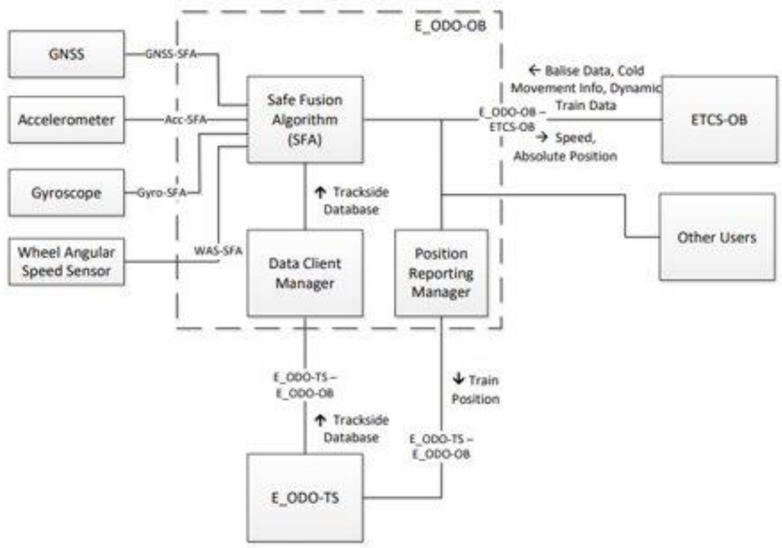


Figure 7-2 Architecture for E_ODO-OB

Figure 11 - X2R2 Architecture for E_ODO-OB (cf. Ref [21]).

X2RAIL-5 architecture introduces upgrade(s) with regards to the existing architecture in order to enhance the integration of the failsafe train positioning system within ETCS and also keeping in mind the goal of reducing the number of balises. The main upgrade consists in including the localisation sensors into the E_ODO-OB system. The second potential upgrade is the migration of the Balise Reader from the ETCS-OB to the E_ODO-OB (still under discussion in the frame of X2RAIL-5).

Functional blocks of E_ODO-OB:

- The Safe Fusion Algorithm (SFA)
- The Balise Telegram Reporter
- Data Client Manager
- Sensors
- Balise Reader (still not decided within X2R5)

On ETCS-OB side, the E_ODO-OB Integrator has two-fold functionality. On one hand to integrate read balise telegrams from E_ODO-OB as inputs to the current positioning functionality on ETCS as if they were physical balises. On the other hand, the odometry functionality typically carried out by ETCS-OB is now received by E_ODO-OB and this information must be integrated into the positioning and speed functions of the ETCS-OB. Similarly, to what is described in E_ODO-OB, the balise reader can either be located at the E_ODO-OB side or ETCS-OB side so far. For this reason, if the balise reader is to stay at the ETCS-OB, then the balise reader requires odometry speed value and in turn it returns read balise telegrams to the E_ODO-OB (see bidirectional arrow from balise reader to E_ODO-OB Integrator). On the contrary, if the balise reader is moved to the E_ODO-OB all these functionalities could be removed from ETCS-OB.

2.2.6 LWG

EUG/LWG defines a concept architecture considering and integrating the on-board localisation architecture defined in the previous initiatives and innovation projects (see above RCA, OCORA, CLUG (1), Shift2Rail).

As per OCORA, LOC-OB component defined in LWG includes in the same building block the VLS (train-based sensor data), including GNSS receivers, inertial sensors, rotational sensors, radar-based sensors, optical sensors or other sources, and the VL (localisation functionalities) with no specified interface between them. LOC-OB input and output interfaces in LWG are defined as per Figure 12.

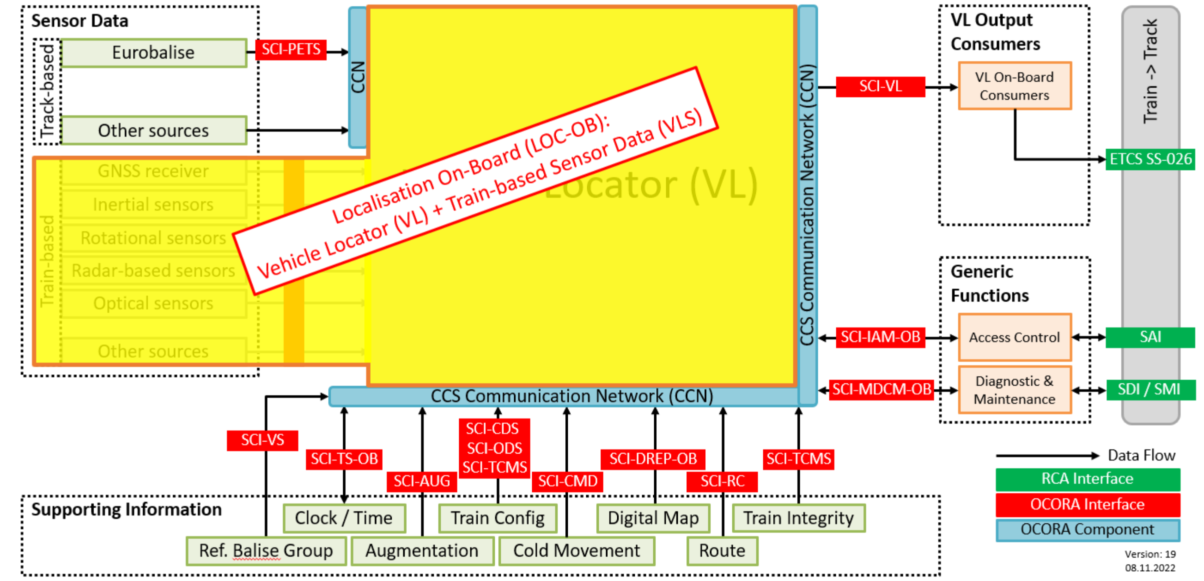


Figure 12 - EUG/LWG Concept Architecture with corresponding RCA/OCORA interfaces (cf. Ref [17]).

3 Operational Context

According to Ref [5] EN50126, system definition and operational context phase entitles the description of the essential characteristics and functions of the system, and the clarification of the interfaces to other systems including the input to be provided and the output to be expected.

LOC-OB operational context is mainly described by:

- The system definition and mission profile
- The system boundaries
- The operational requirements influencing the characteristics of the system
- The Reliability, Availability, Maintainability and Safety (RAMS) requirements

3.1 LOC-OB System Definition and Mission Profile

The goal of LOC-OB is providing the train localisation information to support the mission profile of the trains where it is installed at, while allowing the train safely running on the European railway networks.

The mission profile parameters for the overall current ETCS system are defined in Ref [76] Part 3. When applied to LOC-OB, those shall be read together with the set of High Level User Requirements. Specifically, parameters referring to the balise layout (e.g. maximum distance between balise groups, number of unlinked balise groups….) should be revisited as per UR[10] in Ref [1], requiring LOC-OB to achieve same performances as current ETCS baseline with a significantly reduced number of balises.

The LOC-OB mission profile defines the conditions under which the system is required to accomplish its mission.

The requirements defining the operational and environmental conditions in which LOC-OB should accomplish its mission are collected in Ref [1] as Operational and Environmental conditions. The requirements stating what is expected from the LOC-OB system are collected in D2.1 (cf. Ref [1] Section 5.3.2) categorized as Functional requirements.

The requirements to define the expected performance are collected in Ref [1] as Performance requirements.

The RAMS requirements towards LOC-OB are also collected in Ref [1].

3.2 LOC-OB Boundaries

3.2.1 ETCS BL3R2 function allocation to LOC-OB

In the present monolithic ETCS approach (cf. Ref [28]), the CCS-OB components shall assign a co-ordinate system in accordance with principles describes in Chapter 3 Figure 2b of SUBSET-026 (cf. Ref [28]).

To determine the co-ordinate system and the train position the following functions are required:

ETCS Function 1: Determination of the train front end. The train front end shall be considered as the side of the train where the cab is active. The determination of the active cab shall follow the Section 3.6.1.5 of SUBSET-026 (cf. Ref [28]).

ETCS Function 2: Determination of the reference location (e.g., Last Relevant Balise Group (LRBG)). This function provides the reference location identifier to be used. It is based on balise co-ordinate principle defined in Section 3.4.2 of SUBSET-026 (cf. Ref [28]). It is noted that the reference location is oriented.

ETCS Function 3: Determination of the relative distance from the reference location (e.g., LRBG). This function determines the position of the train front end with regard the side of the reference location, the train orientation and the direction running based on information provided by ETCS Function 1 and ETCS Function 2. The function determines the distance travelled and its confidence interval based on LOC-OB localisation data.

As D2.1 (cf. Ref [1]) state, LOC-OB shall provide the 1D train front end position and then shall embed ETCS Function 1 and ETCS Function 3. ETCS Function 2 is exported to the ETCS component.

This decision is taken since LOC-OB has several users and not only an interface to the ETCS. Function 1 does not need to be exported to other users factorising the safe algorithms into LOC-OB.

Embedding ETCS Function 2 in LOC-OB is not considered since the reference location used by LOC-OB is provided in the dataset (no need to export ETCS Function 2 to all users).

As defined in Section 2.1.2, this assumption may evolve with the definition of a standardised CCS-OB.

Allocation of the ETCS function to LOC-OB is currently under discussion.

LOC-OB system is to be a subsystem of the CCS-OB system, providing the localisation information required by the user functions defined in D2.1 (cf. Ref [1]) while ensuring modularity, interchangeability and upgradeability requirements as per D2.1 (cf. Ref [1]) by constituting a separate logical component from the ETCS OBU. To ensure the provision of safe and reliable train localisation information, the LOC-OB needs, apart from its own sensor data, additional supporting information. Altogether, the systems requiring an output from or providing an input to LOC-OB constitute its boundaries. Notice that input and output boundary systems or functions stand for logical information exchange, but do not necessarily have a direct interface with LOC-OB.

3.2.2 Wider system of interest

The main actors, focusing on the systems requiring an input from the LOC-OB system, are defined in Ref [1].

The detailed map of the Wider System of Interest (WSoI cf. Ref [1]) represents the boundaries for LOC-OB specifying the functions which require localisation information from localisation (Figure 13 and Figure 14). The required system capabilities (i.e., localisation information to be provided by the LOC-OB) are defined in Ref [1] System Capabilities.

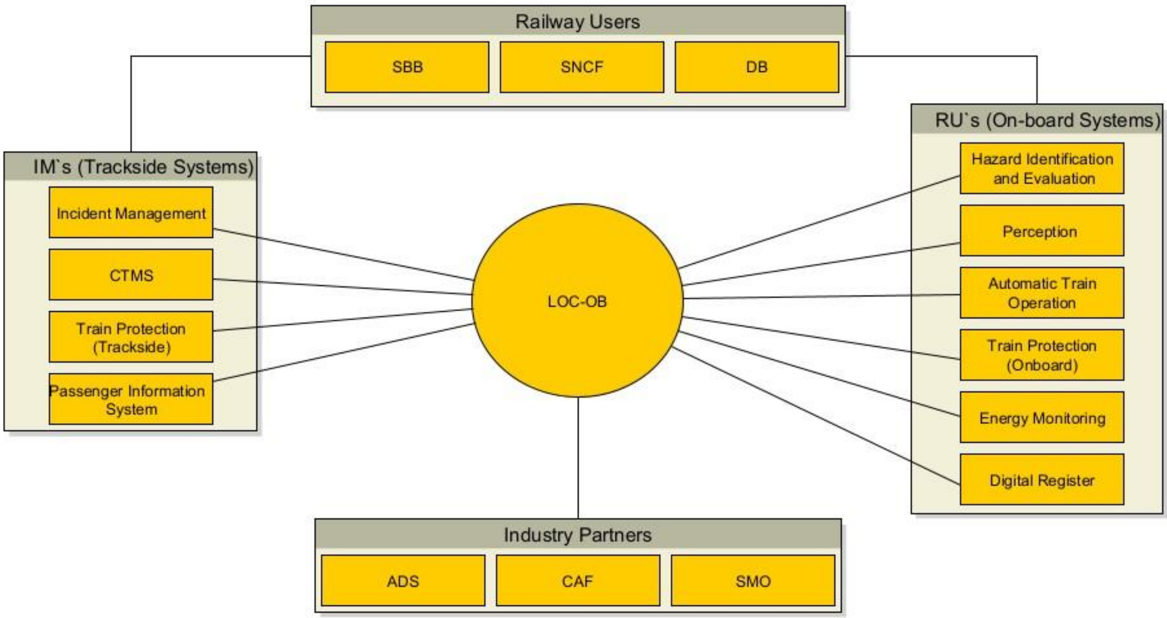


Figure 13 - Stakeholder Map of Localisation on-board System (Ref [1]).

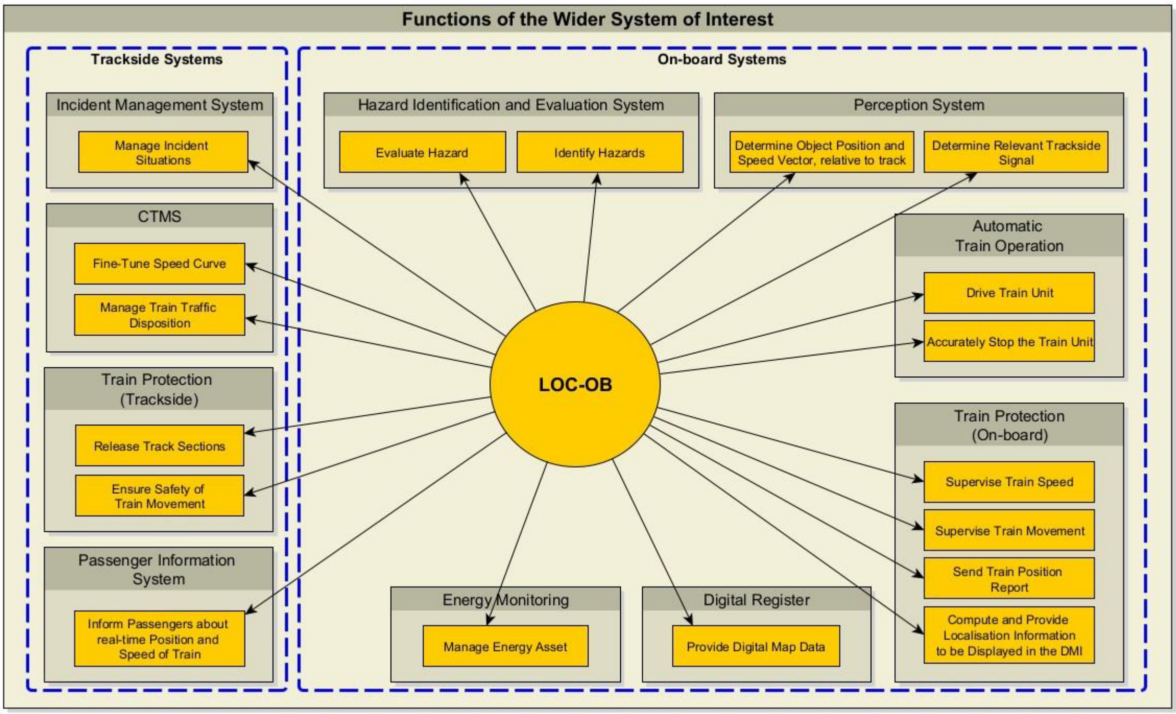


Figure 14 - LOC-OB User Functions of Wider System of Interest (Ref [1]).

LOC-OB Output	*System Capability*
1D Position of Train Front End (estimated, underestimation, overestimation)	*SysCap [1]*
1D Speed (estimated, underestimation, overestimation)	*SysCap [2]*
1D Acceleration (estimation, underestimation, overestimation)	*SysCap [3]*
3D Position (estimation, uncertainty)	*SysCap [7]*
3D Speed (estimation, uncertainty)	*SysCap [8]*
3D Acceleration (estimation, uncertainty)	*SysCap [9]*
Movement direction (estimation, confidence status)	*SysCap [4]*
Track ID (estimation, confidence status)	*SysCap [10]*
Vehicle Attitude (yaw/heading, pitch and roll estimation and uncertainty)	*SysCap [6]*

Table 2 - LOC-OB output boundaries - User functions.

As discussed in Ref [1] Section "LOC-OB constraints", there are different constraints and potential variants w.r.t the input boundaries and interface definition of LOC-OB. To achieve the required functionalities and performances, the LOC-OB system requires additional inputs apart from its own sensor data, those are the LOC-OB supporting information.

LOC-OB Input	Description
Digital Map	*Digital map data (provided by DR) provides geographical and topological description of the railway which can be used to:* - *ensure map matching of geographical coordinates to railway locations (i.e., tracks),* - *aid fusion algorithm by providing additional data,* - *ensure check of navigation solution to increase the safety level.*
Reserved Route	*Reserved route is the unique path on the topology assigned to a vehicle/train from start to end of movement. It can be used to validate or determine the position of a train w.r.t track selectivity.* *Also, it could be considered together with the digital map information in order to reduce track id errors when using GNSS+IMU.* *Appendix A in Ref [2] states the main open questions and concerns with regards to the use of route information as LOC-OB input. A dedicated study needs to be performed to analyse the potential safety risks set by LOC-OB using the route information from trackside to compute localisation information given that this route information has actually been generated based on the localisation information provided by the LOC-OB.*
Augmentation	*Augmentation data can be used to improve the system´s performance (e.g., integrity or accuracy). E.g., EGNOS, weather conditions…*
Train Integrity	*Train integrity status is required by LOC-OB in order to implement "cab anywhere supervision". When the LOC-OB is not installed in the front end of the train and/or the train can be separable (coupled, de-coupled) in regular operation cab anywhere is required.*
Dynamic Train Configuration	*Covers operational data such as train length valid for a single journey and cab status. It is required by LOC-OB to determine the movement direction and the train front end position.*
Static Train Configuration	*LOC-OB configuration data such as the positioning of the sensors and antenna are required to correct the position to provide the Estimated Front End.*
Cold Movement Detector	*Unexpected/unintentional movements can happen when ETCS is powered off. To check the validity of the stored position upon initialisation it is needed to know whether the train has moved*

	or not and, potentially, also the distance it has moved while powered off.
EUB Information	*The EUB Telegram information is needed to consider passed balises information in the fusion algorithm together with map data.*
Reference location (e.g., LRBG)	*The reference location (such as the LRBG or a reference point defined in the map) is used to determine the position using the reference location id and the estimated distance.*

Table 3 - LOC-OB input boundaries - Supporting Information

3.3 Operational Requirements

The requirements stating under which operational conditions LOC-OB is expected to work are defined in Ref [1] as Operational and Environmental conditions requirements.

4 LOC-OB External Interfaces

4.1 Introduction

The OCORA architecture approach foresees that building blocks shall have qualified, well-defined standardized interfaces. This approach shall:

- avoid uncontrollable dependencies and relations between components due to a high number of interconnections through low coupling;
- lead to narrow interfaces, that are easy to understand, extend, maintain, and reimplement;
- lead to fewer operations to be performed by the overall system by the usage of well-arranged and shared functionalities, which are easier to maintain and are less error prone.

The communication between LOC-OB and its WSoI (Wider System-of-Interest) is central to its functionality. It is assumed that LOC-OB cannot solely rely on its integrated sensors but also needs information of other building blocks (e.g., digital map data of the digital register on-board). It thus has several interfaces to other components of the WSoI for example trackside or on-board systems. Those will be discussed in this chapter.

Wherever possible and reasonable, the interfaces are named identically to the interfaces defined in the OCORA project (cf. Ref [49]).

If safe information needs to be exchanged between subsystems, the communication must provide at least a safe channel too. Otherwise, the safety of the message is compromised by the unsafe communication channel. All information transmitted over external interfaces must use safe and secure protocols. A holistic security concept is out of scope at this stage, as this document just outlines the technologies and the communication interfaces in terms of their functionalities.

Standard Communication Interface (SCI)

The Standard Communication Interface provides data from external systems of the WSoI to LOC-OB and vice-versa. Information can be pulled, pushed, or continuously received through an interface by a defined format over a standardised communication system, i.e., network bus.

These interfaces are specified within OCORA to ensure the modularity and interdependencies of the different subsystems. An interface is understood in this context as a message format defining the information that is exchanged and the procedure including the contractual behaviour of the involved systems independent of the underlying implementation, protocol, or physical transmitter. The data exchange between modular services over a centralized communication network enables efficient distribution and usage of information and the specialization of the services, such as localisation.

Within this project, all communication between LOC-OB and the WSoI shall be standardised in the form of SCIs.

The communication interfaces can either be an input, output or bidirectional link. SCIs can be only accessed via the subjacent CCS Communication Network (CCN).

4.2 Interfaces

The interfaces of the LOC-OB are separated into:

- Input interfaces from external systems: LOC-OB receives information through these interfaces.
- Output interfaces to external systems: LOC-OB provides output information through these interfaces.
- Bidirectional interfaces from and to external systems: LOC-OB receives and provides information through these interfaces.

An overview of the interfaces is given in Figure 15, showing the input, output and bidirectional interfaces.

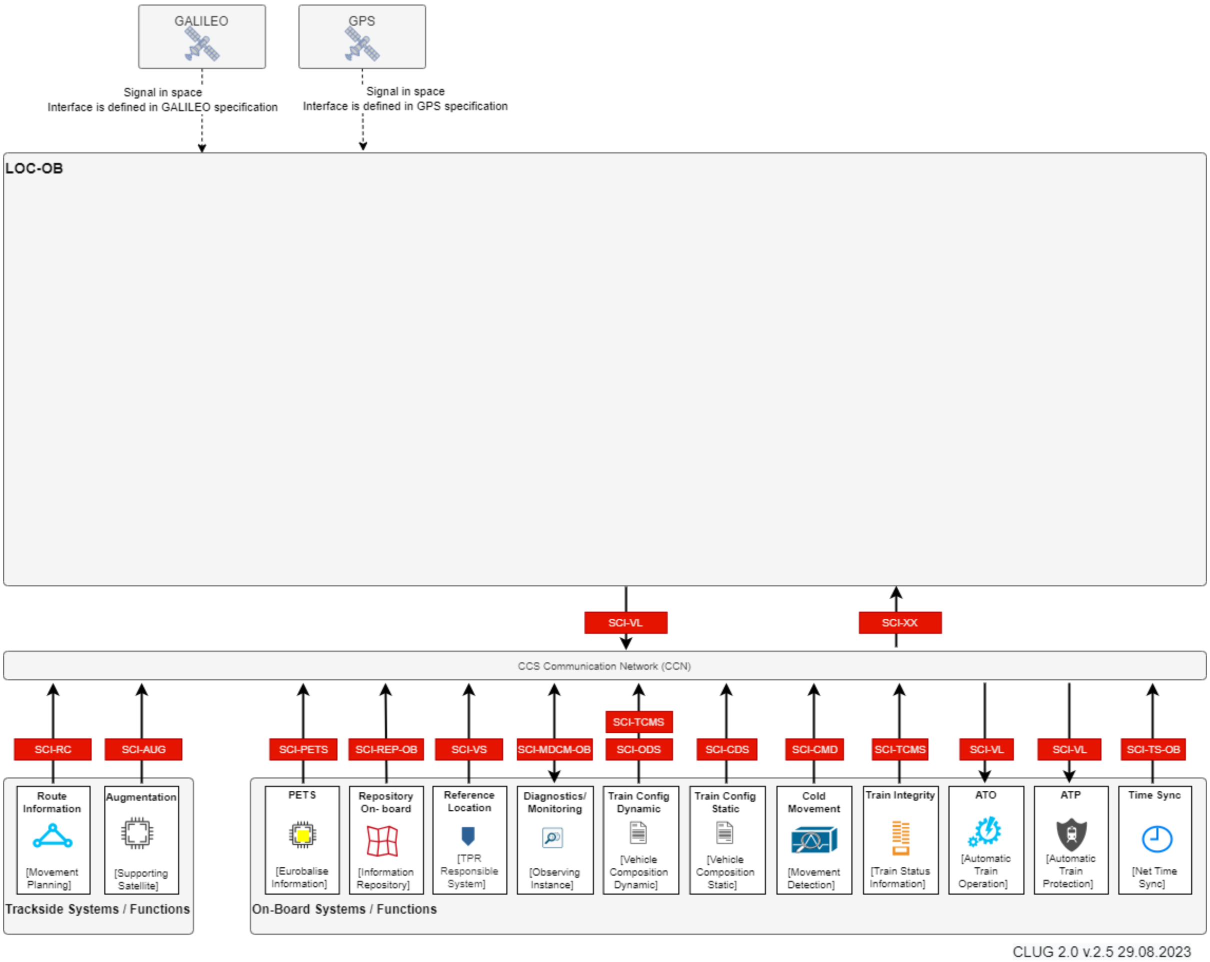


Figure 15 - LOC-OB Interfaces.

4.2.1 System External Input Interfaces

External Input Interfaces are SCI - Route Control (SCI-RC), SCI – Augmentation (SCI-AUG), GPS, GALILEO, SCI - Physical ETCS Transponder Service (SCI-PETS), SCI - Digital Map Repository On-Board (SCI-REP-OB), SCI - Vehicle Supervisor (SCI-VS), SCI - Train Control Management System (SCI-TCMS), SCI - Operational Data Storage (SCI-ODS), SCI - Configuration Data Storage (SCI-CDS), SCI - Cold Movement Detection (SCI-CMD) and SCI - Time Service On-Board (SCI-TS-OB).

The interfaces are not yet completely defined by OCORA. For further information consult the OCORA roadmap document [40]. OCORA stopped the work on their architecture. System pillar Train CS Domain is mandated to take over this task and is in close cooperation with the OCORA Team. Completeness of the interface definitions will be established during the system pillar modelling process.

Interface Name:	SCI-REP-OB
Description	The SCI-REP-OB provides Map Data from the Repository On-Board (REP-OB) to the LOC-OB unit by the CCN.
Peripheral System/Provider	Repository On-Board
Implementation State	Planned
Data Flow Direction	Unidirectional: Repository On-Board to LOC-OB component. Note: 1. The generation of Map Data is under the responsibility of trackside systems. The interface between the trackside and the Repository On-Board is defined in another interface (SCI-DM), that is outside the scope of LOC-OB. 2. We assume that Map Data is delivered as static data once. Mechanisms like forecast of delivery of fragments based on relevance (the vehicle requests actively the part of the Map Data relevant for its current position) are not taken into account at this stage.

Interface Name:	SCI-PETS
Description	SCI-PETS provides Balise information from the Physical ETCS Transponder Service (PETS) component of the European Train Protection - On-Board (ETP-OB) building block to LOC-OB through the CCN.
Peripheral System/Provider	Localisation Trackside
Implementation State	Partially in operation
Data Flow Direction	Unidirectional: Trackside EUB to PETS to LOC-OB component. Note: The interface between the trackside EUB and the PETS (on-board) is defined in another interface (SCI – Eurobalise (SCI-EUB)), that is outside the scope of LOC-OB.

Interface Name:	SCI-VS
Description	The SCI-VS interface provides the information of the Vehicle Supervisor (VS) which reference location should be used (e.g., LRBG).
Peripheral System/Provider	Vehicle Supervisor component of the ETP-OB.
Implementation State	Planned
Data Flow Direction	Unidirectional: ETP-OB, more specifically the vehicle supervisor, to LOC-OB component.

Interface Name:	SCI-RC
Description	The SCI-RC interface provides the information of an interlocked and safe train path uniquely assigned to a train/vehicle. Note: This interface is not yet defined and needs a safety study first. Depending on the outcome of this safety study, this interface might be obsolete. See also discussion on Appendix A in Ref [2] regarding the main open questions and concerns with regards to the use of route information as LOC-OB input.
Peripheral System/Provider	Route Control (RC) - part of the Operations Control Systems – Infrastructure Manager.
Implementation State	Under evaluation
Data Flow Direction	Unidirectional: RC trackside to LOC-OB component.

Interface Name:	SCI-AUG
Description	The SCI-AUG interface provides Augmentation Data (supporting information such as GNSS augmentation or the knowledge of temporary conditions) from trackside that can enhance sensor measurements for real-time information in severe conditions (i.e., tunnel, leaves on rails, etc.). Note: EGNOS information can also be received by a GNSS receiver from the signal in space. This acquisition is in the responsibility of the supplier selecting the set of sensors.
Peripheral System/Provider	Augmentation Service Trackside, transmitted over FRMCS to the vehicle.
Implementation State	Planned
Data Flow Direction	Unidirectional: Trackside to LOC-OB component. Note: 1. The trackside system is responsible for augmentation data transmitted over FRMCS to the vehicle, distributed to the on-board system by the CCN. 2. The connection from FRMCS to CCS will be the Ethernet Consistent Network (ECN)/ECN Gateway (Firewall). The different OSI layers will be handled there.

Interface Name:	GPS / GALILEO
Description	GPS / GALILEO signals are transmitted over space from the satellites towards the LOC-OB sensors. The interface is defined in GPS / GALILEO specifications.
Peripheral System/Provider	Space RF transmission over the GNSS vehicle antenna.
Implementation State	In Operation for various services such as air traffic.
Data Flow Direction	Unidirectional: From Space to LOC-OB roof antenna.

Interface Name:	SCI-TCMS
Description	The interface SCI-TCMS transmits the Train Integrity Information of the Train Control and Management System (TCMS) to LOC-OB. This information is needed if the train is separable (coupling equipment in place) in regular operation and for the composition of trains for which LOC-OB is not installed at the front end of the train (cab anywhere).
Peripheral System/Provider	TCMS (over TCMS Gateway of the CCS)
Implementation State	Planned
Data Flow Direction	Unidirectional: TCMS to LOC-OB component.

Interface Name:	SCI-ODS
Description	The SCI-ODS interface provides dynamic train configuration such as train length, cab status, and a representation of the current dynamic train configuration.
Peripheral System/Provider	ETP-OB; more specifically the Operational Data Storage (ODS).
Implementation State	Partially in operation
Data Flow Direction	Unidirectional: ETP-OB (more specifically ODS) to LOC-OB component.
Description	The SCI-CDS interface delivers static train configuration data. Depending on the LOC-OB architecture, it might be necessary to store the sensor and antenna positions in SCI-CDS. For sensors that are installed physically within LOC-OB there is no need to publish their installation position towards SCI-CDS.
Peripheral System/Provider	ETP-OB; more specifically the Configuration Data Storage (CDS).
Implementation State	In operation
Data Flow Direction	Unidirectional: ETP-OB (more specifically CDS) to LOC-OB component.

Interface Name:	SCI-CMD
Description	The SCI-CMD (Cold Movement Detection) interface delivers information on whether the train moved while LOC-OB was off or not in operation. Note: We assume that the data delivered is the minimal information whether the vehicle got moved or not while LOC-OB was inactive. Additional information like distance moved etc. could be available, but this cannot be verified since the implementation state is "planned".
Peripheral System/Provider	ETP-OB; more specifically the CMD.
Implementation State	Planned
Data Flow Direction	Unidirectional: ETP-OB (more specifically the CMD) to LOC-OB component.

Interface Name:	SCI-TS-OB
Description	The SCI-TS-OB interface provides time synchronisation. The reference time is defined by the overall CCS-OB system.
Peripheral System/Provider	Time Services On-Board (TS-OB)
Implementation State	Planned
Data Flow Direction	Unidirectional: TS-OB to LOC-OB component.

4.2.2 System Output Interfaces

The output interface of LOC-OB is named SCI - Vehicle Locator (SCI-VL). It shall be capable to broadcast the results of LOC-OB to the CCS user functions/systems including safe and non-safe information.

The interface is currently not finally defined within OCORA. However, the data will be provided over the CCN which is based on ethernet technologies and defined within OCORA. By default, users of localisation information have a link to the CCN or are provided by it.

Interface Name:	SCI-VL
Description	The SCI-VL interface is the central and unique output interface of LOC-OB. It delivers all desired computed information to the CCS-OB components such as autonomous train operation (ATO) and the train protection (ETP, national train protection) systems. Note: All LOC-OB output is distributed through the SCI-VL interface via the CCN.
Peripheral System/User	ATO-OB, ETP-OB, TDS, TCMS etc.
Implementation State	Planned
Data Flow Direction	Unidirectional: LOC-OB to on-board CCS-OB component.

4.2.3 System Bidirectional Interfaces

The bidirectional interface is SCI - Monitoring, Diagnostic, Configuration, Maintenance On-Board (SCI-MDCM-OB).

Interface Name:	SCI-MDCM-OB
Description	The Monitoring, Diagnostics, Configuration and Maintenance On-Board (MDCM-OB) building block provides on-board monitoring and diagnostics information through the SCI-MDCM-OB interface. LOC-OB sends its diagnostic information to the MDCM-OB for a system-wide inspection and supervision.
Peripheral System/Provider	MDCM-OB
Implementation State	Planned
Data Flow Direction	Bidirectional: MDCM-OB to LOC-OB component and vice versa.

5 LOC-OB HL Architecture

5.1 System Context

As the successor project of CLUG (1), CLUG 2.0 claims to be the continuation of the development of a feasible architecture proposal needed to create a LOC-OB unit (formerly introduced as Train Localisation OBU (TLOBU)).

The objectives of the CLUG 2.0 LOC-OB architecture in the frame of the project are:

- the general improvement of the architecture of the LOC-OB system;
- the enhancement of architectural design and quality;
- the finding and analysis of gaps as well as the alignment with respect to preceding architectures.

To improve the architectural quality, it is necessary to consider the definitions and design decisions made in preceding architectures further.

5.1.1 Scope of LOC-OB within the global OCORA architecture proposal

The scope of the LOC-OB as presented in Chapter 4 of this document, is to cast into the OCORA architecture to define the interfaces and architecture of the LOC-OB within this environment. Within the OCORA architecture, LOC-OB is a modular part of the CCS-OB that is independent and separated from the ETP-OB. The combination of LOC-OB and ETP-OB could be seen as an equivalent to today's ETCS-OB.

The CCS-OB provides several services that can be used by the LOC-OB. An example is the Repository On-Board (REP-OB) which handles the Map Data and its interface to trackside. On the other hand, LOC-OB provides a localisation service to the CCS-OB system. An exchange between the LOC-OB and the other CCS-OB components is necessary. A complete list of external interfaces is specified in Section 4.2. of this document.

Thus, the LOC-OB architecture can focus on the interfaces to these components. Figure 16 shows the context and scope of the LOC-OB within the OCORA architecture. LOC-OB is composed of the building blocks VL and VLS. CLUG 2.0 proposes an architectural solution for a LOC-OB unit that is compatible with the boundaries shown in Figure 16.

Note: Changes to the outside functions and interfaces of this rectangle will be difficult and may cause incompatibilities with the OCORA definitions.

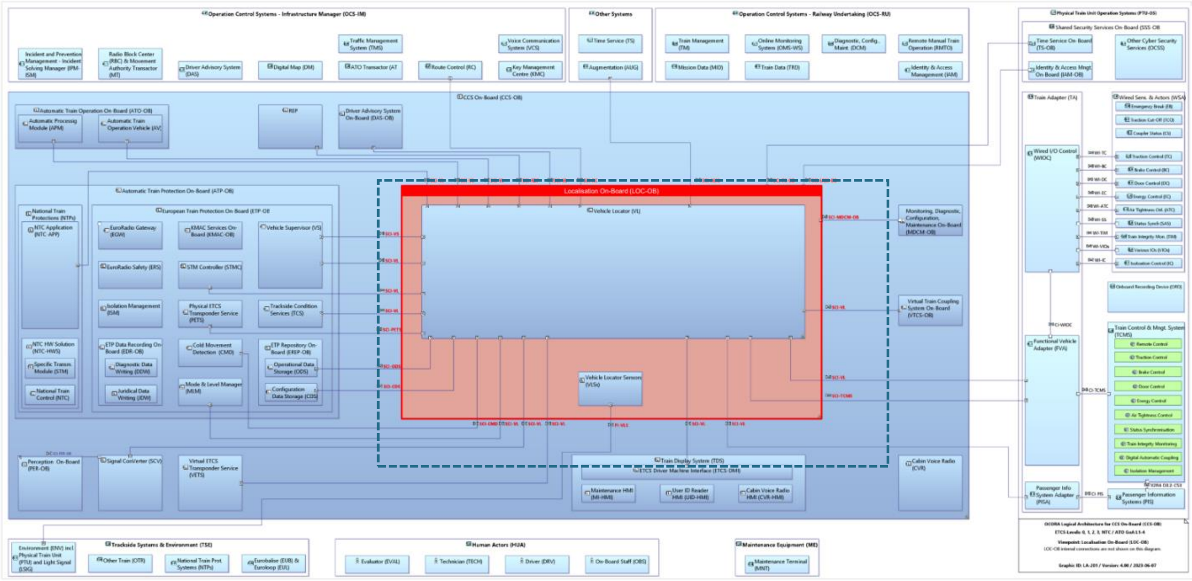


Figure 16 - Localisation On-Board (LOC-OB) – logical architecture (VL and VLS in the dotted square) as defined in OCORA (cf. Ref [49]). For a better readable figure, please see end of referenced document.

5.2 Functionalities of LOC-OB

LOC-OB in the context of CLUG 2.0 with a preliminary defined sensor set mainly aims to aggregate GNSS and EGNOS data with other sensors such as inertial sensors, odometers and additional information like Map Data or - if applicable - route information (cf. discussion in Ref [2]). The result shall be an improvement of localisation through multi-sensor fusion, to deliver more robust, accurate and safe localisation information.

To guide the development of the LOC-OB unit, the following functionalities are structured and defined as follows:

- On-board Measurement: This functionality handles the acquisition and processing of localisation sensor data.
- Integrity: This functionality guarantees the integrity of all LOC-OB functions and outputs. It is responsible for Fault Detection and Exclusion (FDE) of the measured data and the computation of the safe confidence intervals or confidence statuses associated to the estimated navigation data with respect to the requested safety integrity levels.
- Navigation: Multi-sensor fusion algorithms are processing the measured data together with supporting information such as Map Data or augmentation data (other than EGNOS) to compute localisation information. The result of this calculation is delivered to user functions/systems as safe and non-safe information. While non-safe information is used for uncritical user systems like the PIS, safe information is reliably assigned with a specific SIL and can be further used by safety-relevant systems.
- Map Data Processing functionality: Within the LOC-OB, the acquired Map Data needs to be processed according to the use-case of the navigation functionality.

- Interface functionalities: They are responsible for receiving and providing information from or to other systems of the CCS-OB.

These components exchange data with each other. Some components consume and provide information from and to external systems. A complete overview of system functions and data acquisition via the interfaces from the WSoI is available in this section.

To foster the modular approach of the LOC-OB unit, all the described functionalities must be developed for platform-independency. Between these platforms there may nevertheless be different constraints that must be respected. The design of LOC-OB subsystems shall consist of segregated functional units which are independent of hardware interfaces and communicate according to standardised interfaces.

5.2.1 On-board Measurement

The on-board measurement functionality is responsible for the sensor operation, data acquisition and processing of information on the train movement as input to the sensor fusion algorithm.

It is the supplier's responsibility to choose the sensors for the set. In the case of CLUG 2.0, the on-board Measurement consists of an IMU, GNSS antenna and receiver, along with other sensors like speedometers and radars.

5.2.2 Navigation

The navigation functionality is responsible for the computation of localisation estimated information by processing the standardised data and data from external information sources. A map-assisted multi-sensor fusion algorithm will provide continuously the estimate of the train's position (absolute and relative), speed, acceleration, track selectivity etc. (non-exhaustive list). The resulting information is delivered in a safe and non-safe manner to user functions/systems.

5.2.3 Integrity

The Integrity function is in charge of protecting the safety-critical applications / users from feared events which induce an integrity risk.

The Integrity function is composed of:

- Data Failure Detection and Exclusion (FDE) functions that are applied to sensor outputs and Navigation functions.
- Functions that calculate confidence intervals (position, speed, acceleration), confidence status (direction, track selectivity) and data integrity.

5.2.4 Map Data Processing

LOC-OB acquires the map from the Repository On-Board (REP-OB) unit. The REP-OB unit handles the map data for all on-board users, such as PIS, etc. The REP-OB system is retrieving the map data from trackside. The digital map data can be validated through additional information within the map data (versioning, time and date etc). Updates are either triggered by the DR trackside or in case of a failed on-board validation by the Repository on-board.

LOC-OB acquires the Map Data from the REP-OB and might need to transform the Map Data according to the needs of the localisation functionality. This depends on the localisation methods and sensors used and is thus a functionality that is implemented within LOC-OB.

Map matching methodologies are used within the Navigation and Integrity functions.

5.2.5 Interface Functions

LOC-OB is embedded as a central element in a WSoI.

Next to measured data, LOC OB depends on additional information from external functions/systems (i.e., digital map data, route information and CMD) to compute continuous position information.

This supporting information is gathered over input interfaces or exchanged with bidirectional interfaces.

According to OCORA all data is physically distributed via the CCN.

The following section introduces the functions of the core components of the LOC-OB architecture. They are assigned functional responsibilities, and it is defined, which functions provide what kind of information over which interface.

5.2.5.1 Main External System Constituents

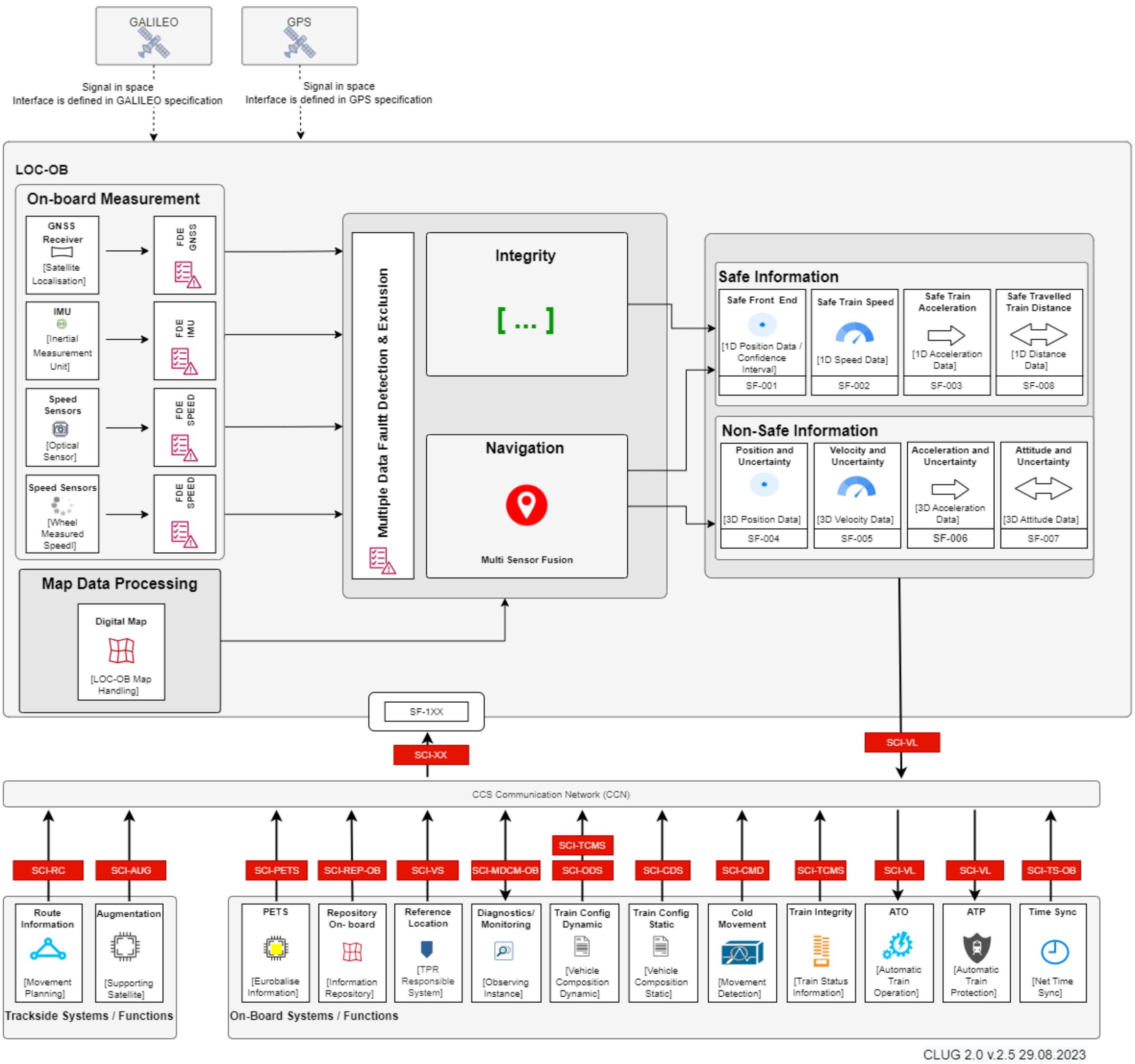


Figure 17 - Main External System Constituents.

Note: In Figure 17, the complete structure of LOC-OB is presented, including all interfaces and external systems. The clustered functionalities, such as on-board Measurement, Integrity, Navigation, Map Data Processing, Safe and Non-Safe Information, and all system functions SF-xxx, are provided as a guide and visual aid to enhance comprehension. It's important to note that these functionalities are not compulsory for the design or implementation of LOC-OB as a system.

5.2.5.2 System Interface Functions of LOC-OB

The following definitions are provided by the ERTMS LWG User Group. More detailed information can be found in the document LOC-OB System Definition and Operational Context Ref [17] Chapter 5.2.

5.2.5.3 Input Functions

The input functions needed for the LOC-OB system are defined below. Safe input functions will use messages over a safe and secure protocol. Non-safe input functions will use messages over a secure protocol.

The interfaces corresponding to the input functions are defined in Chapter 4 of this document.

Function Name:	Acquire Map Data SF-101
Expected Data	LOC-OB acquires Map Data, e.g., topology and topography information, described through objects defined within an object catalogue, further explained in the Chapter 6. Note: The validity of provided information in the Map Data is determined by an indicator. LOC-OB is responsible for requesting an update of the Map Data if it has expired. This request is a normal part of communication and does not affect the main data flow direction of the interface, which is from the external system towards LOC-OB.
Interface	SCI-REP-OB
Data Availability	Start of Mission
Implementation State	Planned
Data Flow	Pull by LOC-OB (proposal)

Function Name:	Acquire Route SF-102
Expected Data	Route information is a defined sequence of track characteristics that determine the locked or planned path along the railway network represented by a subset of Map Data Ref [17]. Note: Similar to Map Data, the information is assigned with validity and the request is not part of the data flow direction.
Interface	SCI-RC
Data Availability	Start of Mission
Implementation State	Planned
Data Flow	Pull by LOC-OB

Function Name:	Acquire Augmentation SF-103
Expected Data	The expected augmentation data shall contain information provided by the satellite-based augmentation system (SBAS), e.g., EGNOS, distributed by trackside to establish the independence of the satellite visibility.
Interface	SCI-AUG
Data Availability	Start of System
Implementation State	Planned
Data Flow	Pull by LOC-OB

Function Name:	Acquire Train Integrity SF-104
Expected Data	The received data shall include information about train integrity for two use cases: 1) LOC-OB is not installed at the front of the train (cab anywhere); 2) if the train is always connected in regular operation.
Interface	SCI-TCMS
Data Availability	Start of System
Implementation State	Planned
Data Flow	Pull by LOC-OB (proposal)

Function Name:	Acquire Static Train Configuration SF-105
Expected Data	Expected are the configuration, position, and orientation of the sensors and measurement devices mounted on the train.
Interface	SCI-CDS
Data Availability	Start of System
Implementation State	Planned
Data Flow	Pull by LOC-OB

Function Name:	Acquire Dynamic Train Configuration SF-106
Expected Data	The following information is expected: train length, status of cabs, rigid definition of the primary moving direction, definition of trains front end.
Interface	SCI-ODS, SCI-TCMS
Data Availability	Start of System
Implementation State	Planned
Data Flow	Pull by LOC-OB (proposal)

Function Name:	Acquire CMD Status SF-109
Expected Data	Expected information is if the train has moved while LOC-OB was not in operation. The LOC-OB will need this information to know if the last location it saved, can still be considered valid or not. Note: LOC-OB requires at least the information if the train is still in the same position as before the shutdown. If more information is available, such as the covered distance, this can be provided to LOC-OB as well. Note: CMD is mandatory if LOC-OB is not "always on".
Interface	SCI-CMD
Data Availability	Start of System.
Implementation State	Planned
Data Flow	Pull by LOC-OB.

Function Name:	Aquire EUB Telegram SF-107
Expected Data	We expect EUB telegram information (country code; Balise Group ID; position in group; number of Balises in the group). The information is needed to consider passed balises in the multi-sensor fusion, e.g., by linking received balise information with Map Data in the Digital Map.
Interface	SCI-PETS
Data Availability	Start of System and then event-based delivered.
Implementation State	Partially in operation.
Data Flow	Push by PETS-OB.

Function Name:	Acquire Reference Location SF-108
Expected Data	The expected information shall contain a reference location on the track network, which LOC-OB uses to provide relative positioning information, e.g., distance. The reference location can be for example a geographical track-bounded point (track edge point) but also a BG. Note: this function may very well be a subfunction of SF-101 as all the reference locations need to be localized on the map.
Interface	SCI-VS
Data Availability	Start of Mission and then event-based delivered.
Implementation State	Partially in operation
Data Flow	Push by VS

Function Name:	Acquire Control Time SF-201
Expected Data	Expected is a reference time by a trusted and safe source.
Interface	SCI-TS-OB
Data Availability	Start of Mission and then continuously delivered.
Implementation State	Planned
Data Flow	Push by TS-OB

5.2.5.4 Bidirectional Communication Function

Safe data transmitted and received by bidirectional communication functions is sent by a safe and secure protocol. Non-safe data is sent by a secure protocol.

Function Name:	Acquire and Provide Control Diagnostics and Maintenance SF-203
Expected Data	LOC-OB shall provide data on its own system status and performance and consume diagnostics of the overall CCS-OB. Furthermore, LOC-OB is expected to be notified of system-wide update activity. This function provides means for system health measurement and fault recovery. The information provided by this function can be used by other functional blocks in CCS-OB to determine the state of the LOC-OB. With this insight, it is possible to establish proactive monitoring for system functionality.
Interface	SCI-MDCM-OB
Data Availability	Start of System and then continuously delivered.
Implementation State	Planned
Data Flow	Pull and push by LOC-OB

5.2.5.5 Output Functions

Safe output information is sent by a safe and secure protocol. Non-safe output information is sent by a secure protocol.

Function Name:	Provide Safe Train Front End 1D Position Dataset SF-001
Expected Data	1D position dataset with safe confidence interval delivered with respect to the last reference location.
Interface	SCI-VL
Data Availability	Start of Mission and then in a specified frequency continuously delivered.
Implementation State	Planned
Data Flow	Push by LOC-OB
Traceability	SysCap [1], [4]

Function Name:	Provide Safe Train Speed SF-002
Expected Data	1D speed with safe confidence interval.
Interface	SCI-VL
Data Availability	Start of Mission and then in a specified frequency continuously delivered.
Implementation State	Planned
Data Flow	Push by LOC-OB
Traceability	SysCap [2]

Function Name:	Provide Safe Train Acceleration SF-003
Expected Data	1D acceleration with safe confidence interval.
Interface	SCI-VL
Data Availability	Start of Mission and then in a specified frequency continuously delivered.
Implementation State	Planned
Data Flow	Push by LOC-OB
Traceability	SysCap [3]

Function Name:	Provide Estimated Distance Travelled (since power on) SF008
Expected Data	1D distance delivered in in relation to system initialization.
Interface	SCI-VL
Data Availability	Start of Mission and then in a specified frequency continuously delivered.
Implementation State	Planned
Data Flow	Push by LOC-OB
Traceability	SysCap [1]

Function Name:	Provide 3D Position and Uncertainty SF-004
Expected Data	3D position and uncertainty.
Interface	SCI-VL
Data Availability	Start of Mission and then in a specified frequency continuously delivered.
Implementation State	Planned
Data Flow	Push by LOC-OB
Traceability	SysCap [7]

Function Name:	Provide 3D Velocity and Uncertainty SF-005
Expected Data	3D velocity and uncertainty.
Interface	SCI-VL
Data Availability	Start of Mission and then in a specified frequency continuously delivered.
Implementation State	Planned
Data Flow	Push by LOC-OB.
Traceability	SysCap [8]

Function Name:	Provide 3D Acceleration and Uncertainty SF-006
Expected Data	3D acceleration and uncertainty.
Interface	SCI-VL
Data Availability	Start of Mission and then in a specified frequency continuously delivered.
Implementation State	Planned
Data Flow	Push by LOC-OB
Traceability	SysCap [9]

Function Name:	Provide 3D Attitude (Rotational Angles) and Uncertainty SF-007
Expected Data	3D attitude and uncertainty.
Interface	SCI-VL
Data Availability	Start of Mission and then in a specified frequency continuously delivered.
Implementation State	Planned
Data Flow	Push by LOC-OB
Traceability	SysCap [6]

6 Digitial Map

6.1 Introduction

Within an on-board localisation solution, the usage of a Digital Map is advantageous to calculate track-bounded positioning information. In addition, track features can be used to validate position measurements. Map Data needs to be a source of safe and reliable information to be useful for these applications.

The Digital Map is understood as a source of information provided by trackside from the IM with topological, topographical and infrastructure data which is logically and spatially conjoined. LOC-OB is one of the users of partial information on the Digital Map, among many other systems and components.

The Digital Map is a digital representation of physical infrastructure. The on-board localisation system can use Map Data including track features for a range of possible use cases listed as examples below:

- As input for mapping a three-dimensional position to a track-bounded characteristic.
- To determine the track selectivity and provide the identifier of the current track edge on which the train front end is located.
- Compensation and validation of inertial sensor errors based on map data/track features (e.g., azimuth/direction angle, the radius of curvature, slopes, gradients, etc.).
- Determination of the running train direction or orientation of the active cab based on the base topology model/node edge model.
- Verification of the integrity of the system by checking the measured track features with respect to Map Data.

Within CLUG 2.0, the goal is to evaluate existing Digital Map approaches and define which layers and attributes are needed for localisation purposes. The minimal set of map elements needed for CLUG 2.0 is defined in Section 6.4.2 Topics like maintenance and distribution of the map data are out of scope.

6.2 Related Work

In earlier publications, CLUG (1) and the RCA initiative released various documents on the capabilities, modelling methodology and distribution of the Digital Map. Whilst the RCA cluster is a complete collection of topics even beyond plain on-board localisation topics, the CLUG (1) document of WP5 (cf. Ref [50]), reflects on the minimal map content required by the localisation algorithm and optional information in a retrospective of the project. The main conclusions of Ref [50] towards a Digital Map are:

- Be usable for the long-term.
- Structured as simple as possible.
- Universally extendable.

- Unique representation

Further topics like the segmentation of the Digital Map, potential data formats for the exchange of the Map Data and concepts for the update of the on-board map data are addressed in Ref [9].

The contribution of the CLUG 2.0 initiative is the continuation of the co-inclusion of the RCA Digital Map cluster achievements. The scope of CLUG 2.0 is set to:

- Digital map data model.
- Basic modelling methodology of the Digital Map.
- Evaluation of the RCA object catalogue for CLUG 2.0.
- Digital Map data validity and reliability.

6.3 Digital Map Model

6.3.1 Topology

The Digital Map data model defined for the localisation use cases is a node-edge model (cf. Section 6.4) derived from Ref [51] topology considerations.

This diagram below represents the relationships between the main topology objects: track nodes and track edges. These two objects build the fundamental topology which is only updated if the infrastructure layout is physically changed. Navigability, track edge, track node, track edge section and track edge point provide a set of domain objects to represent the network topology (cf. Ref [50]).

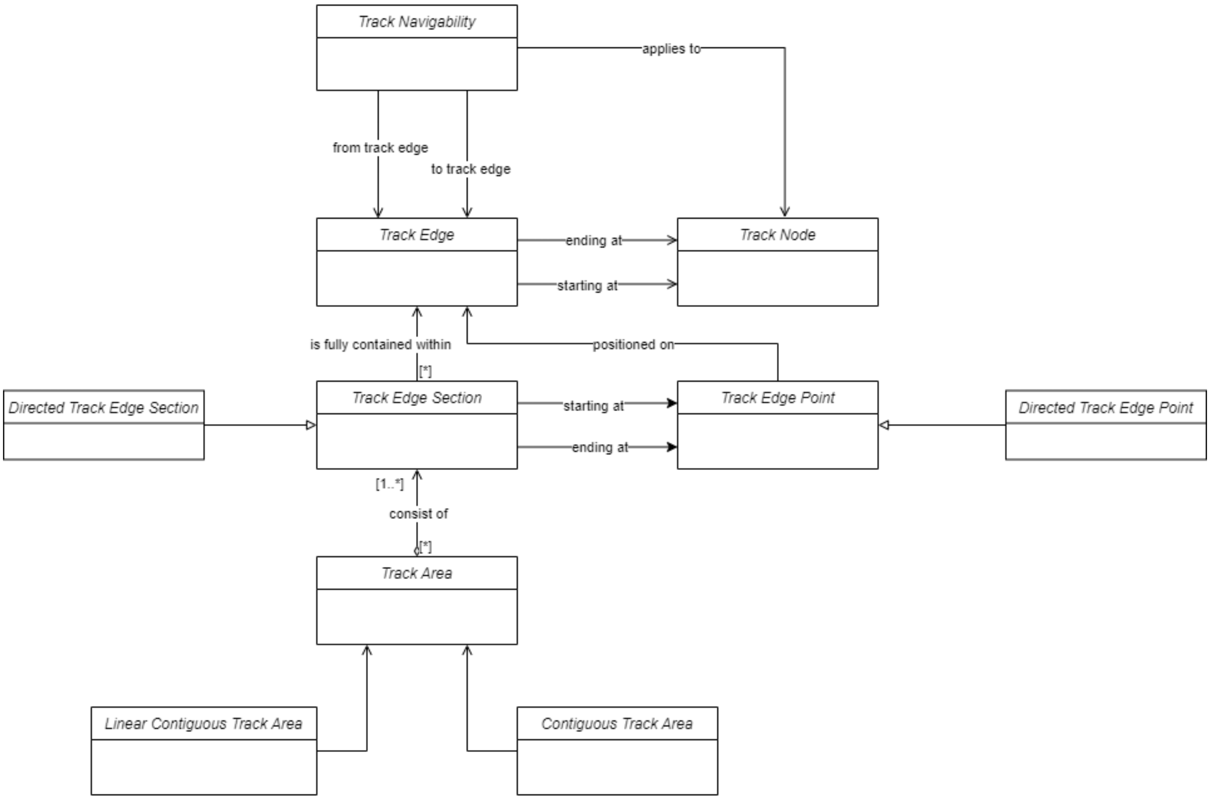


Figure 18 - Topology Relations with element borders and information encapsulation. This figure was originally published in Ref [12].

6.3.2 Topography

After having defined the base objects and their relation to each other, it is necessary to define their geographical representation. The goal is to have a model of the geographical reality which is manageable in size and scale. Therefore, it is important to have a clear understanding of the level of detail needed and the implied consequences any form of approximation will have.

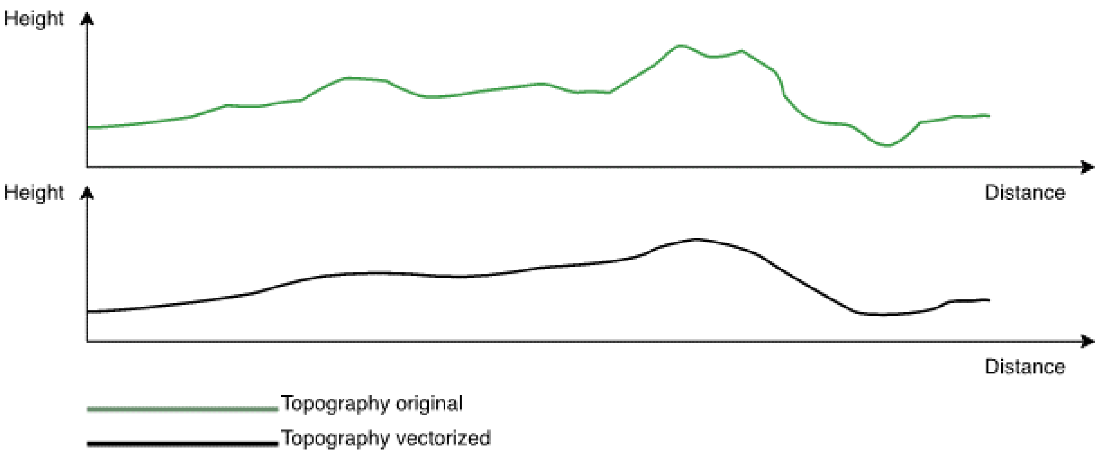


Figure 19 - Approximation Topography.

6.3.3 Digital Map Data Layers

Viewed from a different angle, the Digital Map is a collection of multiple layers of information. We differentiate between a trackside and an on-board representation of the Digital Map. Various use cases can be addressed with a purpose-driven selection of the layer information. It is important to differentiate between trackside validated safe map data and on-board derived operational data.

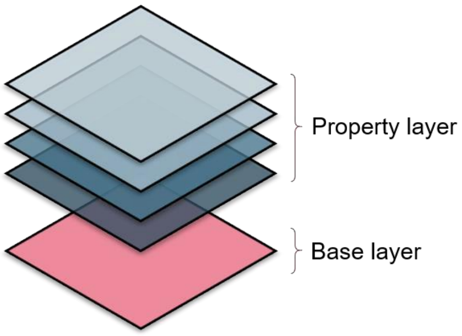


Figure 20 - Layer Representation.

6.3.4 Layer Extraction

A track is split into nodes and edges. Where nodes can be the entry points of a railway point, buffer stops or system borders.

For each of these layers, the track is split into segments on which the geometry can be described by a geometric primitive with a set of defined parameters for a vector-based approach. In the point-based map the geometry is described by track edge points. The distance from the start of the segment to the track point is essential for the calculation of the desired output. Since the segmentation is different for each layer, this must be done for each layer separately.

In the RCA Digital Map Concept, there is a differentiation of the following data types 9(cf. Ref [9]):

- Engineering data
- Geographical map data
- Operational data
- Safety-related map data
- Non-safety-related map data
- Reliable data

Within the on-board localisation, there is a clear focus on engineering, reliable and operational data.

6.3.5 Engineering Data

Engineering data is construction-based data of elements like buildings, tunnels, and environmental data. As an overlay, it can help to interpret information of the operational data layer.

6.3.6 Reliable Data

Reliable data of the Digital Map is based on the existing topology domain from RCA domain knowledge along with some additional information regarding track geometry and location Information.

6.3.7 Operational Data

Operational Data can contain temporary states or properties of infrastructure and its elements, which are overlaid on the Map Data.

6.4 Digital Map Modelling Methodology

Capturing an existing rail infrastructure in a digital model is a complex undertaking. Maintenance and distribution of this data in a user-specific context requires additional capabilities from the modelling methodology. Taking these prerequisites into account, the actual modelling methodology of a Digital Map foresees the usage of organisational data objects (Version, Release Information etc.) and content data objects (Geo-coordinates, Area Definition, etc.) in a base net element service topology model. The data of this model is structured in tier levels, specifically tier 0 to tier 3. Properties from the lowest tier level can be inherited by the upper tier levels. This approach offers detached editing of objects and groups (i.e., a track gets extended, a Buffer Stop is removed, and a new track is connected). This ensures that information from the lowest tier remains unchanged even if properties of higher tier levels are adopting new functionality or characteristics (cf. Ref [12]).

This methodology leads to a consistent model and offers the following key features:

- Catalogued objects can represent physical and logical elements (Track Node, Track Edge, Track Points).
- The information about the location in the form of geo-coordinates is directly assigned to these objects.
- The objects are formed into topological groups that have a defined start/end and can be interconnected.
- The positioning information of the topological group is relative to their superordinated objects.
- The navigability information describes how to traverse the node-edge model between the adjacent edges.

6.4.1 Specific Object Modelling

Even though the modelling methodology outlines the basic structure of objects, it does not specify how connecting objects are created. There are two methods for modelling track features: vector and point-based approaches. This chapter covers an introduction and analysis of both methods.

6.4.1.1 Point-Based Modelling

Object: Line

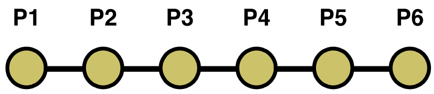


Figure 21 - A straight line described by discretely sampled points.

Data:

	X	Y	Z
P1	0	1	0
	0	2	0
P3	0	3	0
	0	4	0
P5	0	5	0
	0	6	0

Table 4 - Sample data for a point-based modelling approach of a straight line in a positive y-direction.

In a point-based approach, the map information of objects and the connection between these objects are modelled with a discrete raster. A specified global and often fixed resolution is used to model the objects and lines. This means interconnected line objects are modelled with a base point information every 10 m over a total distance of 200 m even if only the beginning and the end are needed for topological reference.

Advantages:

- To generate the base map layer, existing planning data can be rasterized.
- If a network layout is captured using physical sensors such as lasers or tripods, the data obtained is sampled discretely.
- All information can be traced back to one uniform element (a point).
- A point-based modelling approach requires less computational effort of LOC-OB.

Disadvantages:

- The grid size of the raster is determining the resolution. This resolution influences the accuracy of the solution and is not adjustable to specific areas of interest.
- The amount of data in the Digital Map can be harder to manage for maintenance and updates, depending on how many objects are included.
- Recorded and measured point-based representations of the Digital Map are prone to noise.
- Linear interpolation must be applied for the usage of map characteristics in between two discrete representations which may lead to errors.

6.4.1.2 Vector-Based Modelling

Object: Line

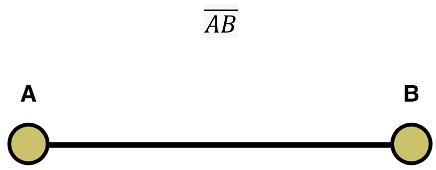


Figure 22 - A straight line represented by a starting and ending point.

Data:

	X	Y	Z
A	0	1	0
	0	6	0

Table 5 - Sample data for vector-based modelling approach of a straight line in a positive y-direction.

In a vector-based modelling approach, the track features are represented by a starting and ending point and a continuous function defining the behaviour of values in between. The vector-based model can be beneficial as railway tracks are not constructed with arbitrary geometries but using well-defined geometric primitives such as lines, circle segments and clothoids. Due to this, it is possible to formulate a model based on a track segmentation at the transition of these primitives. The example shows just a simple line – in reality, a track can have different segment borders in the horizontal, vertical, and longitudinal projections (cf. Figure 19). This information can be modelled with a vector-based approach as well.

Advantages:

- The storage type depends on the complexity of the mapping and not on the sampling rate. This can potentially result in a smaller map size.
- The process of deriving a point-based from a vector-based is simpler than vice-versa. Therefore, compatibility with point-based models is given.
- The vector-based model is capable of reflecting the infrastructure more accurately since the geographical characteristics of the tracks can be modelled with continuous transitions. For example, an area with a high density of elements can be handled more accurately without increasing the overall resolution of the complete map.
- A projection onto the track does not result in a cross-track error compared to a point-based map.

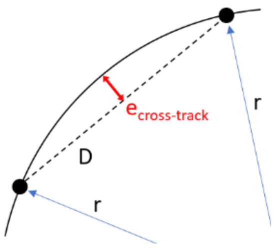


Figure 23 - Illustration of the induced cross-track error due to a linear interpolation between two points in a curve.

Disadvantages:

- The approximation of the geometry causes more effort as the base geometry of the corresponding base object needs to be determined. This depends on the availability of engineering data – planning, construction, and surveying.
- The vectorization of point-based measurements requires additional computation and modelling effort.

6.4.1.3 Comparison and Conclusion

A comparison between point-based and vector-based modelling towards the resulting map quality has been done and is documented in Ref [51]. The study states that vector-based modelling offers greater accuracy and a smaller map size at the cost of a more complex engineering process to create a vector model. The output of a vector-based model requires very little computation to be identical to that of a point-based vector model. The latter is the better choice from a pure safety (ETCS) point of view, as it allows a very easy translation from point coordinates to relative distances. However, it is not easy to define the required level of detail which correlates to the map accuracy.

For CLUG 2 Further investigations and comparisons are necessary and need to be assessed in the next work packages.

6.4.1.4 Mapping of the RCA Object Catalogue to CLUG 2.0

The Digital Map object model structures the various topology objects in 4 different tiers; namely tiers 0 to 3. Objects in each tier are referencing the objects either within their own or the underlying tiers. Information can be inherited from lower tier levels to higher tier levels but not vice versa.

Tier 0 consists of common objects and information like version, release, and geo-information.

Tier 1 consists of base network topology objects that define the basic node-edge model. Information like geo coordinates, operational points and line references are already inherited from the common objects within tier 0.

Tier 2 consists of spatial topology objects such as spot, linear, and area objects which have abstract references to tier 1. These references enable the localisation of the object on the base network topology. Information like track edge (tier 1), geo-coordinates (tier 0), or line reference (tier 0), are inherited from lower tier levels.

Tier 3 consists of domain objects from specific applications like ATO, Incident Prevention Management (IPM), advanced protection system, Plan Execution (PE), Planning System (PAS), LOC and perception (non-exhaustive list). In addition, tier 3 also includes objects related to other domains like track assets, track geometry, track properties, track conditions, and track infrastructure. Tier 3 objects have topological references to tier 2 objects. These references help locate the object on spatial topology. Information like line reference (tier0), track edge (tier1), and track edge section (tier2) are inherited from lower tier levels (cf. Ref [12]).

6.4.2 Detailed Object Mapping for CLUG 2.0

The following chapter is defining the minimal needed set of objects of the RCA object catalogue to fulfil the CLUG 2.0 localisation requirements. Objects that are yet not assigned to the localisation user but have the potential to support localisation are listed here but marked with a “no” comment in the column “Localisation Mapping”.

6.4.2.1 Tier 0: Common Objects

For a detailed description see Ref [12] Chapter 5.

RCA Nr.	Tier 0 Common Objects	Localisation Mapping	Source	RCA description / CLUG 2.0 justification
5.1	**Version**	**yes**	**RCA**	The version is a unique piece of information to clearly distinguish between different states (version states) of an object during its complete lifecycle.
			CLUG 2.0	The Information is mandatory for a reliable versioning of the data.
5.2	**Map Data**	**yes**	**RCA**	The map data is a collection of all the relevant objects corresponding to different tiers of map object model and for the area of control of a subsystem.
			CLUG 2.0	This is the base information for all relevant objects and therefore needed for further localisation functionality.
5.4	**Geo-Coordinates**	**yes**	**RCA**	Geo-coordinates are used to locate topology objects (like track nodes and track edge points) on or alongside track.
			CLUG 2.0	The information delivers the geo-coordinates of topology objects and needed for projection functionality.
5.5	**Line Reference**	**no**	**RCA**	The line reference is used to link the location of a spot object to a reference point on the line indicated by a line number, a line kilometre and optional a track number.
			CLUG 2.0	The information delivers relative distances and track ID. They may be used for faster processing of desired results.
5.6	**Operational Point**	**no**	**RCA**	The operational points are used to provide a macroscopic viewpoint of the railway network (station, shunting yard etc.).
			CLUG 2.0	This information may be used to trigger changes in the required accuracy of LOC-OB (i.e., if the train enters a station, the accuracy requirement decreases, etc.).

Table 6 - Tier 0 mapping. For a complete object description, please refer to Ref [12].

6.4.2.2 Tier 1: Base Network Topology Objects

For a detailed description see Ref [12] Chapter 6.

RCA Nr.	Tier 1 Base Network Topology Objects	Localisation Mapping	Source	RCA description / CLUG 2.0 justification
6.1	**Track Node**	**yes**	**RCA**	A Track Node is a position on the topological model of the track network where a Track Edge starts or ends.
			CLUG 2.0	One of the main objects to model the track infrastructure as a node-edge model and a central object for relative localisation.
6.2	**Track Edge**	**yes**	**RCA**	A Track Edge is a an object that connects exactly two Track Nodes.
			CLUG 2.0	One of the main objects to model the track infrastructure as a node-edge model and essential for the representation of the track layout.
6.3	**Track Navigability**	**yes**	**RCA**	Track Navigability describes how to navigate between the adjacent Track Edges at Track Nodes.
			CLUG 2.0	This information adds the necessary information to the track layout for the behaviour of edges at points.

Table 7 - Tier 1 mapping. For a complete object description, please refer to Ref [12].

6.4.2.3 Tier 2: Spatial topology objects

For a detailed description see Ref [12] Chapter 7.

RCA Nr.	Tier 2 Spatial Topology Objects	Localisation Mapping	Source	RCA description / CLUG 2.0 justification
7.1.2	**Track Edge Point**	**yes**	**RCA**	Base element to describe non-directional spot objects alongside or on a Track Edge with additional attributes.
			CLUG 2.0	Can be used as a reference object to receive distance information.
7.1.3	**Directed Track Edge Point**	**yes**	**RCA**	Base element to describe directional spot objects in relation to the referenced Track Edge.
			CLUG 2.0	Usable to determine directional information.
7.2.2	**Track Edge Section**	**yes**	**RCA**	Base-element to describe non-directional objects with a linear extension on or at the side of a Track Edge.
			CLUG 2.0	Reference object to be used for track selectivity and relative distance information.
7.2.3	**Directed Track Edge Section**	**yes**	**RCA**	Specialised element for explicit usage direction to the referenced Track Edge.
			CLUG 2.0	Base element to model directed linear objects between Track Edge Points.
7.3.2	**Track Area**	**yes**	**RCA**	A group of Track Edge Sections. The sections do not have to be connected or adjacent to each other.
			CLUG 2.0	Could be helpful after CMD to narrow down the new position and give at least a partial movement authority.
7.3.3	**Contiguous Track Area**	**yes**	**RCA**	Specialised class of Track Area to group connected Track Edge Sections that can form one or more paths.
			CLUG 2.0	Further detail to Track Area.
7.3.4	**Linear Contiguous Track Area**	**yes**	**RCA**	Specialised class of Track Area to group connected Track Edge Sections that can form only one path.
			CLUG 2.0	Further detail to Track Area.

Table 8 - Tier 2 Spatial Topology Objects. For a complete object description, please refer to Ref [12].

6.4.2.4 Tier 3: Domain Objects

For a detailed description see Ref [12] Chapter 8.

RCA Nr.	Tier 3 Domain Objects	Localisation Mapping	Source	RCA description / CLUG 2.0 justification
8.3	**Gradient**	**yes**	**RCA**	Gradient describes the absolute vertical alignment of the track with the use of lines and circles. Base element to define topography (z axis/absolute height).
			CLUG 2.0	Input for global localisation and may be combined with an inertial sensor.
8.4	**Curve**	**yes**	**RCA**	Curve describes the horizontal alignment of the track with the use of lines, circles and clothoids. Base element to define the direction of a track (x/y axes/ direction).
			CLUG 2.0	Input for global localisation and may be combined with an inertial sensor.
8.5	**Cant**	**yes**	**RCA**	Cant describes the rate of change in elevation between the two rails of a track. Base element to capture curve incline of a track.
			CLUG 2.0	Input for global localisation and may be combined with an inertial sensor.
8.9	**Balise**	**yes**	**RCA**	Technical device that stores static information in form of a telegram that can be read by passing by railway vehicles.
			CLUG 2.0	Element that can be used as safe position reference.
8.10	**Balise Group**	**yes**	**RCA**	Group of technical devices with the same reference position assigned in the track.
			CLUG 2.0	Logical entity to organise balises in groups. Can have a own coordinate system to determine direction of the vehicle.
8.13	**Landmark**	**yes**	**RCA**	Determines a prominent Landmark along the trackside for localisation purposes.
			CLUG 2.0	Needed as Reference for objects without an individual class.
8.15	**Platform Edge**	**yes**	**RCA**	Defines a section of a passenger platform.
			CLUG 2.0	Needed to determine confidence interval accuracy.
8.16	**Tunnel**	**yes**	**RCA**	A physical representation of the tunnel infrastructure. Consists out of sub elements tunnel portal and tunnel tube.
			CLUG 2.0	Can be used to switch/interpret GNSS information in the computation process of localisation information.
8.27.2	**Generic Spatial Objects**	**yes**	**RCA**	A representation of generic spatial objects alongside the track.
			CLUG 2.0	Can be used as reference for GNSS information and their uncertainty since the objects possess static 3d coordinates.

8.27.3	**Generic Linear Objects**	**yes**	**RCA**	Defines the generic linear objects alongside the track for localisation, perception, or incident prevention purposes.
			CLUG 2.0	Can be used to switch/interpret GNSS information in the computation process of localisation information.

Table 9 - Tier 3 Domain Objects. For a complete object description, please refer to Ref [12].

6.4.3 Digital Map Follow-Up Topics

A Digital Map with the selected objects from the RCA object catalogue should be capable of serving as base information for on-board localisation. Nevertheless, the selection is not mapped to requirements at this document creation stage. If any topics have not been addressed or objects are missing, they are included in the gap analysis section. The results of the analysis can then be applied to the EU-Rail System Pillar as the successor of the RCA cluster.

Detected gaps:

<u>Role of LOC-OB as localisation information and map data provider to other on-board systems:</u>

- It needs to be defined if and how map data is provided to other systems by LOC-OB.

<u>Layer generation and maintenance of the core information:</u>

- It might be worth considering developing and implementing a Digital Map multi-layer file format and editing platform. These files can be redacted as a single entity and selected layers can be exported right before the transmission of the information. This would keep the redacting effort low since just one entity needs to be changed/edited instead of multiple. The introduction of such a file format can help to further standardise the LOC-OB solution. In the long run, the time to introduce changes in the infrastructure to the digital map data shall be reduced.

<u>Structuring of Objects into Tiers:</u>

- The methodology on how objects get assigned to tier levels may need to be revised. At this moment, an object-oriented categorisation (polymorphism) is applied. Therefore, the smallest possible entities (assigned to tier 0) can be used to create more complex objects (assigned to tier 1-3) as base elements.

6.5 Data Validity and Reliability

The source of the Digital Map is hosted and redacted within a trackside system, the DR, by the IM. The Digital Map is transferred through an interface (specified in OCORA Ref [49]) to the on-board system and from there, to the various users such as LOC-OB. This copy of the Digital Map is hosted locally within an on-board system (Repository on-board). The on-board system is observing the integrity of the map data (version, validity date, file checksum etc.) and the trackside system DR initiates updates.

Before the data of the Digital Map can be used by any user system, the Digital Map must be activated. The activation process ensures that the map data is not corrupted and valid for the given period, and the correct map version is authorised for the system. Activation can only be performed when the REP-OB has synchronised the current map data based on the map reference data (cf. Ref [51]).

An activation process assures:

- The integrity of map data;
- Presence of validated (activated) map data on the train;
- Usage of correct map data version for operation.

Since synchronised map data is imperative for activation and an unsynchronised version can potentially compromise the safety of consuming systems, such asynchronous states must be safely detected and correspondingly avoided by a deactivation process.

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 of the responsibility of the REP-OB to deactivate the potentially obsolete or asynchronous versions of map data in the train. This is ensured by deactivating the version of map data upon encountering unexpected events.

A deactivation process ensures:

- Prevention from the usage of corrupt/outdated map data.
- Best possible capacity usage due to an accurate data foundation.
- Better resilience against deliberate manipulation of map data or data transmission.

7 Conclusions

This document provides an overview of the capabilities of LOC-OB and the operational context in which the localisation system will be operating. Furthermore, we list previous projects covering on-board location functionality to give an overview of different approaches to achieve the objective of safe on-board localisation and modular architectures.

After identifying the ETCS functionalities to be transferred from EVC to LOC-OB, a definition of the LOC-OB system boundaries is proposed by defining the input and output interfaces. These interfaces are aligned with the OCORA architecture [14], which is widely regarded as the basis for a common understanding of a modular on-board architecture. OCORA was chosen as it represents the most sophisticated architecture of a modular CCS design for on-board systems.

A high-level architecture is proposed in section 5. It intends to give the reader a better understanding of how a solution of a localisation solution could be designed, what set of sensors may be part of LOC-OB and which functions need to be integrated to fulfil the required functionalities. Nevertheless, this architecture is likely to differ from the final implementation of LOC-OB.

One of the main pieces of information as input for LOC-OB is the digital map containing the relevant network elements as well as an accurate topological model of the railway network. These elements are selected and explained in the final part of the document. Point- and vector-based modelling techniques for generating such data are compared in terms of data size and engineering effort. No clear favourite could be found as both have their advantages and disadvantages.

A rough design of a localisation system including its functionalities is proposed in this document. Some questions remain open, as most of the surrounding systems are not in a stable state either. This requires further clarification of the interfaces and functional distribution between these systems before a stable system definition and from there, a proper, standardizable architecture for LOC-OB can be developed. These discussions will be continued in the ERJU system pillar TrainCS, architecture and operational design domains and in the innovation pillar R2Dato work packages 21 (Absolute Safe Train Positioning (ASTP) - operational requirements), 22 (Absolute Safe Train Positioning - system architecture, design & RAMS) and 27 (Digital Register Specification, development and implementation). The findings of the architecture of CLUG 2.0 will be of value for the ongoing initiatives.

8 APPENDIX A: CLUG 2.0 WP2 References

REF	Document/Source	Title/WEBSITE	Version	Date
[1]	CLUG 2.0 D2.1	Operational Needs and System Capabilities of the LOC-OB System	1.0	30/11/2023
[2]	CLUG 2.0 D2.2	Start of Mission and Track Selectivity	1.0	30/11/2023
[3]	CLUG 2.0 D2.3	LOC-OB System Definition and Operational Context	1.0	30/11/2023
[4]	CLUG 2.0 D2.4	LOC-OB System Requirements	1.0	30/11/2023
[5]	DIN EN 50126-1:2017 (E)	Railway Applications. The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) Generic RAMS Process	-	06/12/2017
[6]	DIN EN 50126-2:2017 (E)	Railway Applications. The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS) Systems Approach to Safety	-	07/12/2017
[7]	RCA.Doc.14	RCA Terms and Abstract Concepts	0.4	26/04/2022
[8]	RCA.Doc.40	RCA Architecture Poster	1.0	30/09/2022
[9]	RCA.Doc.46	Digital Map – Concept	1.1	31/05/2021
[10]	RCA.Doc.59	Digital Map – System Definition	0.5	22/04/2022
[11]	RCA.Doc.68	RCA Concept: Track Occupancy	1.0	14/09/2022
[12]	RCA.Doc.69	MAP Object Catalogue	0.2	16/03/2022
[13]	ERA-ERTMS	European Rail Traffic Management System (ERTMS) https://www.era.europa.eu/domains/infrastructure/european-rail-traffic-management-system-ertms_en	-	30/11/2023
[14]	OCORA-TWS01-030	System Architecture	3.0	08/12/2022
[15]	OCORA-TWS01-100	Localisation-On-Board-(LOC-OB) - Introduction	4.0	13/06/2023
[16]	OCORA-TWS01-101	Localisation-On-Board-(LOC-OB) - High-level Requirements	3.0	08/12/2022
[17]	EUG-22E126	LOC-OB System Definition and Operation Context	1.1	08/12/2022
[18]	X2R2-WP3-D-ANS-059-01	D3.1 System Requirement Specification of the Fail-Safe Train Positioning Functional Block	06	18/12/2018
[19]	X2R2-WP3-D-ANS-035-09	D3.2 System Architecture Specification and System Functional Hazard Analysis of the Fail-Safe Train Positioning subsystem	09	21/02/2020
[20]	X2R2-TSK3.9-T-ANS-003-02	D3.8 Stand Alone System Requirements Specification for Fail-Safe Train Positioning	06	04/12/2019
[21]	X2R2-TSK310-D-CAI-001-06	D3.9 System Architecture Specification and System Functional Hazard Analysis of the Fail-Safe Train Positioning subsystem	05	22/04/2020
[22]	CLUG (1) D2.1	High-Level Mission Requirements Definition	2.14	28/01/2021
[23]	CLUG (1) D2.2	Operational Scenarios Definition	2.4	28/01/2021
[24]	CLUG (1) D2.5	Preliminary Architecture Definition (CO)	3.8	12/04/2021
[25]	CLUG (1) D3.3.1	TLOBU solution A performance analysis report in terms of Availability and Integrity	2.4	24/05/2022
[26]	CLUG (1) D5.7	Preliminary Definition of the System Performances and Interfaces	1.1	29/06/2022
[27]	ETCS BL3R2 – TSI CCS SUBSET-023	Glossary of Terms and Abbreviations	3.3.0	13/05/2016
[28]	ETCS BL3R2 – TSI CCS SUBSET-026	System Requirements Specification	3.6.0	13/05/2016
[29]	ETCS BL3R2 – TSI CCS SUBSET-036	FFFIS for Eurobalise	3.1.0	17/12/2015
[30]	ETCS BL3R2 – TSI CCS SUBSET-041	Performance Requirements for Interoperability	3.2.0	17/12/2015
[31]	ETCS BL3R2 – TSI CCS SUBSET-091	Safety Requirements for the Technical Interoperability of ETCS in Levels 1 and 2	3.6.0	12/05/2016
[32]	ETCS BL3R2 – TSI CCS SUBSET-119	Train Interface FFFIS	1.2.0	24/11/2020
[33]	ETCS BL3R2 – TSI CCS SUBSET-121	DMI-EVC Interface FFFIS	1.0.2	01/12/2020
[34]	ERA-CSMs	Common Safety Methods https://www.era.europa.eu/domains/safety-management/common-safety-methods_en	-	30/11/2023
[35]	ERA	ERTMS Longer Term Perspective	1.5	18/12/2015
[36]	CLC/TS 50701:2021	Railway applications - Cybersecurity	-	01/04/2023
[37]	97s0665	ERTMS/ETCS Environmental Requirements	5	30/09/1998
[38]	DIN EN 50121	Railway applications – Electromagnetic compatibility (Part 1-Part 5)	-	01/11/2017
[39]	CR1368	CR1368: Enhanced onboard localisation	-	02/07/2020
[40]	OCORA-TWS01-025	OCORA Modularisation Roadmap Proposal	1.00	04/07/2023
[41]	IEC 61373:2010	Railway applications – Rolling stock equipment – Shock and vibration tests	-	01/04/2011

[42]	DIN EN 45545	Railway applications – Fire protection on railway vehicles (Part 1 - Part 7)	-	01/08/2013
[43][1]	UNISIG	Concept for evolution of the on-board architecture	0.5	09/09/2021
[44]	Council of the EU and the European Council	Rail transport policy https://www.consilium.europa.eu/en/policies/rail-transport-policy/	-	30/11/2023
[45]	ETR Ausgabe 11/2022 Nr. 11	Auswirkungen des Vertrauensintervalls auf Kapazität und Pünktlichkeit des Bahnsystems (Impact of the confidence interval on capacity and punctuality in railway systems)	-	11/2022
[46]	OCORA-BWS01-020	Glossary	3.21	01/12/2022
[47]	ERA_ERTMS_040026	Introduction to ETCS Braking Curves	1.5	12/08/2020
[48]	UIC 544-1	Brakes – Braking power	6th ed	01/10/2014
[49]	OCORA-TWS01-035	CCS On-Board (CCS-OB) Architecture	3.0	01/12/2022
[50]	CLUG (1) D5.4	Definition of the required Maps for Localisation	1.3	23/06/2022
[51]	RCA.Doc.57	Digital Map - Evaluation Reference Model	0.3	30/11/2021
[52]	ETCS BL3R2 – TSI CCS SUBSET-113	ETCS Hazard Log	1.5.0	10/05/2022
[53]	ERTMS-GL-68	ERTMS users Group - Engineering Guideline; 68. Start of Mission in Level 2/3 (B3)	2-	03/12/2021
[54]	ERTMS-GL-80	ERTMS users Group - Engineering Guideline; 80. ERTMS/ETCS Hybrid Train Detection Engineering	3-	19/12/2022
[55]	CR1350	CR1350: Always connected, always reporting	-	21/11/2022
[56]	CR1367	CR1367: Cab Anywhere supervision	-	26/01/2023
[57]	EEIG 92S126	ERTMS/ETCS RAMS Requirements Specification Chapter	6	30/09/1998
[58]	ISO/IEC/IEEE 29148	Systems and software engineering — Life cycle processes — Requirements engineering	-	01/11/2018
[59]	CLUG (1) D2.3	High Level System Requirements	2.4	28/01/2021
[60][1]	FDS-2022-01	Estimation Impact Performance ce l’erreur de localisation	1.4	28/02/2023
[61][1]	201/162.1	Impact of confidence interval on capacity and punctuality regarding a railway system with ETCS	1	21/12/2022
[62]	CLUG (1) D2.6	Preliminary External Interface Definition	4.3	12/04/2021
[63]	RCA.Doc.77	Digital Map – Quality Framework	0.2	18/08/2022
[64]	CLUG (1) D2.4	Preliminary Hazard Analysis and Safety Requirements	1.5	12/04/2021
[65]	DIN EN 50155:2018	Railway applications – Rolling stock – Electronic equipment	-	05/2018
[66]	UIC 533:2011	Vehicles protection by earthing of metal parts	-	01/04/2011
[67]	UIC 758:2005	Use of mobile radio on the railways – antennas	-	01/05/2005
[68]	DIN EN 61703:2016	Mathematical expressions for reliability, availability, maintainability and maintenance support terms	-	01/08/2017
[69]	ISO 8855:2011	Road vehicles – Vehicle dynamics and road-holding ability – Vocabulary	-	01/12/2011
[70]	DIN EN 50129:2018	Railway applications – Communication, signalling and processing systems – Safety related electronic systems for signalling	-	06/2019
[71]	DIN EN 50657:2017	Railway applications – Software on-board Rolling Stock	-	11/2017
[72]	DIN EN IEC 62443-3-3:2019	Industrial communication networks – Network and system security, part 3-3: System security requirements and security levels	1.0	08/2013
[73]	DIN EN 50128	Railway applications – Communication, signalling and processing systems – Software for railway control and protection systems	-	03/2012
[74]	DIN EN 50159-2:2001	Railway applications – Communication, signalling and processing systems – safety related communication in transmission systems	-	04/2011
[75]	ETCS BL3R2 – TSI CCS SUBSET-035	Specific Transmission Module FFFIS	3.2.0	16/12/2015
[76]	ETCS BL3R2 – TSI CCS SUBSET-088	ETCS Application Levels 1&2 – Safety Analysis	3.7.0	18/12/2019
[77]	RCA.Doc.54	Solution Concept: MAP	0.3	22/04/2022
[78]	Institute of Navigation	Performance assessment of GNSS signals in terms of time to first fix for cold, warm and hot start https://www.researchgate.net/publication/292840783_Performance_assessment_of_GNSS_signals_in_terms_of_time_to_first_fix_for_cold_warm_and_hot_start	-	01/01/2010
[79]	IEEE Transactions on Instrumentation and Measurement	RTK-LoRa: High-Precision, Long-Range, and Energy-Efficient Localization for Mobile IoT Devices	-	04/12/2020

[1] Confidential. Not publicly available.

		https://www.researchgate.net/publication/346658103_RTK-LoRa_High-Precision_Long-Range_and_Energy-Efficient_Localization_for_Mobile_IoT_devices		

9 APPENDIX B: CLUG 2.0 WP2 Acronyms

ACRONYM	CONCEPTS
AD	Abstract Device
ADOR	ATO Data Only Radio
ADS	Airbus Defense and Space
AE	ATO Execution
AO	Abstract Object
AoE	ATO over ETCS
API	Application Programming Interface
APM	Automatic Processing Module
ASTP	Absolute Safe Train Positioning
AT	ATO Transactor
ATC	Air Tightness Control
ATO	Automatic Train Operation
ATO-OB	ATO - On-Board
ATP	Automatic Train Protection
ATP-OB	Automatic Train Protection - On-Board
AUG	Augmentation
AV	Automatic Train Operations Vehicle
BC	Break Control
BG	Balise Group
BIU	Brake Interface Unit
BTM	Balise Transmission Module
CAB	Driver Cabin
CAF	Construcciones y Auxiliar de Ferrocarriles
CCN	CCS Communication Network
CCS	Control Command and Signalling
CCS-OB	Control Command and Signalling - On-Board
CDS	Configuration Data Storage
CENELEC	European Committee for Electrotechnical Standardization
CLUG	Certifiable Localisation Unit using GNSS
CMD	Cold Movement Detection
CS	Coupler Status
CSS	Cab Signalling System
CTMS	Capacity and Traffic Management System
CVR-HMI	Cabin Voice Radio - Human Machine Interface
DAS	Driver Advisory System
DAS-OB	Driver Advisory System - On-Board
DB	Deutsche Bahn
DC	Door Control
DCM	Device and Config Management
DDW	Diagnostic Data Writer
DIN	Deutsche Institut für Normung e. V.
DM[1]	Digital Map
DM[2]	Diagnostics and Monitoring
DMI	Driver Machine Interface
DM-OB	Digital Map - On-Board

DR	Digital Register
DREP-OB	Digital Map Repository - On-Board
DRV	Driver
EB	Emergency Brake
EC	Energy Control
ECN	Ethernet Consist Network
EDOR	ETCS Data Only Radio
EDP	Engineering and Data Preparation
EDR-OB	ETP Data Recording - On-Board
EEIG	European Economic Interest Grouping
EGNOS	European Geostationary Navigation Overlay Service
EGW	Euroradio Gateway
E_ODO	Enhanced Odometry system
E_ODO-OB	Enhanced Odometry - On-Board
E_ODO-TS	Enhanced Odometry - Trackside
ENV	Environment
EoA	End of Authority; End of Movement Authority if target speed equals 0 km/h.
ER	EuroRadio
ERA	European Union Agency for Railways
EREP-OB	ETP Repository - On-Board
ERS	EuroRadio Safety
ERTMS	European Railway Traffic Management System
estFE	Estimated Front End
ETCS	European Train Control System
ETCS-DMI	ETCS - Driver Machine Interface
ETCS-OB	ETCS - On-Board
ETP	European Train Protection
ETP-OB	European Train Protection - On-Board
EUB	Eurobalise
EUG	ERTMS User Group
EUL	Euroloop
EVAL	Evaluator
EVC	European Vital Computer
FDE	Fault Detection and Exclusion
FFFIS	Form Fit Function Interface Specification
FFFIS ER	FFFIS Euro Radio
FFFIS OB	FFFIS FRMCS Onboard
FIS	Functional Interface Specification
FOT	Fixed Object Transactor
FRMCS	Future Railway Mobile Communication System
FS	Full Supervision (ETCS mode)
FTP	File Transfer Protocol
FVA	Functional Vehicle Adapter
GA	Grant Agreement
GAL	Galileo
GNSS	Global Navigation Satellite System
GPS	US Global Positioning System

GSM-R	Global System for Mobile Communications - Rail(ways)
HUA	Human Actors
H2020	Horizon 2020 programme
I/O	Input/Output
IAM	Identity and Access Management
IAM-OB	Identity and Access Management - On-Board
IC	Isolation Control
ICE	Intercity-Express
IM	Infrastructure Manager
IMU	Inertial Measurement Unit
IPM	Incident Prevention Management
IS	Isolation (ETCS mode)
ISM	Incident Solving Manager
JDW	Juridical Data Writing
JRU	Juridical Recording Unit
KMAC-OB	KMAC Services - On-Board
KMC	Key Management Centre
LC	Level Crossing
LEU	Lineside Electronic Unit
LoA	Limit of Authority; End of Movement Authority if target speed greater than 0 km/h.
LOC-OB	Localisation - On-Board
LRBG	Last Relevant Balise Group
LS	Light Signal
LS	Limited Supervision (ETCS mode)
LTM	Loop Transmission Module
LWG	(EUG) Localisation Working Group
MA	Movement Authority
MAPO	Max Accepted Position Overestimation
MAPU	Max Accepted Position Underestimation
MASO	Max Accepted Speed Overestimation
MASU	Max Accepted Speed Underestimation
maxSFE	Maximum Safe Front End
MCI	Mission Confidence Interval for Operations
MD	Message Data
MDCM	Monitoring, Diagnostics, Configuration, Maintenance
MDCM-OB	Monitoring, Diagnostics, Configuration, Maintenance - On-Board
ME	Maintenance Equipement
MHT	Minimum Headway Time
MI-HMI	Maintenance - HMI
minSFE	Minimum Safe Front End
MLM	Mode and Level Manager
MNT	Maintenance Terminal
MOL	Mobile Object Locator
MOT	Mobile Object Transactor
MT	Movement Authority Transactor
MTTR	Mean Time To Restore
NL	Non-Leading (ETCS mode)

NP	No Power (ETCS mode)
NTC	National Train Control
NTC-HWS	National Train Control - HW Solution
NTPs	National Train Protections
OA	Object Aggregation
OBS	On-Board Staff
OBU	On-Board Unit
OCORA	Open CCS On-Board Reference Architecture
OCS	Operations Control System
OCSS	Other Cyber Security Services
ODO	Odometry
ODR	Online Dispute Resolution
ODS	Operational Data Storage
OMS	Online Monitoring System
OP	Operational Plan
OpNeed	Operational Need
OS	On-Sight (ETCS mode)
OSI	Open Systems Interconnection
OTR	Other Train
P	Point
PAS	Planning System
PE	Plan Execution
PER-OB	Perception - On-Board
PETS	Physical ETCS transponder service
PHA	Preliminary Hazard Analysis
PIS	Passenger Information System
PISA	Passenger Info System Adapter
PKI	Public Key Infrastructure
PS	Passive Shunting (ETCS mode)
PSL	Person Supervisor and Locator
PT	Post Trip (ETCS mode)
PTU	Physical Train Unit
PTU-OS	Physical Train Unit - Operation Systems
RAMS	Reliability, Availability, Maintainability and Safety
RAMSS	Reliability, Availability, Maintainability, Safety and Security
RBC	Radio Block Centre
RC	Route Control
RCA	Reference CCS Architecture
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
REP-OB	Repository On-Board
Req	Requirement
RMTO	Remote Manual Train Operation
RoHS	Restriction of Hazardous Substances
RU	Railway Undertaking
RV	Reversing (ETCS mode)
SAI	Standard Authentification/Authorisation Interface
SAI-OB	Standard Authentification/Authorisation Interface - On-Board

SAS	Status Control
SB	Stand By (ETCS mode)
SBAS	Satellite Based Augmentation Systems
SBB	Schweizerische Bundesbahnen AG
SCI-*	Standard Communication Interface
SCV	Signal ConVerter
SDI	Standard Diagnosis Interface
SDT	Safe Data Transmission
SF	System Failure (ETCS mode)
SFA	Safe Fusion Algorithm
SF-*	System Function
SH	Shunting (ETCS mode)
SL	Safety Logic
SL	Sleeping (ETCS mode)
SM	Safety Manager
SMO	Siemens Mobility
SN	National System (ETCS mode)
SNCF	Société nationale des chemins de fer français
SoM	Start of Mission
SR	Staff Responsible (ETCS mode)
SSS-OB	Shared Security Services On-Board
STM	Specific Transmission Module
STMC	STM Controller
SysCap	System Capability
TA	Train Adapter
TCMS	Train Control Management System
TCO	Traction Cut-Off
TCS	Trackside Condition Services
TCP/IP	Transmission Control Protocol / Internet Protocol
TDS[1]	Train Display System
TDS[2]	Train Detection System
TECH	Technician
TFFR	Tolerable Functional Failure Rate
THR	Tolerable Hazard Rate
TI	Track Intrusion
TIM	Train Integrity Monitoring
TIMS	Train Integrity Monitoring System
TLC	TeLeCommunications
TLOBU	Train Localisation On-Board Unit
TIS	Train Information System / Track Isolating Switch
TM	Train Management
TMS	Traffic Management System
TR	Trip (ETCS mode)
TRD	Train Data
TS[1]	Time Service
TS[2]	Traction Control
TSE	Trackside Systems and Environment

TSI	Technical Specification for Interoperability
TS-OB	Time Service - On-Board
TSV	Tab-Separated Values
TTD	Trackside Train Detection
TU	Train Unit
TVPS	Track Vacancy Proving Section
UID-HMI	User ID Reader - HMI
UN	Unfitted (ETCS mode)
UNISIG	Union Industry of Signalling
VBR	Virtual Balise Reader
VBTS	Virtual Balise Transmission System
VCS	Voice Communication System
VETS	Virtual ETCS Transponder Service
VIO	Various I/Os
VL	Vehicle Locator
VLS	Vehicle Locator Sensors
VS	Vehicle Supervisor
VTCS-OB	Virtual Train Coupling System - On-Board
WB	Workbench
WIOC	Wired I/O Control
WP	Work Package
WSA	Wired Sensors and Actors
WSoI	Wider System-of-Interest
X2RAIL	Shift to rail

10 APPENDIX C: CLUG 2.0 WP2 Glossary

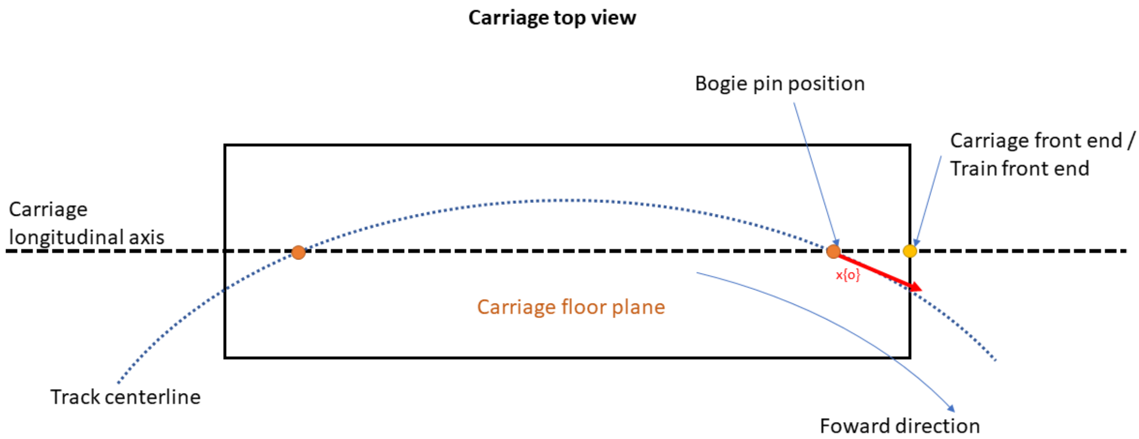
This appendix is aimed at ensuring terminology alignment and common understanding throughout CLUG 2.0 WP2 documentation. Terms definitions are already captured and hence referenced to:

- Ref [17] → EUG-22E126 “LOC-OB System Definition and Operational Context”
- Ref [7] → RCA.Doc.14 “RCA Terms and Abstract Concepts”
- Ref [12] → RCA.Doc.69 “MAP Object Catalogue”
- Ref [28] → ETCS BL3R2 – TSI CCS SUBSET-026 “System Requirements Specification”
- Ref [24] → CLUG (1) D2.5 “Preliminary Architecture Definition”
- Ref [25] → CLUG (1) D3.3.1 “TLOBU Solution. A Performance Analysis Report in Terms of Availability and Integrity”
- Ref [47] → ERA_ERTMS_040026 “Introduction to ETCS Braking Curves”

Terms not explicitly defined below but used within WP2 documentation can be found in the references above as well as in OCORA-BWS01-020 Glossary (Ref [46]) and SUBSET-023 (Ref [27]).

1D reference frame

It is the one-dimensional reference frame where the along track speed and acceleration are expressed. It is defined by the x-axis of the bogie frame $\{o\}$ (cf. definition Bogie reference frame).



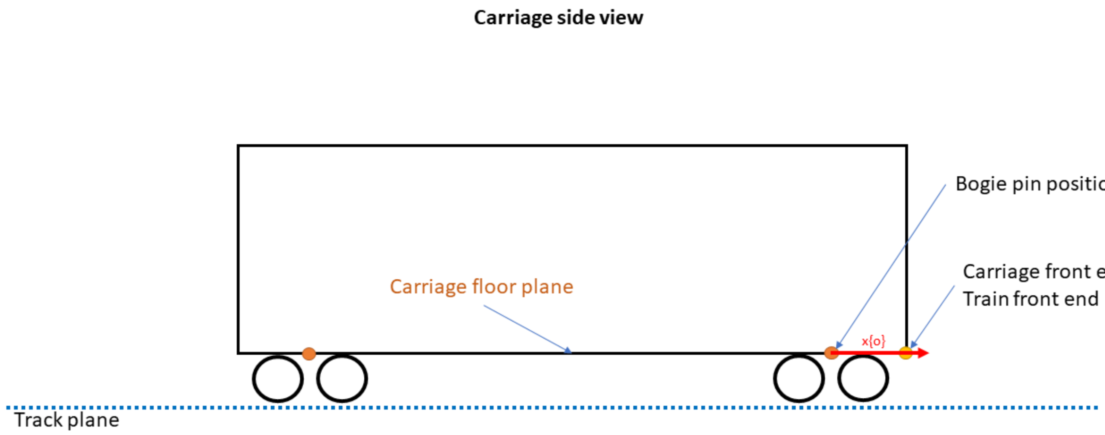


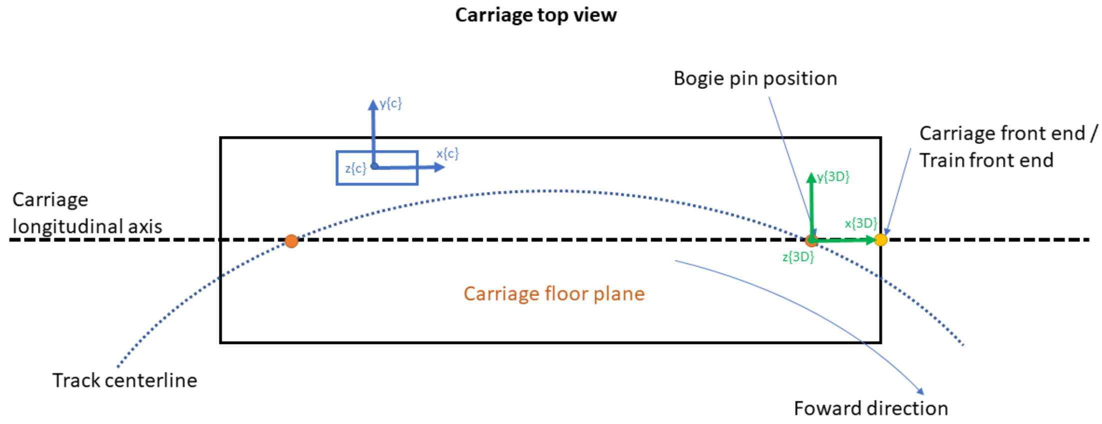
Figure 24 - 1D reference frame represented by the x-axis of the bogie frame $\{o\}$.

Source: N/A. Definition to be applied within CLUG 2.0 WP2

3D reference frame {3D}

It is the three-dimensional reference frame where the velocity and 3D acceleration are expressed on the 3 axis component values. The origin is the bogie pin. The orientation is the same as the carriage frame $\{c\}$ (cf. definition of Carriage reference frame) by a right trihedron.

The 3D reference frame is oriented according to ISO 8855-2011 (c.f. Ref [69]).



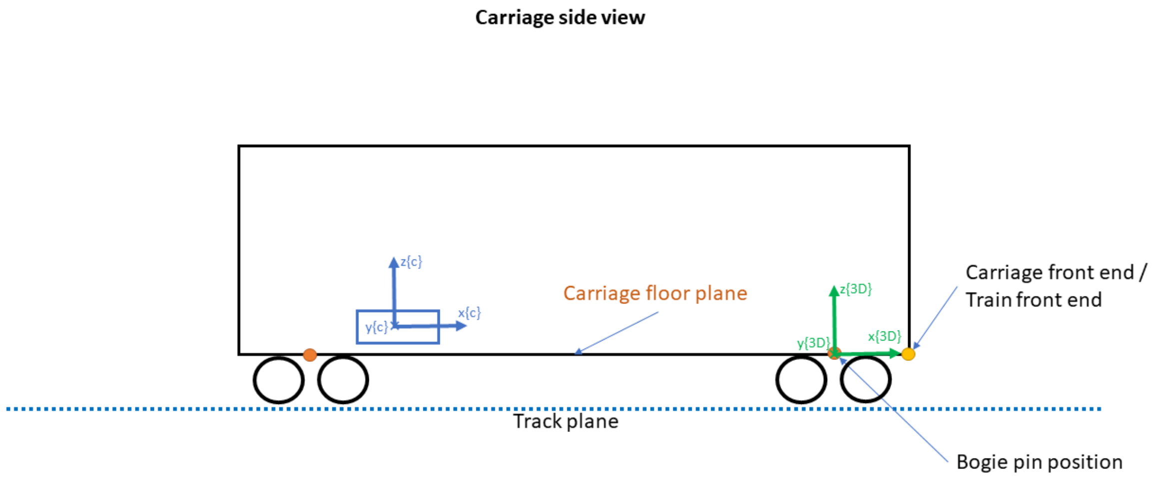


Figure 25 - 3D reference frame and carriage frame $\{c\}$.

Source: N/A. Definition to be applied within CLUG 2.0 WP2

Absolute position or 3D position

The absolute position of the train is defined as the location of the bogie pin projected to the top height of the rails expressed in the format Longitude, Latitude and Altitude in the reference system ETRS89. For the definition of the train front end please refer to the glossary entry (cf. Train Front End, yellow point in Figure 25).

Source: N/A. Definition to be applied within CLUG 2.0 WP2

Accuracy

The difference between true and computed value. This value can be for example a position or a velocity.

Source: adapted from Ref [17]

Angular rate

The angular rate, also called angular velocity, indicates the speed or rate at which the angular position of an object changes. Usually given in $\left[{}^{rad}/_{s}\right]$.

Source: N/A. Definition to be applied within CLUG 2.0 WP2

Area of Uncertainty

The Area of Uncertainty is an abstract illustration of the combined sensor and map uncertainties used to qualitatively explain interrelations between LOC-OB inputs and outputs. In contrast to the ETCS Confidence Interval, the Area of Uncertainty illustrates the uncertainty along and perpendicular to the track. The Area of Uncertainty is not an output of the LOC-OB, and its concept does not refer to any specific LOC-OB algorithm or calculation step.

Source: N/A. Definition to be applied within CLUG 2.0 WP2

Attitude

Describes the orientation of a rigid body (resp. line or plane) with respect to a reference coordinate system (x, y and z axis). In case of CLUG 2.0 the train front reference frame $\{t\}$ is the coordinate system of the rigid body which is oriented with respect to the navigation reference frame $\{n\}$.

The rotation necessary to rotate the object from the reference system to its current system can be specified using Euler angles, rotation matrices or rotation quaternions (and others). The rotations in CLUG 2.0 are given in Euler angles, more precisely in the Tait-Bryan angles with the intrinsic rotation convention yaw, pitch and roll (or z-y'-x''). In this case, the rotations are executed successively in the order yaw, pitch and roll, and after each rotation the next rotation is performed in the previously rotated coordinate system.

Source: N/A. Definition to be applied within CLUG 2.0 WP2

Augmentation

Methodology for improving ("augmenting") the performance of a sensor system (e.g., localisation systems) by providing supporting information. In this case augmentation data could be supporting information such as temporary slippery conditions (rail friction coefficient) that can be regarded by the sensors and/or fusion logic to improve the overall performance.

Note: a dedicated form of augmentation data is GNSS Augmentation (cf. definition)

Source: Ref [17]

Availability or "confidence interval<Max_confidence interval Availability"

Availability of the LOC-OB outputs is the probability or the proportion of time that the LOC-OB outputs are available, and the LOC-OB provides the required safe accuracy, integrity and continuity performances.

Note 1: Therefore, the LOC-OB is available as long as it is providing localization parameters (position, speed, etc...) together with their confidence intervals smaller than the required Maximum confidence intervals and it complies with the required Tolerable Hazard Rate (THR).

Note 2: availability depends on external conditions of use (by model or by specification)

Source: Ref [25]

Body fixed reference frame {b}

It has the same origin of carriage frame $\{c\}$ and can be regarded as the frame where a sensor is mounted.

Source: Ref [59]

Bogie reference frame {o}

The bogie reference frame $\{o\}$ is placed along the orientation of the bogie (cf. Figure 26). During straight paths, $\{o\}$ is oriented as $\{t\}$.

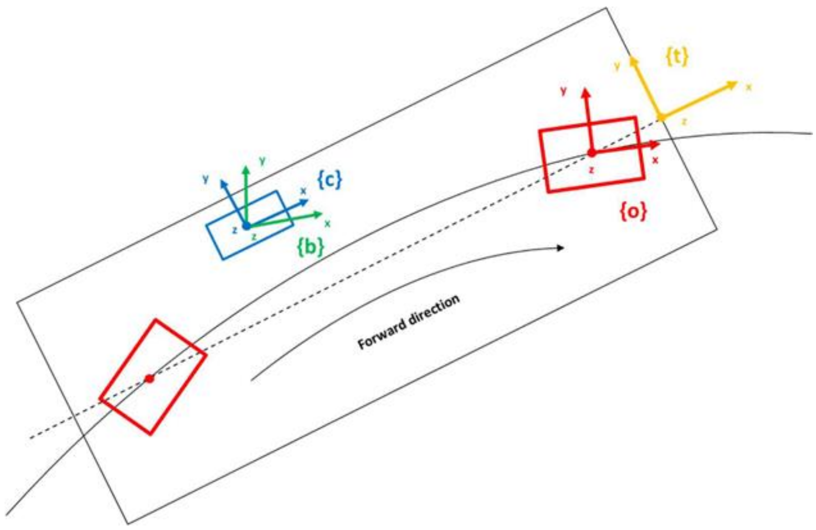


Figure 26 - On-board reference frames: front train $\{t\}$, bogie $\{o\}$ and carriage $\{c\}$ reference frames (Ref [17]).

On the plane defined by the carriage floor, the x axis $\{o\}$ is the tangent of the track centreline towards the train front end. The bogie pin close to the train front end is the origin of this coordinate system.

The bogie pin is located on the longitudinal axis of the carriage.

Source: adapted from Ref [17]

Braking curves

ETCS supervises both the position and speed of the train to ensure they continuously remain within the allowed speed and distance limits, and – if necessary – it will command the intervention of the braking system to avoid any risk of the train exceeding those limits. For this purpose, ETCS on-board computer must predict the decrease of the train speed in the future, from a mathematical model of the train braking dynamics and of the track characteristics ahead. This prediction of the speed decrease versus distance is called a braking curve.

Source: Ref [47]

Braking percentage – Brake power – Brake force

Dimensionless values for assessing the braking performance of a railway vehicle or a train, which determine the permissible line speed in a section of line. The braking percentage relate the braking weight of a vehicle or train to its mass to compare the braking performance of different trains with their different loads. Braking performance definition and methodology to determine the braking performance of railway vehicle and trains, as well as the conversion of the braked weight to the braked weight percentage is defined in Ref [48].

Source: Ref [48]

Cab

The space in the power unit or driving unit of the train containing the operating controls and providing shelter and potentially seats for the driver or engine crew (cf. Ref [27]). In modern locomotives, the driver's cabs are located at the ends of the vehicle. Locomotives used in shunting are often managed with a central driver's cab.

Source: Ref [17]

Cab, Active

The active cab is the cab associated with an ERTMS/ETCS on-board equipment, from which the traction is controlled.

Source: Ref [27]

Cab A

One end of a train/shunting consist, statically defined by the manufacturer.

Source: Ref [17]

Carriage front end

It is represented by a point along the longitudinal axis (cf. yellow point in Figure 25). This point is the most forward element belonging to the carriage.

Note: the carriage front end and the train front end are coincident only when the carriage is in the front of the train (train = set of carriages).

Source: N/A. Definition to be applied within CLUG 2.0 WP2

Carriage reference frame {c}

It has the same origin of body frame $\{b\}$. However, its orientation is coincident with train front reference frame $\{t\}$ or 3D reference frame $\{3D\}$. This reference frame is defined because the orientation from body frame $\{b\}$ to carriage frame $\{c\}$, which is represented by mounting misalignment, shall be estimated and compensated by the sensor fusion algorithms.

Source: Ref [59]

Clothoid / Euler spiral

A clothoid (i.e., Euler spiral) function gradually reduces the bending radius in the bending direction, hence a linear relation between radius and length exists.

Source: Ref [12]

Confidence interval

The position, speed, acceleration interval within which the LOC-OB assumes the true train position, speed, acceleration is, with a defined probability (THR).

Source: adapted from ETCS Confidence Interval in Ref [27]

User functions

Functions of systems within the wider system of interest using localisation information.

It is equivalent to the term VL Output Consumers in Ref [17], defined as grouping of on-board and trackside users of localisation information.

Source: Ref [17]

(operational) Continuity

Operational Continuity of the LOC-OB outputs is defined as the probability that the LOC-OB output are made usable and safe to its users during a train's operation phase without involving delay, presuming they are available at the beginning of the operation phase, i.e., the LOC-OB is initialized. Continuity can also be specified per hour of operation.

Note: CLUG (1) and CLUG 2.0 investigations so far that there is only operational continuity to be quantified by the impact on the operational line service Reliability; there is no safety critical continuity requirement in railway in opposition to aviation.

Source: adapted from Ref [25]

Digital Map

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

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

Source: adapted from Ref [77]

Digital Register

Digital Register is the nomenclature used within CLUG 2.0 WP2 for the system englobing the Digital Map functionalities with potentially extended scope.

Source: N/A. Definition to be applied within CLUG 2.0 WP2

Earth fixed reference frame {e}

The origin of the earth fixed reference frame $\{e\}$ is the centre of mass of the earth and coincides with the origin of the inertial reference frame $\{i\}$. The x- and y-axes lie in the equatorial plane. The y-axis intersects the zero meridian, while the z-axis coincides with the Earth's rotation axis. This coordinate system is often referred to as the Earth centred, Earth fixed (ECEF) coordinate system. The earth fixed reference frame $\{e\}$ rotates with respect to the inertial reference frame $\{i\}$ due to the Earth's rotation.

Source: N/A. Definition to be applied within CLUG 2.0 WP2

End of Authority (EoA) (Limit of Authority)

When the Target Speed at the End of MA is zero, the End of MA is called EoA; when the target speed is not zero, it is called the Limit of Authority (LoA). This nonzero target speed can be time limited.

Source: Ref [28]

Estimated Speed

The speed the ETCS or LOC-OB equipment estimates the train is running at, with the highest probability according to the physical characteristics of the train and to the LOC-OB equipment working conditions. The speed is provided using the 1D reference frame $\{o\}$ (cf. Figure 24).

Source: Ref [17]

Estimated Train Front End Position

The position the ETCS or LOC-OB equipment estimates the Train Front End (cf. definition) is at, with the highest probability according to the physical characteristics of the train and to the localisation working conditions. Also referred to as "Estimated Position" (cf. Ref [27]), as the distance of the Train Front End from a localisation reference detected by the on-board.

Source: Ref [17]

ETCS Confidence Interval

The distance interval within which the ERTMS/ETCS on-board assumes the actual train position is, with a defined probability. It comprises the odometer over-reading and under-reading amounts, plus twice the location accuracy of the reference BG.

Source: Ref [27]

ETCS Mission

Any train movement started under the supervision of an ERTMS/ETCS on-board equipment in one of the following modes: Full Supervision (FS), Limited Supervision (LS), Staff Responsible (SR), On-Sight (OS), Non-Leading (NL), Unfitted (UN), or National System (SN).

The ETCS Mission is ended when any of the following modes is entered: Standby (SB), Shunting (SH).

Source: Ref [27]

ETCS Start of Mission (SoM)

ETCS SoM procedure starts with on-board cab activation (i.e., the ETCS On-Board Unit (OBU) being in mode SB with a desk opened and no connection to trackside established) and it is finished as soon as the train leaves ETCS mode SB.

Source: Ref [28]

ETRS89

The European Terrestrial Reference System 1989 (ETRS89) is an ECEF (Earth-Centred, Earth-Fixed) geodetic Cartesian reference frame, in which the Eurasian Plate as a whole is static. The coordinates and maps in Europe based on ETRS89 are not subject to change due to the continental drift.

ETRS89 is the EU-recommended frame of reference for geodata for Europe.

Source: Ref [24]

Generic Functions

Generic functions common to every functional box (diagnostic, maintenance, and access control) in the context of RCA and OCORA.

Source: Ref [17]

GNSS

Global Navigation Satellite System (GNSS) refers to a constellation of satellites providing signals from space that transmit time signals. The GNSS receivers then use this data to determine location. Among these constellations we can cite the US´s GPS constellation, the European constellation (GALILEO) and the Russia´s GLONASS.

Source: Ref [24]

GNSS Augmentation

Augmentation data leads to more accurate localisation information (along-track position, along-track speed) and faster estimation of accurate localisation after startup of the LOC-OB in operation. It enhances GNSS localisation information to support functionalities such as track selectivity.

While GNSS augmentation data through Space-Based Augmentation Systems (SBAS) can be consumed directly by GNSS receivers, the purpose of this system function is to receive augmentation data through a terrestrial dissemination service with the advantage of not being always dependent on the visibility of augmentation satellites.

Augmentation data is not limited to GNSS and could be supporting information such as temporary slippery conditions (rail friction coefficient) that can be regarded by the sensors and/or fusion logic to improve the overall performance.

Source: Ref [17]

Hazard

A condition that could lead to an accident.

Source: Ref [5]

IMU

An Inertial Measurement Unit (IMU) is an electronic device that measures and reports a body's specific force, angular rate, and sometimes the orientation of the body, using a combination of accelerometers, gyroscopes, and sometimes magnetometers.

Source: Ref [24]

Inertial reference frame {i}

As the name suggests, it is a non-rotating coordinate system, which is also a non-accelerating right-handed Cartesian 3D frame. The origin of this reference frame is placed in the Earth's centre of mass, and the three axes are fixed with respect to the fixed stars. In particular, the z-axis coincides with the Earth's rotation axis, the x-axis and the y-axis lie in the equator plane.

Source: N/A. Definition to be applied within CLUG 2.0 WP2

Integrity risk

The probability during the period of operation that an error, whatever is the source (but excluding malicious attacks), results in the real train motion parameter being outside of the computed confidence interval, and the LOC-OB is not informed within the specific allocated time.

Source: Ref [24] and Ref [25]

Kinematic data

In the scope of CLUG 2.0, kinematic data is understood as the position, speed, acceleration, attitude and angular rate of the train.

Source: N/A. Definition to be applied within CLUG 2.0 WP2

L_DOUBTOVER

Combination of Q_LOCACC and over-reading amount.

Source: Ref [28]

L_DOUBTUNDER

Combination of Q_LOCACC and under-reading amount.

Source: Ref [28]

Localisation Information

Set of spatial values referenced to the rail network, and kinematic variables referenced to the train unit, that enable determining the position of the train unit in a specific point of the network and its dynamic behaviour from its speed, acceleration, and orientation values.

Source: Ref [7]

Map Data

During the operation, the Map Data is used to realize system specific functionalities, e.g., for on-board localization, perception or ATO. The Map Data includes a build-up set of edges along with associated nodes (e.g., points, buffer stops), the relevant infrastructure characteristics (e.g., curve radius and gradients), and location information (e.g., specific reference points, balises). The Map Data remain unchanged during operation phase until the next provisioning of Map Data.

The so-called Map Data from the Digital Map is based on the existing MAP Object Catalog (Ref [12]).

Source: adapted from Ref [9]

Mission

An objective description of the fundamental task to be performed by a system (cf. ETCS Mission definition).

Source: Ref [27]

Navigation reference frame {n}

Its origin coincides with the origin of a train front reference frame $\{t\}$. However, the directions of its axis are not fixed to the vehicle but are only depending on the geographical locations. The standard ISO 8855-2011 (cf. Ref [69]) establishes that the z-axis of $\{n\}$ is vertical upward, while there is freedom to choose the orientation of the x- and y-axes within the horizontal plane. In the CLUG 2.0 project, it is chosen to fix the x-axis pointing north and the y-axis pointing west. Note that, due to such a definition, $\{t\}$ and $\{n\}$ are aligned when the vehicle is at level, facing north.

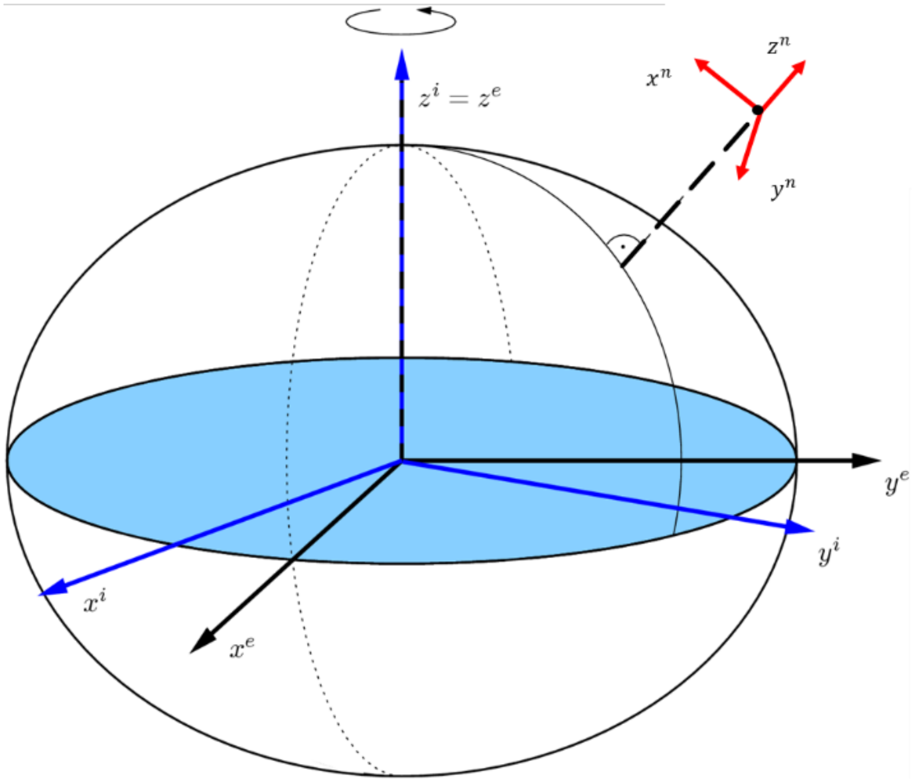


Figure 27 - Reference frames with respect to the earth center.

Source: N/A. Definition to be applied within CLUG 2.0 WP2

Over-reading amount

The distance the train may have travelled less far than the estimated position. The distance is estimated by the ERTMS/ETCS on-board equipment taking into account the odometer inaccuracy plus the error for the detection of a balise location, as defined in the EUB specifications.

Source: Ref [27]

Performing a Mission (PaM)

Performing a Mission is defined as the procedures necessary to carry out a Mission. This step is usually preceded by Start of Mission. A mission includes an ETCS Mission.

Source: Ref [2]

Q_LOCACC

Balise installation tolerance.

Source: Ref [28]Reference location

A location on the track used as a reference for the train position (cf. definition of Estimated Train Front End Position).

Note: In current ETCS the reference location usually is a balise group (cf. Ref [27] definition of reference location)

Source: Ref [27]

Safe and Available/Unavailable situations

Figure 28 and Figure 29 are an illustration of a computed estimated position with its computed confidence interval versus the required Maximum Confidence Interval (MCI).

In both situations the train position remains safe, but in the second situation where confidence interval > MCI, the LOC-OB is considered not available (computed confidence interval is higher than required MCI). In the case of the speed confidence interval > MCI, this situation is more an operational concern as quickly recoverable by slowing down the train.

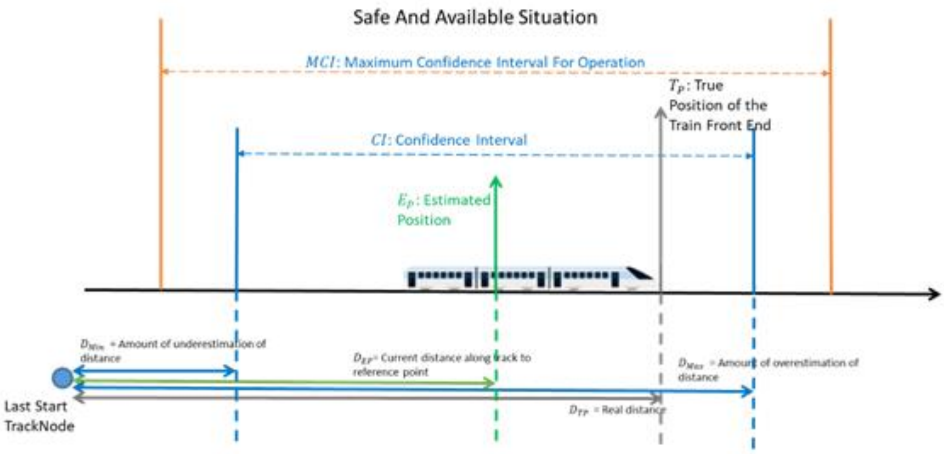


Figure 28 - Safe and available situation. Estimated position, computed Confidence Interval versus specified Maximum Confidence Interval.

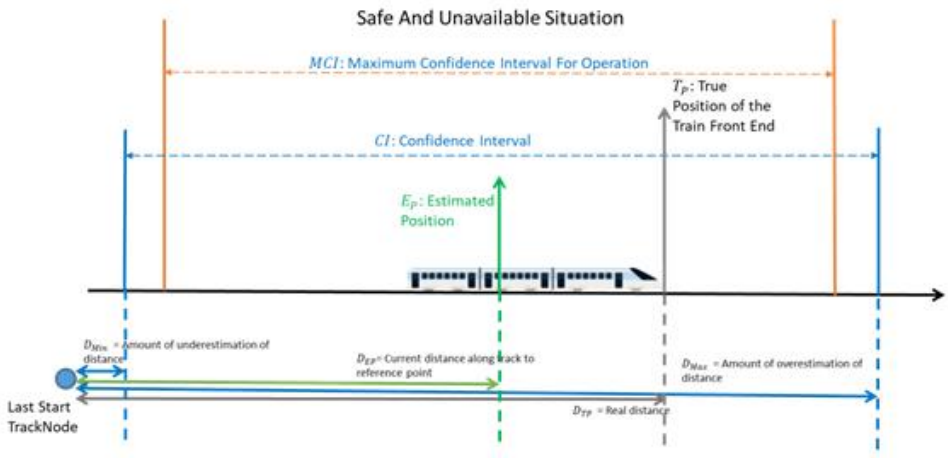


Figure 29 - Safe and unavailable situation. Estimated position, computed Confidence Interval versus specified Maximum Confidence Interval.

Source: Ref [25]

Starting a Mission

The term Starting a Mission defines a Scenario in which the Start of Mission (ETCS SoM) Procedure reaches a specified mode:

- Precondition: OBU is in mode SB with the desk closed
- Postcondition: Train is in mode FS/OS

Source: N/A. Definition to be applied within CLUG 2.0 WP2

Supporting Information

Information not directly translatable into localisation information but needed to provide the desired output. This information will be used by internal LOC-OB processes to enable, improve or validate localisation information (e.g., Augmentation).

Source: Ref [17]

Track Selectivity

Track Selectivity is the ability of a system to determine on which track the train front end is located in any topology (According to the Figure 30: Coming from Track A and driving over the point is the train front end on Track B or C or Track A at a certain point in time?).

Track selectivity does not cover the determination of a concrete position along a specific track. This is pictured in Figure 30 where it is NOT relevant, which is the absolute or relative position of the train front end on Track A, B or C. Further specified in Figure 31: It is not relevant if the train front end is on track edge 101, 102, 103 or 104, since they all belong to the same Track A.

Please note that although the above definition makes a clear distinction between along-track position/accuracy and Track Selectivity, the process of determining Track Selectivity is closely related to the along-track position/accuracy.

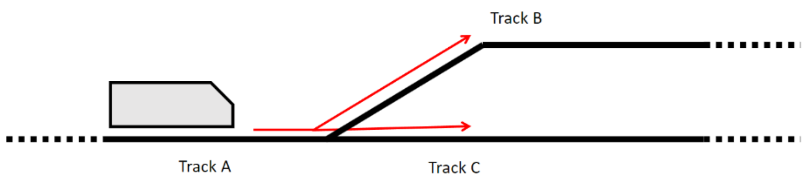


Figure 30 - Train on parting tracks.

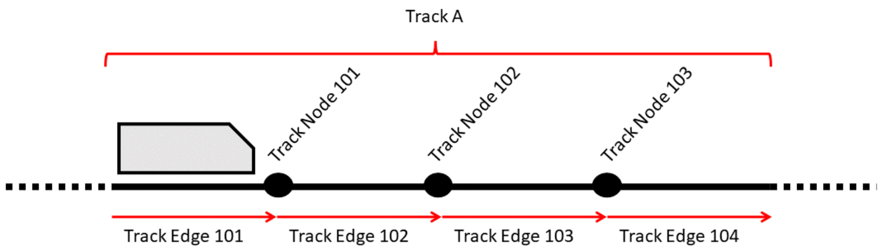


Figure 31 - Train on single track.

Source: Ref [2]

Train

One or more railway vehicles hauled by one or more traction units, or one traction unit travelling alone, running under a given operational number from an initial fixed point to a terminal fixed point. Also referred to as “Train Unit” (cf. Ref [7]).

Source: Ref [17]

Train Front End

Train Front End is represented by a point of the most forward element belonging to the train on the level of the carriage floor along the longitudinal axis (c.f. yellow point in Figure 24 and Figure 25).

Source: N/A. Definition to be applied within CLUG 2.0 WP2

Train front reference frame {t}

It represents the nominal reference frame of the vehicle to be tracked. The origin of the reference frame will be placed at the train front end. The orientation follows the standard ISO 8855: the x-axis is directed along the vehicle longitudinal axis (positive forward), the z-axis is directed along the vertical direction (positive upward) and as a consequence the y-axis lies in the horizontal plane, pointing to the left.

Source: N/A. Definition to be applied within CLUG 2.0 WP2

True train acceleration

Is the real signed acceleration of the train along the track centreline. It is expressed using the 1D reference frame (cf. Figure 24 and Figure 26).

Source: Adapted from True Ground Train Acceleration in Ref [17]

True train position

It is the real position of the train front-end along the track centreline.

Source: Adapted from True Ground Train Position in Ref [17]

True train speed

Is the real speed of the train along the track centreline. It is expressed using the 1D reference frame (cf. Figure 24).

Source: Adapted from True Ground Train Speed in Ref [17]

Under-reading amount

The distance the train may have travelled more far than the estimated position. The distance is estimated by the ERTMS/ETCS on-board equipment taking into account the odometer inaccuracy plus the error for the detection of a balise location, as defined in the EUB specifications.

Source: Ref [27]

Vehicle

Vehicle is the generic term for all railway vehicles (locomotives, railcars, coach, freight wagon and special vehicles). A railway vehicle is identified by a unique vehicle number.

Source: Ref [17]

Velocity

It is a vector describing speed and direction of the motion of an object.

Train velocity in CLUG 2.0 is expressed in the 3D reference frame $\{3D\}$ (cf. Figure 25)

Source: Ref [59]WGS84 (World Geodetic System 1984)

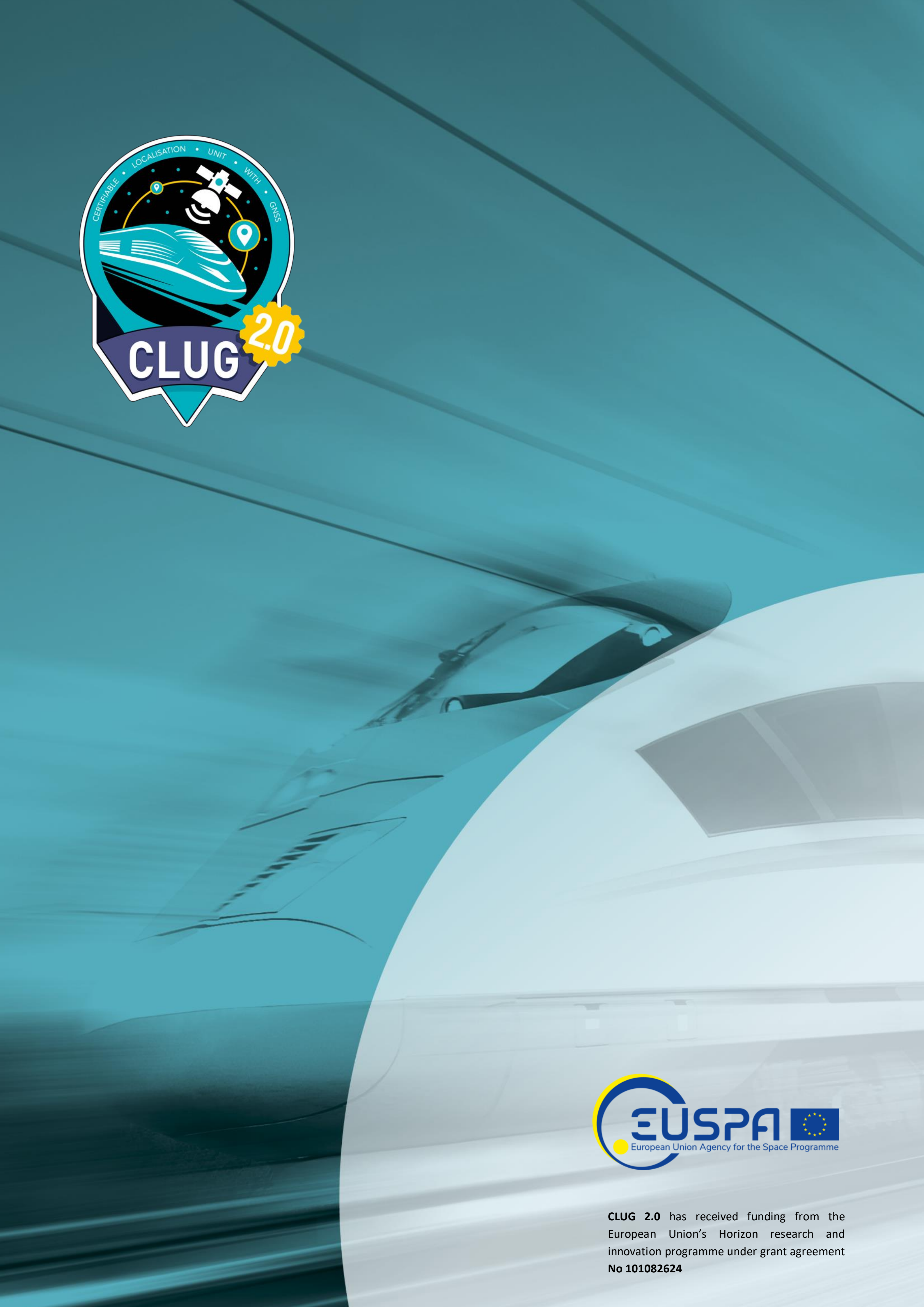
An ellipsoid designed to fit the shape of the entire Earth as well as possible with a single ellipsoid. It is often used as a reference on a worldwide basis, while other ellipsoids are used locally to provide a better fit to the Earth in a local region. GPS uses the centre of the WGS-84 ellipsoid as the centre of the GPS ECEF reference frame.

Source: Ref [24]

Wider System-of-Interest

The Wider System-of-Interest defines the systems and functions working together to accomplish their goals. In the case of the LOC-OB the WSoI is composed of the systems performing the user functions (cf. User Functions) and the systems providing supporting information to the LOC-OB to implement its expected functionalities (cf. Supporting Information).

Source: N/A. Definition to be applied within CLUG 2.0 WP2



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