CLUG DEMONSTRATION OF READINESS FOR RAIL - CLUG 2.0

D2.4 LOCALISATION ON-BOARD SYSTEM REQUIREMENTS

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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.

The purpose of the document D2.4 (LOC-OB System requirements) is to define a set of requirements defining an onboard localisation equipment (a final product and not a demonstrator) derived from the information available in:

CLUG 2.0 D2.1: Operational Needs and System Capabilities of the LOC-OB System

CLUG 2.0 D2.2: Start of Mission and Track Selectivity

CLUG 2.0 D2.3: LOC-OB System Definition and Operational Context

Black box approach

Even if the CLUG 2.0 project is structured around the use of GNSS, SBAS augmentation and Inertial Measurement Unit (IMU) in the railway environment, requirements defined in this document are presented agnostically.

The aim of this approach is to focus on the real need in term of data definition, safety requirements and performances and avoid biases linked to the knowledge of the sensor's performances and drawbacks.

Usage of the defined set of requirements

The set of requirements defined in D2.4 shall be used, in the scope of the CLUG 2.0 project, by the design teams and the Verification and validation teams to analyse:

- The feasibility of the performance requirements (accuracy and safety), or evidence that the requirement is not achievable.
- The feasibility of the functional requirements for the industrial product (even if not achieved for demonstration purpose).

The obtained feedback and results will then be considered in the future definition of Europeans standards.

State of the document

Since CLUG 2.0 is an R&D project involving uncertainties and assumptions toward the needs and external interfaces, the set of requirements may not be used for an industrial project without reworking.

The requirements defined enable the launch of a proof-of-concept campaign, including objectives in line with current knowledge, particularly in terms of performance, while providing certain assumptions concerning the safety of the localisation data.

Several uncertainties remain and may have a major impact on the requirements as:

- Unstable user needs (for example perception or ATO).
- Undefined (and unagreed) embedded CCS architecture.
- Undefined (and unagreed) functional allocation between embedded CCS components.
- Cross-disciplinary work in progress on the definition of the Digital map (definition and handling).
- Availability and definition of supporting information provided to the localisation.
- Real need from the localisation in term supporting information.
- Technology readiness of the sensors and techniques used to achieve the performance requested within the safety objectives.

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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 Purpose

CLUG 2.0 (Certifiable Localisation Unit with GNSS in the railway environment) continues the activity of the CLUG (1) project with the same main objective of demonstrating an on-board GNSS+EGNOS-based multi-sensor fusion architecture enabling safe positioning and navigation whilst also transforming the way train localisation is done today.

The purpose of the present documents (**CLUG 2.0 D2.4:** LOC-OB System requirements) is to define a set of requirements derived from the information available in:

CLUG 2.0 D2.1 (Ref [1]): Operational Needs and System Capabilities of the LOC-OB System

CLUG 2.0 D2.2 (Ref [2]): Start of Mission and Track Selectivity

CLUG 2.0 D2.3 (Ref [3]): LOC-OB System Definition and Operational Context

Even if the CLUG 2.0 project is structured around the use of GNSS, SBAS augmentation and Inertial Measurement Unit (IMU) in the railway environment, requirements defined in this document are presented agnostically.

One of the main goals of the requirement set is to identify information present on-board that can be used by the LOC-OB to solve some identified issues as Start of Mission or Track Selectivity. These requirements are defined through interfaces that are not yet standardised. Furthermore, they may need to be reworked with the results and exported constraints identified in the design and test phases.

Since CLUG 2.0 is an R&D project involving uncertainties and assumptions toward the needs and external interfaces, the set of requirements may not be used for an industrial project without reworking.

2 Overall methodology and strategy

2.1 CLUG 2.0 main technical objectives

As defined in CLUG 2.0 D2.1 Section 1.1 (cf. Ref [1]), CLUG 2.0 is an R&D project focusing on demonstrating the feasibility of using GNSS, augmentation and IMU to replace the current odometry techniques (European Train Control System (ETCS) L2 BL3R2) for technical and economic optimization purposes.

Designing a certified product is not in the scope of CLUG 2.0. (refer to Grant Agreement N°101082624)

2.2 Scope of requirements and black box abroach

Even if the main objectives of CLUG 2.0 is focused on technology (GNSS + Augmentation + IMU), the chosen strategy to define the set of specifications is to use a black box approach with the following objectives:

1) The specifications need to define the LOC-OB objectives and performances to be achieved in operation (final product). The specifications do not cover the specific definition and design of the CLUG2 demonstrator. (Refer to Appendix E to identify the requirements to be tested by the CLUG2 demonstrator)
2) The specifications of LOC-OB need to define (refer to D2.3 (cf. Ref [3])):
    a. Outputs to be provided by LOC-OB.
    b. Available interfaces and data available onboard.
    c. Definition of the environmental surrounding.
3) The specification team do not provide any assumption on the LOC-OB design which is to be done by the design team.
4) Requirements are agnostic of any final industrial solution.

2.3 White / grey box approach

The definition of the sensor-set and the internal architecture is out of the scope of the specifications (WP2).

The white box definition of LOC-OB shall be provided in the design phase (scope of WP4) considering the objectives and surrounding of LOC-OB defined in the specifications.

2.4 Reliability, Availability, Maintainability and Safety (RAMS) activities

As defined in D2.1 Section 1.1 (cf. Ref [1]), RAMS activities are out of the scope of WP2 for independence purpose as required by the CENELEC standards (EN50126 Ref [5] and Ref [6], EN50128 Ref [73] and EN50129 Ref [70]). Some high-level requirements are defined to express the scope of the LOC-OB as an embedded electronic equipment.

RAMS activities are in the scope of WP3.

2.5 Verification, validation, and testing activities

As defined in D2.1 Section 1.1 (cf. Ref [1]), assumption on the testing and V&V activities related to LOC-OB are out of the scope of WP2 for independence purpose as required by the CENELEC standards (EN50126 Ref [5] and Ref [6], EN50128 Ref [73] and EN50129 Ref [70]).

Testing and V&V activities are in the scope of WP4 and WP5 and need to take into consideration the design of the LOC-OB defined in WP4.

Testing and V&V activities must only analyse:

- The feasibility of the performance requirements (accuracy and safety), or evidence that the requirement is not achievable.
- The feasibility of the functional requirements for the industrial product (even if not achieved for this demonstrator).

2.6 Functional analysis

Functional analysis is provided D2.3 Section 7.2 (cf. Ref [3]).

2.7 Traceability

Since D2.4 aims to translate the information available in D2.1 (cf. Ref [1]), D2.2 (cf. Ref [2]) and D2.3 (cf. Ref [3]) into a set of requirements, traceability is achieved with the documents produced by WP2. For reasons of comprehension, some requirements may be linked to ETCS documents.

Traceability to other research projects is not envisaged as D2.3 provide a comparative analysis between initiatives (D2.3 Chapter 4).

2.8 Evolutions and maintenance of D2.4

As CLUG 2.0 is an R&D project, assumptions and inputs used to produce this document are likely to evolve due to:

1) The definition of a standardised Control Command and Signalling On-Board (CCS-OB), including deviations from the assumptions made in CLUG 2.0.
2) The results provided by the proof of concept designed in CLUG 2.0 in term of:
    a. Performance (fine tune of the defined values).
    b. Interfaces and inputs (deletion of unneeded inputs, exported constraint).
3) New needs inherited from other R&D projects (digital map, perception).

WP6 (document D6.6) will take into account the potential differences from the WP2 assumptions.

3 Overall CCS-OB architecture and general assumptions

3.1 Architecture analysis

A comparative analysis of the current European Railway Traffic Management System (ERTMS)/ETCS architecture and the alternative architectures proposed by some other R&D projects is available in D2.3 Chapter 4 (cf. Ref [3]).

3.2 LOC-OB interaction with the CCS-OB architecture

The LOC-OB interaction with the CCS-OB is defined in D2.3 (cf. Ref [3]).

3.3 LOC-OB architecture in the scope of CLUG 2.0

The LOC-OB architecture, in the scope of CLUG 2.0, is defined in the scope of WP4 (D4.1).

3.4 Key information about the architecture

3.4.1 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.

3.4.2 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) Have several users.

3.4.3 ETCS BL3R2 function allocation to LOC-OB

Allocation of the ETCS functions between LOC-OB and ETCS is defined in D2.3 Section 3.2.1. (cf. Ref [3]).

3.4.4 Technological challenges related to ETCS functions

Since CLUG 2.0 main objective is to challenge the ETCS BL3R2 odometry focusing on the sensor dataset (Balise + encoded wheel vs GNSS + IMU):

- Determination of the train front end: is not considered as challenging compared to the present ETCS BL3R2.
- Determination of the reference location (e.g., LRBG): is not considered as challenging compared to the present ETCS BL3R2 and is exported (kept) in the ETCS.
- Determination of the relative distance from the reference location (e.g., LRBG): Reference point management logic remains the same as BL3R2 and is not considered as challenging. Definition of the train position is considered as the focus point of CLUG 2.0 which is then derived into the train front end.

3.4.5 Supporting information

D2.3 (cf. Ref [3], Table 3) identifies a list of supporting information that may be available and provided to LOC-OB to achieve the requested requirements.

It shall be understood that:

1) The supporting information proposed by WP2 is only a proposal to the design team (WP4) and shall not be considered as mandatory.
2) The design team shall only use the needed supporting information to fulfil the requirements in term of safety and performance.
3) Less (no) supporting information will ease development, RAMS analysis, integration, reduce costs etc and shall be favoured.
4) For each used supporting information, CLUG 2.0 shall provide the requested exported constraints especially focusing on safety.
5) The list of supporting information is deeply linked to CCS-OB architecture and may evolve (refer to Section 3.4.1). Availability, safety requirements and quality of the supporting information shall not be taken for granted and every needed supporting information shall be exhaustively analysed especially toward safety.
6) If a supporting information is needed, LOC-OB shall use the format and interface defined by the standardised CCS-OB (refer to Section 3.4.1). A specific mechanism is to be avoided or considered as an internal component of LOC-OB.
7) If the design team (WP4) identify a need toward a supporting information not identified by WP2, a request can be addressed to the system engineers to embed the needed supporting information (exported constraint, change request etc).

3.4.6 Digital Map

D2.3 Chapter 8 (cf. Ref [3]) provides an analysis and a proposal concerning the Digital Map in the scope of CLUG 2.0.

Digital Map is to be considered as a supporting information (refer to Section 3.4.5).

Digital Map is deeply linked to CCS-OB architecture and may evolve (refer to Section 3.4.1).

Some R&D projects focussing on the Digital Map, as OCORA or R2DATO (WP27), stated that the localisation subsystem may need to output map parts validated (by the localisation subsystem) that cover the area surrounding the train position. Since Digital Map definition and mechanisms are not mature enough, the map reference data is not considered as a data outputted by LOC-OB. This statement may evolve with the release of mature Digital Map requirements.

3.5 LOC-OB physical integration

LOC-OB is an electronic equipment embedded in trains.

As defined in Section 2.2, D2.4 adopt a black box approach and does not provide any assumption or requirements toward the physical integration of LOC-OB as:

1) Where the sensors shall be installed.
2) Where the processing equipment shall be installed.
3) The need of sensor redundancy to:
    a. Achieve performance requirements.
    b. Achieve availability requirements.
    c. Achieve safety requirements.
4) The need to have one LOC-OB per cab (two LOC-OB per train). To be noticed that this topic may be related to the CCS-OB (refer to Section 3.4.1).
5) Is redundancy (not only focused on sensors) needed to achieve the availability requirements and if yes how is it managed.

As defined in Section 2.3, the white box definition, including proposals toward physical integration, is to be done in the design phase (WP4).

3.6 Assumptions

3.6.1 SUBSET 26 dataset principles

In opposition to CLUG (1), CLUG 2.0 is following Ref [28] principles with an estimated value (most probable value) and bounded by over and under estimations.

CLUG (1) provides an estimated value, a maximum safe value, and a minimum safe value.

For example:

	CLUG1 proposal	CLUG 2.0 proposal	Comment
Estimated distance travelled	100 m	100 m	
Over estimation	Not provided	10 m	
Under estimation	Not provided	10 m	
Min safe front end	90 m	Not provided	Min safe front end = estimated distance – overestimation.
Max safe front end	110 m	Not provided	Max safe front end = estimated distance + underestimation.

Dataset provided by LOC-OB	Estimated value; over estimation; underestimation	Estimated value; minimum safe value; maximum safe value
Compatibility with ETCS	Yes	No
Estimated value related to safety	Yes	No

Table 1 - Estimated value and confidence interval pro/cons.

CLUG 2.0 promotes the ETCS compatibility.

To be noticed that the safety mechanisms related to the management of the estimated values are deeply linked to the design choices and the technical architecture.

3.6.2 Track selectivity

Track selectivity is analysed in D2.2 (cf. Ref [2]).

From LOC-OB perspective, track selectivity is linked to the determination of the train front end location on a track edge. To be noticed that track selectivity shall be provided within a minimum delay or distance to be defined.

D2.2 (cf. Ref [2]) recommend that LOC-OB shall provide the list of track edge IDs on which the train front end real position may be located. (Refer to the recommendation 2) in D2.2 Section 4.6.2.3 (cf. Ref [2]). Even if this proposal is valid, it add some complexity to the design without a clear added value as the users requesting the track edge are not yet clearly defined.

In this deliverable, the track edge ID mechanism is defined as: LOC-OB shall provide a track edge ID only if LOC-OB can guarantee that the train front end real position is positioned on the track edge with a SIL4 level. In other words, if the confidence interval is covering more than one track edge, the track edge ID provided by LOC-OB shall take a safe default value.

This decision, taken as a compromise, simplify the design.

From the results of the experimentation and the feasibility of the determination of the track edge occupancy onboard in SIL4, this mechanism may be updated to fulfil new needs.

Safety objectives and dangerous situations related to the determination of the track edge ID must be defined by WP3.

3.6.3 Accuracy model

3.6.3.1 Accuracy model, confidence interval and safety requirements

As a reminder, the confidence interval is used to define the safe boundaries of a value and is related to a feared event and a Tolerable Hazard Rate (THR). The confidence interval shall always be provided withing the defined THR. It is not acceptable to provide a value and its confidence interval if safety is not granted within the specified THR.

On the other side, providing a large safe confidence interval may have an impact on the traffic performance (from delays to emergency braking) and must be avoided (with a lower priority than safety).

Failure to provide a value with its confidence interval will primarily trigger emergency braking (triggered by the LOC-OB user).

The accuracy model presented in this chapter focus on the performance objectives and not on safety objectives.

	Confidence interval size < accuracy objectives	Confidence interval size > accuracy objectives	Confidence interval is not calculated or provided
Value is included in the confidence interval within the defined THR: YES	Best performance in safety	Potential capacity issues (delays to EB). No safety issues	Emergency braking, train stops.
Value is included in the confidence interval within the defined THR: NO	! Safety issue, not acceptable !	! Safety issue, not acceptable !	

Table 2 - Accuracy model, confidence interval and safety.

3.6.3.2 CLUG 2 accuracy model

As recommended by Appendix A of D2.1 (cf. Ref [1], Accuracy impact on capacity) and derived from the dedicated capacity study (cf. Ref [60]), CLUG 2.0 promote a two fixed value model of accuracy concerning the train front end position.

This model is focused on the operational need and, in opposition to subset 41 (cf. Ref [30]), is not a bottom-up approach considering the drawback of sensors.

Since this model is not related to sensor technology, achieving, and testing this model of accuracy can be challenging. A collaborative approach between WP2, WP4 and WP5 should be encouraged to propose a coherent approach between the operational need, the possible technical solutions, and the validation method.

The maximum accepted confidence interval regarding the estimated position (MAPU, MAPO) or the estimated speed (MASU, MASO) of the train influences the assessment of the line capacity. The impact of the real-time confidence interval on the transportation plan of the line depends on the operational buffer and areas where the train traffic has small margin (e.g., split of traffic, releasing of switch, stopping in station).

The confidence interval influences the location where the train has to apply a speed restriction, to enforce the safe braking distance and the location to release a part of the track. Thus, the minimal theoretical headway between trains is impacted by the confidence interval.

The operational context (capacity of the line, train traffic bottleneck, high density of traffic, station area, type of train, etc.) derived from the transportation plan and the mission profiles allows to classify track areas by headway and position confidence interval constraints.

To cope with operational use cases with regard the confidence interval and the margin on the headway three specific cases are defined:

a. Area not constrained by the confidence interval: Mainline track, track areas between stations. There is no critical location to achieve the operational headway in this area. Train is travelling

usually at the track operational speed. The capacity of the area is not constrained by the confidence interval, the train characteristics as the safe braking distances and the acceleration make the capacity performance (The confidence interval is small against the safe braking distance and does not influence the capacity.).

b. Area constrained by the confidence interval: Areas such as stations, specific switch areas known as bottleneck where the confidence interval has a direct impact on the train traffic. Trains are slowing down to a stop and after the passenger exchange are accelerating to leave the platform. Trains are queuing and in such mission profiles the confidence interval is major to achieve the headway. A small confidence interval is required to achieve the capacity performances.

c. Stopping accuracy: The confidence interval influences the train location stopping accuracy. To provide an answer to user's needs, to stick to train driving operational rules and to avoid using the release speed, the train has to stop at the operational stopping point. In this case a small confidence interval is required to avoid a train to stop too far from the forecasted operational stop.

From the following, the two fixed value model identify two types of area:

Derived from case a: Area with negligible constraint on the confidence interval or the accuracy with regards to the capacity: Mainline, dense traffic line, track section between two areas with constrains.

Derived from case b and c: Area with constraints on the confidence interval or the accuracy with regards to the capacity or operational regulation: Station area, traffic node (specific point), stopping point (End of Authority (EoA)), Limit of Authority (LoA).

The definition of these areas may evolve with the feedback of WP4 and WP5.

Type of Constraints	Max Accepted Position Overestimation	Max Accepted Position Underestimation	Comment
Area with negligible constraints	60 m	60 m	Value inherited from Ref [60] (80m) and appendix A [1] (40m). Value subject to modification.
Area with constraints	10 m	10 m	Value derived from subset 41 (cf. Ref [30], Accuracy of distances measured on-board). Value subject to modification.

Table 3 - Confidence interval model.

Type of Constraints	Estimated position accuracy along the track with a defined probability of p=95%	Comment
Area with negligible constraints	+/- 4 m	Assumption on the ATO need. Value subject to modification.
Area with constraints	+/- 1.25 m	Assumption on the ATO need. Value subject to modification.

Table 4 - Estimated position accuracy performances.

From the model the following characteristics are deduced:

- The train position confidence interval boundaries “maximum acceptable position overestimation”, "maximum acceptable position underestimation” remain linked to the train location on the track network (located on area with constraints or not).
- The model doesn’t make reference to any reference location.
- The model doesn’t depend on the train speed.

PROS

- The confidence interval boundaries are deterministic with regards to the train position on the track network.
- The choice of area can take into account specific environments e.g., track areas with weak/ no GNSS signal, tunnel, station…
- The model provides efficient ways to improve the performance of the network by asking performance only on specific areas.

CONS

- A principle has to be set to determine the type of area the train is running on.
- The determination of the type of constraint could be derived from the Movement Authority (MA) adding complexity to the system. For example, by receiving the distance to the EoA from the ERTMS, the ASTP at a given distance to the EoA could switch to an area with constraints with an objective to process a confidence interval < 10 m.

Appendix A of Ref [1] (Accuracy impact on capacity) promote a speed dependant accuracy model as an alternative. Even if this model of accuracy eases the validation of the prototypes with regard to the performance requirements, it over specify the need toward the confidence interval size objectives. For example, a slow freight train shall provide a precise localisation even in ceiling speed monitoring.

3.6.4 Reference frame

Reference frame definition is available in the glossary (Chapter 18).

To be noticed that the reference frame shall be identical between data provider and data user and may evolve with the definition of a generic CCS-OB (refer to Section 3.4.1).

3.6.5 Operational modes

No complex operational modes are identified toward LOC-OB. (Operational mode is understood as LOC-OB internal operation and not related to ETCS modes).

Excluding maintenance operations, LOC-OB shall avoid any human interventions.

FOR ILLUSTRATION PURPOSE: Assumptions thereafter are an anticipation of the LOC-OB design and shall not be considered as granted.

After a hardware/middleware initialisation, and only if the equipment integrity is granted, LOC-OB should enter in its nominal mode.

In nominal mode, LOC-OB should:

1) Provide all available data with respect to the requirements.
2) Provide a default invalid value known by the users if the specific data cannot be generated with respect to the requirements, especially safety requirements.

Only if the overall integrity of LOC-OB is not guaranteed for example, the safe computer cannot grant the safety requirements), LOC-OB should enter in a safe failure mode and stop providing any data to any user.

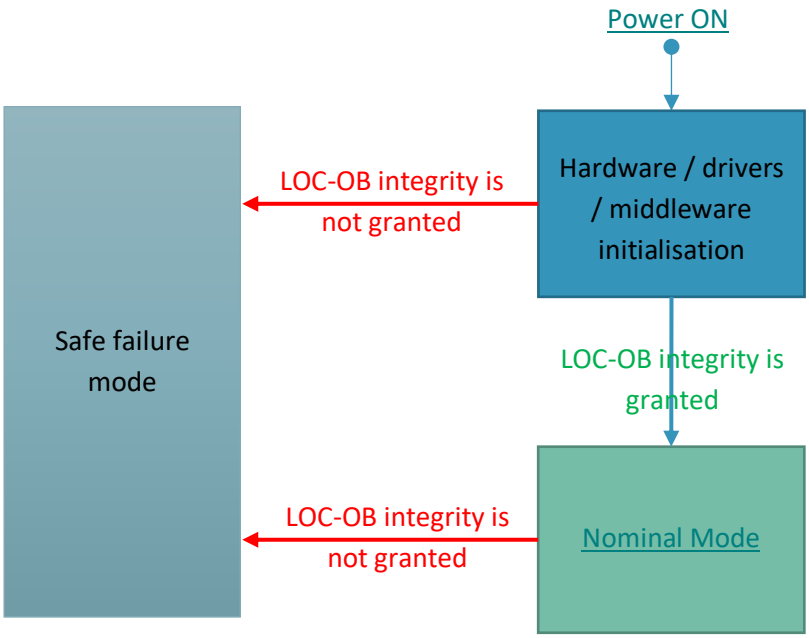


Figure 1 - Illustration of the LOC-OB modes.

4 Analysis of the System Requirements defined in CLUG (1) project

An analysis of the system requirements defined in CLUG (1) including a link to the requirements defined in CLUG 2.0 is available as an appendix:

Appendix A: CLUG (1) requirements

5 System Requirements Categorisation

The system requirements toward LOC-OB can be categorised as following:

1. Functional:

   Interfaces

2. Non-functional

   1. Capacity: Requirements that can have an impact on the capacity of the railway.
   2. Performance: Requirements defining performance values to be achieved.
   3. Interoperability: Requirements referring to interoperability as defined in TSI.
   4. Modularity: Requirement referring to CCS-OB modularity in opposition to a monolithic solution (Modularity scope need to be specified / agreed with more details).
   5. Compatibility: Requirements referring to compatibility with defined interfaces.
   6. Environmental: Environmental surrounding of the system including climatic and EMC.
   7. RAMSS.

6 Requirement template

To facilitate identification of requirements and their attributes, a generic template is defined as following:

Req ID	*A unique identifier is assigned to each requirement:* **SpecSysReq[XXX]**
Requirement	*Define the requirement itself. It shall be considered as the mandatory inputs to be fulfilled in the following phases.* *System requirements are derived from high level users' requirements.*
Additional information	*Complementary definitions or explanations to help the understanding of the requirement. Additional information is not constrained and can contain text, links to other chapters, link to documents etc.*
Category / classification	*Tag used to classify the requirement. Categories are defined in Chapter 5.*
Traceability	*Traceability to high level users' requirement.* UR[XXX] are requirements defined in D2.1 (cf. Ref [1]) SF-XXX are functions defined in D2.3 (cf. Ref [3])
Acceptance Method	*Predefinition on the Verification & Validation methodology. Analysis, lab test, field test. Can be challenged by the V&V team in WP5*
Safety assumption	*Assumption made by the specification team, shall be challenged by the RAMS team according to the WP3 results.*

7 LOC-OB Expected output requirements

7.1 1D localisation requirements

7.1.1 1D localisation dataset

DATA	Unit / resolution	Range	Safety assumption	Default invalid value
Reference location id	N/A	[0;16777214]	Safety related	16777215
Train orientation	N/A	0 Reverse 1 Nominal 2 Unknown	Safety related	Unknown
Position qualifier	N/A	0 Reverse 1 Nominal 2 Unknown	Safety related	Unknown
Estimated distance	Cm (0.01 m) / 1 cm	[0;4 294 967 294]	Safety related (used to define the max/min train safe front end)	4 294 967 295
Underestimation of the estimated distance	Cm (0.01 m) / 1 cm	[0;4 294 967 294]	Safety related	4 294 967 295
Overestimation of the estimated distance	Cm (0.01 m) / 1 cm	[0;4 294 967 294]	Safety related	4 294 967 295
Track edge id	N/A	[0;16777214]	Safety related	16777215
Validity timestamp	Depending on the selected technique (refer to SpecSysReq[034])	Depending on the selected technique (refer to SpecSysReq[034])	Safety related (safe time management)	Depending on the selected technique (refer to SpecSysReq[034])

Table 5 - 1D localisation dataset

Req ID	SpecSysReq[001]
Requirement	The 1D localisation dataset toward the train front end provided by LOC-OB shall include: - Reference location id - Train orientation - Position qualifier (w.r.t. to the reference location) - Estimated distance - Underestimation of the estimated distance - Overestimation of the estimated distance - Track edge id - Validity timestamp
Additional information	Reference location id: Unique identifier of the element from which an estimated distance is given. Comparable to NID_LRBG but not limited to balise technology. could be any point in the digital map set as a reference point/node. Train orientation: Orientation of the train in relation to the direction of the reference location. Comparable to Q_DIRLRBG (refer to SUBSET-026-7 (cf. Ref [28])) but not limited to balise technology. Position qualifier: It tells on which side of the reference location the estimated train front end position is. Comparable to Q_DLRBG (refer to SUBSET-026-7 (cf. Ref [28])), but not limited to balise technology. Estimated distance: Distance along the track between the last relevant reference location and the estimated train front end position. Comparable to D_LRBG (refer to SUBSET-026-7 (cf. Ref [28])) but not limited to balise technology. Underestimation of the estimated distance: The safe distance along the track the train may have travelled further than the estimated train front end position. Comparable to L_DOUBTUNDER (refer to SUBSET-026-7 (cf. Ref [28])) but not limited to balise technology. Overestimation of the estimated distance: The safe distance along the track the train may have travelled shorter than the estimated train front end position. Comparable to L_DOUBTOVER (refer to SUBSET-026-7 (cf. Ref [28])) but not limited to balise technology. Track edge id: ID of the track edge where the train front end real position is. (refer to Section 3.6.2). Validity timestamp: Time stamping of the output, i.e., the time when the localisation information was valid.
Category / classification	Functional
Traceability	UR[001]; UR[019]; SF-001
Acceptance Method	Analysis; Test
Safety assumption	Safety related

Req ID	SpecSysReq[002]
Requirement	LOC-OB shall provide the track edge ID where the train front end position is.
Additional information	Refer to D2.2 (cf. Ref [2], Section 4.4.1)
Category / classification	Functional
Traceability	UR[022]
Acceptance Method	Analysis ; Test
Safety assumption	Not related to safety

7.1.2 1D localisation performance requirements

Req ID	SpecSysReq[003]
Requirement	The absolute value of the Overestimation related to the estimated distance and the absolute value of the Underestimation related to the estimated distance shall be lower than ten meters. surrounding: - An operational stop or speed limitation. - A stop in train station. Surrounding shall be interpreted as +- 500m of a stopping point.
Additional information	Refer to Section 3.6.3.2. |Max Accepted Position Overestimation| = |Max Accepted Position Underestimation| = 10m. The values are results from capacity studies as presented in appendix A of Ref [1].
Category / classification	Capacity; Performance
Traceability	UR[006]; UR[011]; Appendix A of Ref [1]
Acceptance Method	Analysis; Lab test; field test
Safety assumption	Not related to safety

Req ID	SpecSysReq[004]
Requirement	The absolute value of the Overestimation related to the estimated distance and the absolute value of the Underestimation related to the estimated distance shall be lower than sixty meters anywhere the SpecSysReq[003] requirement is not requested.
Additional information	Refer to Section 3.6.3.2. The values are results from capacity studies as presented in appendix A of Ref [1].
Category / classification	Capacity; Performance
Traceability	UR[006] ;UR[011]; Appendix A of Ref [1]
Acceptance Method	Lab test; field test
Safety assumption	Not related to safety.

Req ID	SpecSysReq[005]
Requirement	The absolute error of the estimated distance to the reference location shall not exceed 1.25m, for at least 95% of the cases, surrounding: - An operational stop or speed limitation - A stop in train station. Surrounding shall be interpreted as +- 500m of a stopping point.
Additional information	Refer to Section 3.6.3.2. 2 sigma accuracy may be used for gaussian algorithms.
Category / classification	Performance
Traceability	UR[006]
Acceptance Method	Lab test; field test
Safety assumption	Not related to safety

Req ID	SpecSysReq[006]
Requirement	The absolute error of the estimated distance calculated by LOC-OB shall not exceed 4m (for at least 95% of the cases), anywhere the SpecSysReq[005] requirement is not requested.
Additional information	Refer to Section 3.6.3.2. 2 sigma accuracy may be used for gaussian algorithms.
Category / classification	Performance
Traceability	UR[006]
Acceptance Method	Lab test; field test
Safety assumption	Not related to safety

7.1.3 1D localisation safety requirements

Req ID	SpecSysReq[007]
Requirement	The train front end true position shall be included in the LOC-OB computed confidence interval towards the train front end position within the most constraining user exported THR. Train true position is within [(Reference location id + Estimated distance - Overestimation of the estimated distance); (Reference location id + Estimated distance + Underestimation of the estimated distance)].
Additional information	The Automatic Train Protection (ATP) will process safe protection of the train considering the worst cases possible (max safe front end / min safe front end). To be noticed that the 1D dataset specified is following Ref [28] principles with an estimated value (most probable value) expressed by a distance to a reference location and bounded by and over and an underestimation. Therefore: Min safe front end = Reference location + Estimated distance - Overestimation of the estimated distance. Max safe front end = Reference location + Estimated distance + Underestimation of the estimated distance. THR values will be defined in the scope of WP3. Refer to Section 2.4
Category / classification	RAMSS
Traceability	UR[022]; UR[025]
Acceptance Method	Lab test; field test; verification
Safety assumption	Related to safety

Req ID	SpecSysReq[069]
Requirement	LOC-OB computed localisation data shall be considered unsafe if: • The LOC-OB (including all sensors) is not located in the front of the train (cab), AND • The train consists of coupled wagons, locomotives, etc., AND • Train integrity is not confirmed.
Additional information	This requirement can be managed by LOC-OB or exported as an exported constraint.
Category / classification	RAMSS
Traceability	UR[022]
Acceptance Method	Lab test
Safety assumption	Related to safety

Req ID	SpecSysReq[070]
Requirement	The track edge ID provided by LOC-OB shall refer to the track edge occupied by the train front end real position within the most constraining user exported THR.
Additional information	Refer to Section 3.6.2 and D2.2 (cf. Ref [2], Section 4.4.1). THR values will be defined in the scope of WP3. Refer to Section 2.4.
Category / classification	RAMSS
Traceability	UR[022]
Acceptance Method	Lab test; field test
Safety assumption	Related to safety

7.2 1D speed dataset requirements

7.2.1 1D speed dataset

Data	Unit / resolution	Range	Safety assumption	Default invalid value
Movement direction	N/A	0 Reverse 1 Nominal 2 Unknown	Safety related	Unknown
Estimated train speed	0.1 km/h | 0.1 km/h	[0;6000]	Safety related (used to define the max safe speed)	6001
Underestimation train speed	0.1 km/h | 0.1 km/h	[0;6000]	Safety related	6001
Overestimation train speed	0.1 km/h | 0.1 km/h	[0;6000]	Not safety related (CMD and STANDSTILL out of the scope of LOC-OB)	6001
Validity timestamp	Depending on the selected technique (refer to SpecSysReq[034])	Depending on the selected technique (refer to SpecSysReq[034])	Safety related (safe time management)	Depending on the selected technique (refer to SpecSysReq[034])

Table 6 - 1D speed dataset.

Req ID	SpecSysReq[008]
Requirement	The 1D speed (along the track) dataset provided by LOC-OB shall include: - Movement direction - Estimated train speed - Underestimation train speed - Overestimation train speed - Validity timestamp
Additional information	Movement direction: Direction of train movement in relation to the direction of the reference location, i.e., towards or away from the reference location. Comparable to Q_DIRTRAIN (refer to SUBSET-026-7 (cf. Ref [28])) but not limited to balise technology. Estimated train speed: Absolute (1D) estimated speed value along the track, provided in 1D reference frame (refer to the glossary). Underestimation train speed: The safe upper bound of the speed of the vehicle where the LOC-OB is installed. Overestimation train speed: The safe lower bound of the speed of the vehicle where the LOC-OB is installed. Validity timestamp: Time stamping of the output, i.e., the time when the localisation information was valid.
Category / classification	Functional
Traceability	UR[001]; UR[019]; SF-002
Acceptance Method	Analysis; Test
Safety assumption	- Movement direction: Safety related - Estimated train speed: Safety related - Underestimation train speed: Safety related - Overestimation train speed: Not safety related - Validity timestamp : Safety related

7.2.2 1D speed performance requirements

Req ID	SpecSysReq[009]
Requirement	The confidence interval calculated by LOC-OB (Underestimation of the estimated train speed - Overestimation of the estimated train speed) toward estimated speed shall be better than 2 km/h for speeds lower than 30 km/h, and increasing linearly up to 12 km/h for speeds between 30 km/h and 500 km/h.
Additional information	A large confidence interval provided to the train protection has an impact on the capacity of the line and the duration of the train journey since train reel speed need to be reduced to avoid an emergency braking. Speed performance is required for train protection and has an impact on the capacity of the line and the duration of the train journey.
Category / classification	Performance; Capacity
Traceability	UR[006]; UR[011]; UR[012]; subset41 (cf. Ref [30], Section 5.3.1.2)
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

Req ID	SpecSysReq[010]
Requirement	The absolute error of the estimated train speed provided by LOC-OB shall not exceed ± 1 km/h for speeds from 0 km/h to 100 km/h and ± 1% * v for speeds from 100 km/h to 500 km/h for at least 95% of the cases.
Additional information	2 sigma accuracy may be used for gaussian algorithms.
Category / classification	Performance
Traceability	UR[006]; UR[012]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

7.2.3 1D speed safety requirements

Req ID	SpecSysReq[011]
Requirement	The train true speed shall be lower than the LOC-OB computed max safe speed (Estimated train speed + Underestimation train speed) within the most constraining user exported THR.
Additional information	The ATP will process safe protection of the train considering the worst cases possible (max safe speed). Since CMD and STANDSTILL functions are considered out of the scope of LOC-OB, the overestimation is not considered as a safe value. No feared event has been identified related to a non-detected overestimation. To be noticed that the 1D speed specified is following Ref [28] principles with an estimated value (most probable value) bounded by and over and under estimation. Therefore: Max safe speed = Estimated train speed + Underestimation train speed. THR values will be defined in the scope of WP3. Refer to Section 2.4.
Category / classification	RAMSS
Traceability	UR[023]; UR[025]
Acceptance Method	Analysis; Test
Safety assumption	Related to safety

7.3 1D acceleration requirements

7.3.1 1D acceleration dataset

Data	Unit / resolution	Range	Safety assumption	Default invalid value
Estimated train acceleration	0.01 m/s2 | 0.01 m/s2	[-1000;1000]	Safety related (used to define the max safe acceleration)	1001
Underestimation train acceleration	0.01 m/s2 | 0.01 m/s2	[-1000;1000]	Safety related	1001
Overestimation train acceleration	0.01 m/s2 | 0.01 m/s2	[-1000;1000]	Safety related	1001
Validity timestamp	Depending on the selected technique	Depending on the selected technique	Safety related (safe time management)	Depending on the selected technique

Table 7 - 1D acceleration dataset.

Req ID	SpecSysReq[012]
Requirement	The 1D acceleration (along the track) dataset provided by LOC-OB shall include: - Estimated train acceleration - Underestimation train acceleration - Overestimation train acceleration - Validity timestamp
Additional information	Estimated train acceleration: Signed (1D) estimated acceleration value along the track, provided in 1D reference frame (see glossary). Underestimation train acceleration: The safe upper bound of the acceleration of the vehicle where the LOC-OB is installed. Overestimation train acceleration: The safe lower bound of the acceleration of the vehicle where the LOC-OB is installed. Validity timestamp: Time stamping of the output, i.e., the time when the localisation information was valid.
Category / classification	Functional
Traceability	UR[001]; SF-003; subset 26 (cf. Ref [28], Section 3.13.9.3)
Acceptance Method	Analysis; Test
Safety assumption	Safety related

7.3.2 1D acceleration performance requirements

Req ID	SpecSysReq[013]
Requirement	The computed confidence interval (Underestimation train acceleration - Overestimation train acceleration) toward the estimated train acceleration shall not exceed 0.2 m/s^2.
Additional information	If the underestimation of the estimated train acceleration is significant then the operational performance may be impacted (e.g., a strong underestimated train acceleration will have an impact on the distance between the foots of the emergency brake distance and emergency brake intervention curves). The value defined in the requirement need to be validated with WP4 and WP5.
Category / classification	Performance; Capacity
Traceability	UR[006]; UR[011]; subset 26 (cf. Ref [28], Section 3.13.9.3)
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

Req ID	SpecSysReq[014]
Requirement	The absolute error of the estimated train acceleration shall not exceed 0.05 m/s2 for at least 95% of the cases.
Additional information	Estimated acceleration can be used by the ATO to fine tune driving automation. Estimated acceleration can be also used to save energy by fine tuning of speed, acceleration, and braking.
Category / classification	Performance
Traceability	UR[006]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

7.3.3 1D acceleration safety requirements

Req ID	SpecSysReq[015]
Requirement	The train true acceleration shall be included in the LOC-OB computed confidence interval toward the estimated train acceleration within the most constraining user exported THR.
Additional information	The ATP will define the braking curves considering the worst cases possible (max safe acceleration, min safe acceleration). Subset 26 (cf. Ref [28]) identify a need for acceleration to derive the EBI from the EBD. THR values will be defined in the scope of WP3. Refer to Section 2.4.
Category / classification	RAMSS
Traceability	UR[024]; UR[025]
Acceptance Method	Analysis; Test; Verification
Safety assumption	Related to safety

7.4 3D localisation requirements

7.4.1 3D localisation dataset

Data	Unit / resolution	Range	Safety assumption	Default invalid value
3D Position: latitude	Degree | 1E-7°	[-900 000 000; +900 000 000]	Not safety related	+900 000 001
3D Position: longitude	Degree | 1E-7°	[-1 800 000 000; +1 800 000 000]	Not safety related	+1 800 000 001
3D Position: Altitude	Cm (0.01m) / 1 cm	[-50000; +800000]	Not safety related	+800001
3D Position uncertainty		Covariance matrix of the 3-axis coordinates	Not safety related	0 on each value
Coordinate system	N/A	ETRS89	Not safety related	ETRS89
Validity timestamp	Depending on the selected technique	Depending on the selected technique	Safety related (safe time management)	Depending on the selected technique

Table 8 - 3D localisation dataset.

Req ID	SpecSysReq[016]
Requirement	The 3D train position dataset provided by LOC-OB shall include: - 3D Position - 3D Position uncertainty - Coordinate reference system - Validity timestamp
Additional information	3D Position: 3-axis coordinates of the bogie pin. These coordinates shall cover a point on track. (Refer to the 3D reference frame in the definitions). 3D Position uncertainty: Covariance matrix of the 3-axis coordinates, from which, among other things, the standard deviation of the 3D position can be determined. Coordinate system: Reference coordinate system used to provide 3D position. (ETRS89). Validity timestamp: Time stamping of the output, i.e., the time when the localisation information was valid.
Category / classification	Functional
Traceability	UR[002]; SF-003
Acceptance Method	Analysis; Test
Safety assumption	Not safety related

7.4.2 3D localisation performance requirements

Req ID	SpecSysReq[017]
Requirement	The absolute error of the estimated 3D position shall not exceed 1,25 m for at least 95% of the cases.
Additional information	2 sigma accuracy may be used for gaussian algorithms. To be noticed that the need and the performance objective are not agreed by all partners and need and may be called into question.
Category / classification	Performance
Traceability	UR[006]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

7.5 3D velocity dataset requirements

7.5.1 3D velocity dataset

Data	Unit / resolution	Range	Safety assumption	Default invalid value
3D Velocity: X axis	0.1 m/s | 0.1 m/s	[-1700;1699]	Not safety related	1700
3D Velocity: Y axis	0.1 m/s | 0.1 m/s	[-1700;1699]	Not safety related	1700
3D Velocity: Z axis	0.1 m/s | 0.1 m/s	[-1700;1699]	Not safety related	1700
3D Velocity uncertainty		Covariance matrix of the 3-axis coordinates	Not safety related	0 on each value
Validity timestamp	Depending on the selected technique	Depending on the selected technique	Safety related (safe time management)	Depending on the selected technique

Table 9 - 3D velocity dataset.

Req ID	SpecSysReq[018]
Requirement	The 3D train velocity dataset provided by LOC-OB shall include: - 3D Velocity - 3D Velocity uncertainty - Validity timestamp
Additional information	3D Velocity: Value given for the different axes related to the bogie pin. Output related to the 3D reference frame (refer to definitions). 3D Velocity uncertainty: Covariance matrix of the velocity value per axis, from which, among other things, the standard deviation of the 3D velocity can be determined. Validity timestamp: Time stamping of the output, i.e., the time when the localisation information was valid.
Category / classification	Functional
Traceability	UR[002]; SF-005
Acceptance Method	Analysis; Test
Safety assumption	Not safety related

7.5.2 3D velocity performance requirements

Req ID	SpecSysReq[019]
Requirement	The absolute error of the estimated 3D train velocity shall not exceed 2 km/h on each axis of the 3D reference frame (refer to definitions) for at least 95% of the cases.
Additional information	2 sigma accuracy may be used for gaussian algorithms.
Category / classification	Performance
Traceability	UR[006]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

7.6 3D acceleration requirements

7.6.1 3D acceleration dataset

Data	Unit / resolution	Range	Safety assumption	Default invalid value
3D Acceleration: X axis	0.01 m/s2 | 0.01 m/s2	[-1000;1000]	Not safety related	1001
3D Acceleration: Y axis	0.01 m/s2 | 0.01 m/s2	[-1000;1000]	Not safety related	1001
3D Acceleration: Z axis	0.01 m/s2 | 0.01 m/s2	[-1000;1000]	Not safety related	1001
3D Acceleration uncertainty		Covariance matrix of the 3-axis coordinates	Not safety related	0 on each value
Validity timestamp	Depending on the selected technique	Depending on the selected technique	Safety related (safe time management)	Depending on the selected technique

Table 10 - 3D acceleration dataset.

Req ID	SpecSysReq[020]
Requirement	The 3D train acceleration dataset provided by LOC-OB shall include: - 3D Acceleration - 3D Acceleration uncertainty - Validity timestamp
Additional information	3D Acceleration: Value given for the different axes in reference to the 3D reference frame (refer to definitions). 3D Acceleration uncertainty: Covariance matrix of the acceleration value per axis, from which, among other things, the standard deviation of the 3D acceleration can be determined. Validity timestamp: Time stamping of the output, i.e., the time when the localisation information was valid.
Category / classification	Functional
Traceability	UR[002]; SF-006
Acceptance Method	Analysis; Test
Safety assumption	Not safety related

7.6.2 3D acceleration performance requirements

Req ID	SpecSysReq[021]
Requirement	The absolute error of the estimated 3D train acceleration shall not exceed 0.05 m/s^2 on each axis in the 3D reference frame (refer to definitions) for at least 95% of the cases.
Additional information	2 sigma accuracy may be used for gaussian algorithms. To be noticed that the need and the performance objective are not agreed by all partners and need and may be called into question.
Category / classification	Performance
Traceability	UR[006]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

7.7 Attitude (rotational angles)

7.7.1 Attitude (rotational angles) dataset

Data	Unit / resolution	Range	Safety assumption	Default invalid value
Yaw	Degree | 1E-4°	[0-360°]	Not safety related	0°
Pitch	Degree | 1E-4°	[0-360°]	Not safety related	0°
Roll	Degree | 1E-4°	[0-360°]	Not safety related	0°
Attitude uncertainty		Covariance matrix of the 3-axis coordinates	Not safety related	0 on each value
Yaw angular rate	Degree/s | 1E-4°/s	[TBM -TBM]	Not safety related	0
Pitch angular rate	Degree/s | 1E-4°/s	[TBM -TBM]	Not safety related	0
Roll angular rate roll	Degree/s | 1E-4°/s	[TBM -TBM]	Not safety related	0
Angular rate uncertainty		Covariance matrix of the 3-axis coordinates	Not safety related	0 on each value
Validity timestamp	Depending on the selected technique	Depending on the selected technique	Safety related (safe time management)	Depending on the selected technique

Table 11 - Attitude dataset.

Req ID	SpecSysReq[022]
Requirement	The train attitude (rotational angles) dataset provided by LOC-OB shall include: - Attitude - Attitude uncertainty - Angular rate - Angular rate uncertainty - Validity timestamp
Additional information	Attitude: Rotational angles (yaw pitch and roll) between train front reference frame {t} and navigation reference frame {n}. (cf. Definitions in glossary). Attitude uncertainty: Covariance matrix of the rotational angles, from which, among other things, the standard deviation of the rotational angles can be determined. Angular rate: Rate of change of rotational angles (yaw, pitch, roll) related to the position where sensors providing the information are installed. Angular rate uncertainty: Covariance matrix of the angular rate of rotational angles, from which, among other things, the standard deviation of the rate of change of rotational angles can be determined. Validity timestamp: Time stamping of the output, i.e., the time when the localisation information was valid.
Category / classification	Functional
Traceability	UR[001]; UR[003]; SF-007
Acceptance Method	Analysis; Test
Safety assumption	Not safety related

7.7.2 Attitude (rotational angles) performance requirement

Req ID	SpecSysReq[023]
Requirement	The absolute error of the estimated attitude (rotational angles) shall not exceed 0,1° for yaw, and 0,5° for pitch and roll for at least 95% of the cases.
Additional information	Perception does need precise attitude values to achieve the awaited objectives. 2 sigma accuracy may be used for gaussian algorithms.
Category / classification	Performance
Traceability	UR[006]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

7.8 Estimated Distance Travelled

7.8.1 Estimated Distance Travelled dataset

Data	Unit / resolution	Range	Safety assumption	Default invalid value
Estimated distance travelled	cm / 1 cm	[-4 294 967 294; 4 294 967 294]	Safety related (used to define the max/min train safe front end)	4 294 967 295
Estimated distance max	cm / 1 cm	[-4 294 967 294; 4 294 967 294]	Safety related	4 294 967 295
Estimated distance min	cm / 1 cm	[-4 294 967 294; 4 294 967 294]	Safety related	4 294 967 295
Estimated train speed	0.1 km/h | 0.1 km/h	[0;6000]	Safety related (used to define the max safe speed)	6001
Maximum train speed	0.1 km/h | 0.1 km/h	[0;6000]	Safety related	6001
Minimum train speed	0.1 km/h | 0.1 km/h	[0;6000]	Safety related	6001
Validity timestamp	Depending on the selected technique	Depending on the selected technique	Safety related (safe time management)	Depending on the selected technique

Table 12 - Estimated Distance Travelled.

Req ID	SpecSysReq[024]
Requirement	The dataset toward estimated distance travelled provided by LOC-OB shall include: - Estimated distance travelled - Estimated distance max - Estimated distance min - Validity timestamp
Additional information	The dataset toward estimated distance travelled follow the main principles of Ref [75] (Section 12.3) to ease backward compatibility. Estimated distance travelled: Distance along the track travelled since LOC-OB was powered on. A positive movement direction is defined as a movement in the forward direction in relation to cab A and is indicated with an increasing distance value. A negative movement direction is defined as a movement in the backward direction in relation to cab A and is indicated with a decreasing distance value. Comparable to D_Est. Estimated distance max: The highest value of the vehicle with all over- and under-reading amounts accumulated since the last power-on of LOC-OB. Comparable to D_Max. Estimated distance min: The lowest value of the vehicle with all over- and under-reading amounts accumulated since the last power-on of LOC-OB. Comparable to D_Min. Validity timestamp: Time stamping of the output, i.e., the time when the localisation information was valid.
Category / classification	Functional
Traceability	UR[005]; UR[019]; SF-008;
Acceptance Method	Analysis; Test
Safety assumption	Refer the dataset definition table

8 LOC-OB Operational requirements

Req ID	SpecSysReq[025]
Requirement	Only if safety is not to be compromised, LOC-OB shall not provide a sudden variation of the position and the speed confidence intervals that leads to brake intervention or trip (TR) mode. The increase of the confidence interval shall allow the train to adapt its behaviour to avoid emergency braking.
Additional information	Three use cases are identified: • In the case the sudden increase of the train front end position confidence interval is greater than the distance travelled, the train minimum safe rear end can be seen as going backwards. Therefore, in moving block area, the following train can then trigger brake intervention or trip (TR) mode if the two trains are close to each other. • In the case the sudden increase of the train front end position underestimation is larger than the distance to a target (EOA, speed decrease …), the train can trigger brake intervention. • In the case the sudden increase of the speed underestimation is larger than the margin to the speed curve, the train can trigger brake intervention or trip (TR) mode instead of adapting its speed.
Category / classification	Functional
Traceability	UR[009]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

9 LOC-OB Start of Mission requirements

Req ID	SpecSysReq[027]
Requirement	LOC-OB, from the train power on, shall initialise itself and provide the outputs with no human supervision.
Additional information	refer to D2.2 (cf. Ref [2], Section 2.2.2)
Category / classification	Functional
Traceability	UR[004]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

Req ID	SpecSysReq[028]
Requirement	After being powered up and its initialisation stage ended, LOC-OB shall provide data continuously.
Additional information	LOC-OB is a data provider. User's application shall receive updated data continuously with regard to SpecSysReq[033].
Category / classification	Functional; Performance
Traceability	UR[007]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

Req ID	SpecSysReq[029]
Requirement	After the LOC-OB is powered-on, it shall fulfil entire operational capability in less than 1 minute when initial position is valid under the following conditions: 1. Initial position is known (e.g., last known position is saved before LOC-OB is switched-off). 2. Track edge id is known (e.g., last track edge id is saved before LOC-OB is switched-off). 3. Cold Movement Detection (CMD) doesn't indicate a train movement while the train has been powered off.
Additional information	Refer to D2.2 (cf. Ref [2], Section 4.1.5, Section 4.6.1 & Section 4.6.2)
Category / classification	Performance
Traceability	UR[004]; D2.2 (cf. Ref [2], Section 4.1.5, Section 4.6.1 & Section 4.6.2)
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

Req ID	SpecSysReq[030]
Requirement	After the LOC-OB is powered-on, it shall fulfil entire operational capability in less than 10 minutes when initial position is not valid under any of the following conditions: 4. Initial position is unknown (e.g., last known position is not saved before LOC-OB is switched-off). 5. Track edge id is unknown (e.g., last track edge id is not saved before LOC-OB is switched-off). 6. CMD indicates a train movement during the train is powered off.
Additional information	Refer to D2.2 (cf. Ref [2], Section 4.1.5, Section 4.6.1 & Section 4.6.2)
Category / classification	Performance
Traceability	UR[004]; D2.2 (cf. Ref [2], Section 4.1.5, Section 4.6.1 & Section 4.6.2)
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

Req ID	SpecSysReq[031]
Requirement	In case the LOC-OB cannot reach full operational capability after the system is powered on (e.g., Unknown track segment / track edge), estimated speed and travelled distance since the LOC-OB is powered on shall always be provided.
Additional information	Refer to D2.2 (cf. Ref [2], Section 4.1.5, Section 4.6.1 & Section 4.6.2)
Category / classification	Performance
Traceability	UR[005]; D2.2 (cf. Ref [2], Section 4.1.5, Section 4.6.1 & Section 4.6.2)
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

10 LOC-OB time management requirements

Req ID	SpecSysReq[032]
Requirement	LOC-OB dataset time validity shall not exceed 200 ms when transferred to users.
Additional information	Time validity shall be understood as the dataset define a value corresponding to a state not older than 200 ms. Sensors delays, time to process the fusion algorithms etc shall be considered. Present day odometry time validity usually goes from 200 ms to 500 ms.
Category / classification	Performance
Traceability	UR[007]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

Req ID	SpecSysReq[033]
Requirement	LOC-OB shall provide the processed dataset with a frequency at least equal to 10Hz.
Additional information	Present day EVC time cycle usually goes from 200 ms to 500 ms. Sending a data every 100 ms is a compromise to ensure compatibility with the ATP. To be noticed that some new users as ATP and perception may request higher frequencies.
Category / classification	Performance
Traceability	UR[007]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

Req ID	SpecSysReq[034]
Requirement	LOC-OB shall embed a safe and secure mechanism to detect delays and time incoherencies within the most constraining user exported THR.
Additional information	Undetected offsets or clock drift on interfaces can lead to safety issues.
Category / classification	RAMSS
Traceability	UR[007]; SF-002
Acceptance Method	Analysis; Test
Safety assumption	Related to safety.

11 LOC-OB interface requirements

This section refers to the supporting information that may be used by LOC-OB to achieve the performance and safety requirements and includes major uncertainties. Refer to Section 3.4.5 for more information.

11.1 Exchange mechanism

Req ID	SpecSysReq[035]
Requirement	LOC-OB, user equipment and provider equipment shall use data exchange mechanisms in accordance with the safety, security and interoperability requirements.
Additional information	Most of the interfaces between LOC-OB and provider/user will be defined in future relevant standards. Supplier specific mechanisms shall be avoided. If data is transferred through a communication interface, EN50159 (cf. Ref [74]) shall apply. To be noticed that Subset 147 will define the standard for the network technology being used for the on-board CCS subsystem.
Category / classification	RAMSS
Traceability	UR[015]
Acceptance Method	Analysis; Test
Safety assumption	Related to safety

11.2 LOC-OB providing interface

Req ID	SpecSysReq[036]
Requirement	LOC-OB shall provide its dataset in compliance with the future TSI through the SCI - Vehicle Locator (SCI-VL) interface.
Additional information	
Category / classification	Compatibility; Modularity
Traceability	SF-001 to SF-008
Acceptance Method	Analysis
Safety assumption	Not related to safety

11.3 Digital Map

Req ID	SpecSysReq[037]
Requirement	If needed, LOC-OB shall acquire the Digital Map in accordance with the future TSI through the SCI - Map Repository On-Board (SCI-REP-OB) interface.
Additional information	The Digital Map will be a common source for several users. The future TSI will define standard interfaces toward the Digital Map (including the interface between trackside and on-board as well as between different on-board users). For mor detail, refer to D2.3 (cf. Ref [3], Section 6.2.1). Refer to §3.4.5 concerning the conditional need of this information.
Category / classification	Functional; Compatibility; Modularity
Traceability	UR[015]; SF-101
Acceptance Method	Analysis
Safety assumption	Not related to safety

11.4 Train Routing Information

Req ID	SpecSysReq[038]
Requirement	If available and needed by LOC-OB, LOC-OB shall acquire the train routing information (Movement authority, journey profile or switch information etc) in accordance to the future TSI through the SCI - Route Control (SCI-RC) interface.
Additional information	This information may be useful to fetch the required map data for the train path ahead and to validate the determined position by the LOC-OB against track selectivity. (To be confirmed by design teams and RAMS teams) Train routing information must be understood as the expected geographical path the train may follow based on the current train position and the switch point status and assuming the train is running in forward direction. Today's ETCS MA specifies a distance (in meters) from a fixed, unique and track selective reference location (= BG ID) up to which distance can be driven from this reference location. Refer to §3.4.5 concerning the conditional need of this information.
Category / classification	Functional; Compatibility; Modularity
Traceability	UR[015]; SF-102
Acceptance Method	Analysis
Safety assumption	Related to safety

11.5 Augmentation data

Req ID	SpecSysReq[039]
Requirement	If available and needed, LOC-OB shall comply with the future TSI concerning the use the Augmentation Data (definition of the dataset and exchange mechanism) through the SCI - Augmentation (SCI-AUG) interface.
Additional information	Augmentation data must be understood as complementary data that can optimise the sensors acquisition, for example: - GNSS augmentation as EGNOS. - Sensitive areas for GNSS (tunnels, multipath). - Information about the track conditions that can be used in addition to the wheel encoder (rail friction coefficient). Augmentation data is defined and provided by the Infrastructure Manager (IM). Refer to §3.4.5 concerning the conditional need of this information.
	Compatibility; Modularity
Traceability	UR[015]; SF-103
Acceptance Method	Analysis
Safety assumption	Not related to safety

11.6 Train integrity status

Req ID	SpecSysReq[040]
Requirement	If available and needed by LOC-OB, LOC-OB shall comply with the future TSI concerning the use of Train integrity status. (Definition of the dataset and exchange mechanism) through the SCI - Train Control Management System (SCI-TCMS) interface.
Additional information	This requirement is under discussion and not agreed by all partners. This requirement is only valid if the determination of the train front end is part of LOC-OB. (refer to Section 3.4.3) Refer to §3.4.5 concerning the conditional need of this information.
Category / classification	Compatibility; Modularity
Traceability	UR[015]; SF-104
Acceptance Method	Analysis
Safety assumption	Not related to safety

11.7 Static Train Configuration

Req ID	SpecSysReq[041]
Requirement	If existing, LOC-OB shall acquire the train static configuration from the common on-board Configuration Data Storage (CDS) component through the SCI - Configuration Data Storage (SCI-CDS) interface. Otherwise, specific static configuration information shall be managed as an internal component of LOC-OB.
Additional information	Static train configuration may include sensor positioning definition and other specific parameters. Static configuration data shall allow to achieve the specified performance without compromising system safety. Refer to §3.4.5 concerning the conditional need of this information.
Category / classification	Functional; Compatibility; Modularity
Traceability	UR[015]; SF-105
Acceptance Method	Analysis
Safety assumption	Not related to safety

11.8 Dynamic Train Configuration

Req ID	SpecSysReq[042]
Requirement	If needed, LOC-OB shall acquire the dynamic train configuration, as active cab, train length, rigid definition of the primary moving direction, or definition of trains front end from Train Control Management System (TCMS) through the SCI - Operational Data Storage (SCI-ODS) interface.
Additional information	The status of the driver's cabs is required by the LOC-OB to determine the train front end and the train orientation. The status of a cab could be active, open or closed following an action by the driver. Only one cab is active on the train. Refer to §3.4.5 concerning the conditional need of this information.
Category / classification	Functional; Compatibility; Modularity
Traceability	UR[015]; SF-106
Acceptance Method	Analysis
Safety assumption	Not related to safety

11.9 Eurobalise (EUB) Telegram

Req ID	SpecSysReq[043]
Requirement	If needed and available, LOC-OB shall acquire the EUB Telegram in accordance with the future TSI through the SCI - Physical ETCS Transponder Service (SCI-PETS) interface.
Additional information	This information is useful to validate the determined position by the LOC-OB against the matching physical reference position. To be noticed that no standard interface with the balise reader is yet defined. LOC-OB may acquire the balise telegram from the balise reader or from ETCS. To be noticed that Subset 130 define an exchange of balise information between ETCS-OB and ATO-OB. Refer to §3.4.5 concerning the conditional need of this information.
Category / classification	Functional; Compatibility; Modularity
Traceability	UR[015]; SF-107
Acceptance Method	Analysis
Safety assumption	Not related to safety

11.10 LRBG

Req ID	SpecSysReq[044]
Requirement	If needed, LOC-OB shall use the LRBG reference provided by ETCS through the SCI - Vehicle Supervisor (SCI-VS) interface.
Additional information	The reference location can be the ETCS LRBG. Refer to §3.4.5 concerning the conditional need of this information.
Category / classification	Functional; Compatibility; Modularity
Traceability	UR[015]; SF-108
Acceptance Method	Analysis
Safety assumption	Not related to safety

11.11 Digital Map Reference Point

Req ID	SpecSysReq[045]
Requirement	If needed, LOC-OB shall use the reference points defined in the Digital Map through the SCI-VS interface.
Additional information	The reference location can be a geographical track-bounded point. Refer to §3.4.5 concerning the conditional need of this information.
Category / classification	Functional; Compatibility; Modularity
Traceability	UR[015]; SF-108
Acceptance Method	Analysis
Safety assumption	Not related to safety

11.12 Cold movement

Req ID	SpecSysReq[046]
Requirement	If available and needed, LOC-OB shall comply with the future TSI concerning the use of Cold Movement information. (Definition of the dataset and exchange mechanism).
Additional information	A Cold Movement Detector can be standardised to be shared with several on-board users. To be noticed that a supplier specific external CMD mechanism shall be avoided. Refer to §3.4.5 concerning the conditional need of this information.
Category / classification	Functional; Compatibility; Modularity
Traceability	UR[015]; SF-109
Acceptance Method	Analysis
Safety assumption	Not related to safety

12 LOC-OB RAMS requirements

12.1 Reliability

Req ID	SpecSysReq[047]
Requirement	The LOC-OB hardware shall comply with the overall CCS-OB reliability as defined in Ref [57] Chapter 2. Minor failure: λ <1,25 10-4/h. Reduced service failure: λ < 3,3 10-6/h. Immobility failure: λ < 3,7 10-7/h.
Additional information	The mission profile for these values is defined in document Ref [57] Chapter 2. These values are defined at the overall CCS-OB system level and should be derived in accordance with a future overall CCS architecture. To be overall noticed: - A minor failure of the LOC-OB hardware could lead to a warning information requiring service intervention within a failure specific period to prevent reduced performance. - A failure of the LOC-OB hardware could lead to a reduced service with the consequence of a reduced performance. - A failure of the LOC-OB hardware could lead to immobility, for instance in case of a transition into the System Failure (SF) mode.
Category / classification	RAMSS
Traceability	UR[013]
Acceptance Method	Analysis
Safety assumption	Not related to safety

12.2 Availability

Req ID	SpecSysReq[048]
Requirement	If the confidence intervals are larger than the acceptable position confidence interval (position), maximum acceptable speed confidence interval (speed) or maximum acceptable acceleration confidence interval (acceleration) for a cumulative 60 seconds (or more) for two hours, the time is accounted in the overall LOC-OB unavailability.
Additional information	Since exceeding the confidence interval accuracy targets may not lead to any incidence on the railway operations, this requirement is to be considered as a tolerance toward the performance requirements.
Category / classification	RAMSS
Traceability	UR[013]
Acceptance Method	Analysis
Safety assumption	Not related to safety

Req ID	SpecSysReq[072]
Requirement	If the LOC-OB is not providing data at the defined rate, the LOC-OB is considered as unavailable during this time.
Additional information	If the users are not receiving the data within the defied time out, user my enter in safe procedures.
Category / classification	RAMSS
Traceability	UR[013]
Acceptance Method	Analysis
Safety assumption	Not related to safety

Req ID	SpecSysReq[049]
Requirement	The LOC-OB shall have an overall availability of 99,998% during operation.
Additional information	Refer to the availability target analysis from document 22E126 (cf. Ref [17]). To be notice that the SpecSysReq[048] affect the overall availability defined in this requirement.
Category / classification	RAMSS
Traceability	UR[013]
Acceptance Method	Analysis
Safety assumption	Not related to safety

12.3 Maintainability

Req ID	SpecSysReq[050]
Requirement	LOC-OB shall manage useful data toward maintenance in an internal log memory and through the SCI - Monitoring, Diagnostic, Configuration, Maintenance On-Board (SCI-MDCM-OB) interface.
Additional information	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.
Category / classification	Functional
Traceability	SF-203
Acceptance Method	Analysis
Safety assumption	Not related to safety

Req ID	SpecSysReq[067]
Requirement	LOC-OB shall log overall availability issues and specific relevant events as timestamped events.
Additional information	Availability issues are linked to the non-respect of: -SpecSysReq[003] -SpecSysReq[004] -SpecSysReq[009] -SpecSysReq[013] To achieve requirement: -SpecSysReq[050] Specific relevant events are to be determined and includes unusual activities of every sensor class.
Category / classification	Functional
Traceability	SF-203
Acceptance Method	Analysis
Safety assumption	Not related to safety

Req ID	SpecSysReq[051]
Requirement	LOC-OB shall be designed as a generic application (cf. EN50126, Ref [5] and Ref [6]).
Additional information	As a generic application, LOC-OB will ease its integration in the future CCS-OB and will ease technologic updates.
Category / classification	RAMSS
Traceability	UR[013]; UR[014]
Acceptance Method	Analysis
Safety assumption	Not related to safety

Req ID	SpecSysReq[052]
Requirement	LOC-OB shall be designed to ease software updates (including security patches) by avoiding complex workshop procedures requiring bench testing.
Additional information	The ability of updating the LOC-OB software is essential. To minimize maintenance cost, the default update deployment mechanism shall be remotely (e.g., over-the-air) with no physical presence of any maintenance personnel on site (e.g., on the train).
Category / classification	RAMSS
Traceability	UR[013]; UR[026]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety.

Req ID	SpecSysReq[054]
Requirement	The LOC-OB's design and maintenance concept shall meet a Mean Time To Restore (MTTR) ≤ 1h.
Additional information	The MTTR is defined in EN50126 (cf. Ref [5] and Ref [6]). The time elapsed to restore starts when the failure occurs and ends when the LOC-OB is ready for service. The administrative delay, Logistic Delay shall not be counted into the MTTR.
Category / classification	RAMSS
Traceability	UR[013]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

Req ID	SpecSysReq[055]
Requirement	Preventive maintenance or periodic sensor calibration period of the overall LOC-OB shall exceed 2 years.
Additional information	If possible, preventive maintenance or periodic sensor calibration period shall be avoided if immobilisation of the train and staff intervention is needed. Also, if several sensors are used, the preventive maintenance plan shall factorise their preventive maintenance or calibration.
Category / classification	RAMSS
Traceability	UR[013]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

12.4 Safety

Req ID	SpecSysReq[056]
Requirement	The safety of the LOC-OB shall be ensured and demonstrated according to the Common Safety Methods (cf. Ref [34]) and the EN 50126 standard (cf. Ref [5] and Ref [6]).
Additional information	The LOC-OB is a safety related constituent, Common Safety Methods and the EN 50126 standard (cf. Ref [5] and Ref [6]) shall apply.
Category / classification	RAMSS
Traceability	UR[020]
Acceptance Method	Analysis
Safety assumption	Related to safety

Req ID	SpecSysReq[057]
Requirement	If needed, calibration procedure(s) shall fulfil with the safety requirement.
Additional information	Calibration may impact safety. For example, using one sensor to calibrate another one may induce a common mode failure.
Category / classification	RAMSS
Traceability	UR[025]
Acceptance Method	Analysis; Test
Safety assumption	Related to safety

Req ID	SpecSysReq[066]
Requirement	If LOC-OB cannot guarantee safe operation due to internal safety process faults (for ex: safe computer failure): LOC-OB shall not provide any information to the users.
Additional information	Refer to Section 3.6.5
Category / classification	RAMSS
Traceability	UR[025]
Acceptance Method	Analysis; Test
Safety assumption	Related to safety

Req ID	SpecSysReq[068]
Requirement	If LOC-OB is unable to produce a data within the awaited THR due to insufficient information to guarantee safe results (one or several sensor failure or unavailability), LOC-OB shall provide a default invalid value for the data concerned and shall provide all other data as specified.
Additional information	Refer to Section 3.6.5
Category / classification	RAMSS
Traceability	UR[025]
Acceptance Method	Analysis; Test
Safety assumption	Related to safety

12.5 Security

Req ID	SpecSysReq[058]
Requirement	LOC-OB shall fulfil requirements and recommendations for cybersecurity as specified in CLC/TS 50701 (cf. Ref [36]) with the purpose to demonstrate that the system is up to date from a cybersecurity perspective and that it meets and maintains the target level of security for the entire system life cycle.
Rationale	Cybersecurity threats shall be considered and mitigation measures shall be provided. Since LOC-OB users are numerous and have different levels of criticality (ATP to infotainment), special attention must be paid to secure and non-secure digital interfaces. LOC-OB shall be accessible according to users and roles.
Category / classification	RAMSS
Traceability	UR[026]
Acceptance Method	Analysis; Test
Safety assumption	Related to safety

13 LOC-OB Environmental requirements

13.1 97s0665

Req ID	SpecSysReq[059]
Requirement	LOC-OB components shall comply with applicable environmental standards.
Additional information	Ref [37] can be useful as a guidance. Ref [37] describes the minimum system specific environmental requirements for the operation of ERTMS track side and train mounted equipment toward the following topics: · Ambient temperature · Solar Radiation · Humidity · Wind and pressure pulses · Altitude · Water and precipitation · Pollutants and contaminants · Mechanical (shock and vibration) · Electrical (power supplies) · Electromagnetic Compatibility · Ergonomics Ref [37] point an exhaustive list of standards such as Ref [65] or Ref [38] Chapter 4. Detailed requirement and acceptance criteria toward each component of the LOC-OB shall be defined for each solution depending on the conception choices as sensors positioning, use of safe computer, etc.
Category / classification	Environmental
Traceability	UR[016]; UR[018]
Acceptance Method	Analysis; Test
Safety assumption	Not related to safety

13.2 Fire protection

Req ID	SpecSysReq[060]
Requirement	LOC-OB components shall comply with the Ref [42] standard: Railway applications - Fire protection on railway vehicles. The latest edition shall apply.
Additional information	
Category / classification	Environmental
Traceability	UR[016]
Acceptance Method	Analysis
Safety assumption	Related to safety

13.3 REACH / RoHs

Req ID	SpecSysReq[061]
Requirement	LOC-OB components shall comply with the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) and RoHS2 directives. The latest edition shall apply.
Additional information	The directives referred are: ROHS2 directive: 2011/65/UE 8 June 2011 REACH directive: (CE) no 1907/2006
Category / classification	Environmental
Traceability	UR[016]
Acceptance Method	Analysis
Safety assumption	Related to safety

13.4 Specific environmental cases assumptions

Req ID	SpecSysReq[071]
Requirement	LOC-OB shall take into consideration each sensor specific challenging environmental condition and each sensor failure mode to perform in all situations not considered as incredible or Improbable.
Additional information	Each sensor has week point that need to be considered in the LOC-OB architecture. The design team in charge of the definition of the LOC-OB set of sensors. The V&V team will define the challenging scenarios with regard to the LOC-OB set of sensors. For illustration purpose, GNSS technology is sensitive to signal obstructions (tunnels) and wheel sensors are sensitive to slip and slide effects.
Category / classification	Environmental
Traceability	UR[018]
Acceptance Method	Analysis; Test
Safety assumption	Related to safety

14 Conclusions

The requirements defined enable the launch of a proof-of-concept campaign, including objectives in line with current knowledge, particularly in terms of performance, while providing certain assumptions concerning the safety of the localisation data.

The confrontation of this set of requirements within WP4 and WP5 will provide an important feedback on the feasibility of a safe localisation equipment using GNSS/SBAS and IMU as main sensors.

WP6 will then provide a gap analysis that will be considered in other European initiative, as R2DATO, up to the definition of TSI.

Although completeness of requirements is a primary objective, the fact that the project is a research project means that assumptions were made and some results from other works package or standardisation teams are not yet produced.

Several uncertainties remain and may have a major impact on the requirements as:

- Unstable user needs (for example perception or ATO).
- Undefined (and unagreed) embedded CCS architecture.
- Undefined (and unagreed) functional allocation between embedded CCS components.
- Cross-disciplinary work in progress on the definition of the Digital map (definition and handling).
- Availability and definition of supporting information provided to the localisation.
- Real need from the localisation in term supporting information.
- Technology readiness of the sensors and techniques used to achieve the performance requested within the safety objectives.

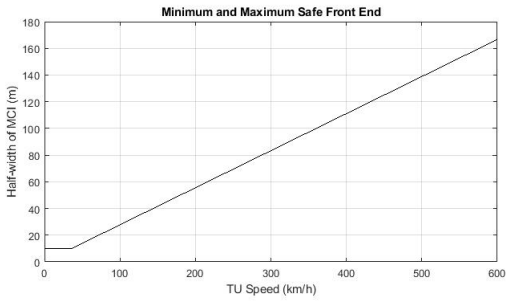
It is not expected that the identified uncertainties are going to impact the CLUG 2.0 demonstration. These uncertainties are going to be considered in other projects as R2DATO.

15 Appendix A: CLUG (1) requirements

15.1 Functional requirements (inc. performance requirements)

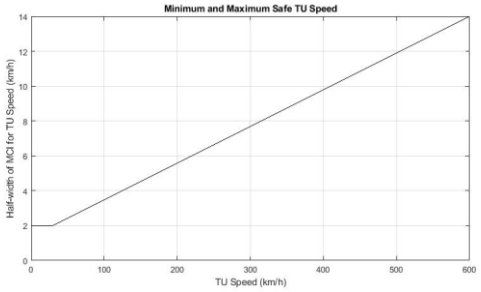
15.1.1 Safety-Related Functions

15.1.1.1 Minimum and Maximum Safe Front End Position

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-01'	Trace to CLUG 2.0 system requirement	Comment
SR_R01	The Train Localisation On-Board Unit (TLOBU) shall provide: • Estimated Front End (estFE) Position • Minimum Safe Front End (minSFE) and Maximum Safe Front End (maxSFE)	Partially covered by SpecSysReq[001]	CLUG 2.0 follow the definitions of the subset 026. Under and over estimation is provided instead of the minimum and maximum train front end.
SR_R04	The half-width of the Mission Confidence Interval for Operations (MCI) is 10 m for speeds below 36 km/h then the distance run in 1 second at speeds higher than 36 km/h up to 600 km/h.  **Half-width of MCI for Min and Max Safe Front End**	partially covered by SpecSysReq[003] SpecSysReq[004]	CLUG 2.0 does not refer to a speed accuracy model but refer to a two static values accuracy model.
SR_R09	The resolution for estFE, minSFE and maxSFE shall be 0.1 m.	Covered by SpecSysReq[001]	
SR_R10	The TLOBU shall provide the outputs specified in this function every 200 ms.	Covered by SpecSysReq[032]	CLUG 2.0 define a 10hz frequency.

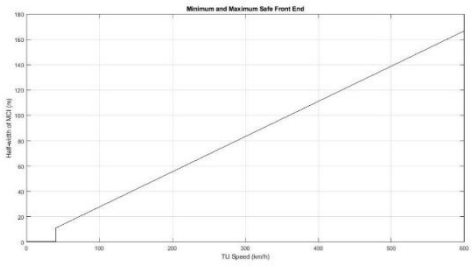
SR_R100	The outputs of this function shall be estimated less than 200 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	CLUG 2.0 define a 100ms period.
SR_R101	The outputs of this function shall meet the safety targets defined in D2.4 'Preliminary Hazard Analysis': • Tolerable Functional Failure Rate (TFFR≤ 5E-10/h • Max Safe Data Transmission (SDT = 24h • No single failure • SIL4	Not covered	CLUG 2.0 does not define quantitative values toward safety requirements.
SR_R142	In case compliance to SR_R04 cannot be accomplished within the required safety requirement defined in SR_R101, the minSFE and maxSFE output shall as a conservative estimate comply to the safety requirement defined in SR_R101.	Covered by SpecSysReq[066]	Simplified in CLUG 2.0. Whatever the case, safety shall be guaranteed.
INFO	SR_142 means that the true position shall always be bound by the confidence interval (i.e., minSFE and maxSFE). And in challenging conditions where the accuracy requirements might not be fulfilled, the Min and Max Safe Front End interval shall continue to ensure compliance to the safety requirement SR_R101.	Covered by SpecSysReq[007]	Simplified in CLUG 2.0. Whatever the case, safety shall be guaranteed.
INFO	The minSFE and maxSFE shall be estimated as an interval around the reported position (estFE), within which the front end of the train is located.	Covered by SpecSysReq[001]	

15.1.1.2 Safe Train Unit (TU) Speed

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-04'	Trace to CLUG 2.0 system requirement	Comment
SR_R11	The TLOBU shall provide: • Estimated TU Speed • Minimum and Maximum TU Speed	Covered by SpecSysReq[008]	CLUG 2.0 follow the definitions of the subset 026. Under and over estimation is provided instead of the minimum and maximum TU speed.
SR_R12	The half-width of the MCI is ± 2 km/h for speed lower than 30 km/h, then increasing linearly up to ± 14 km/h at 600 km/h.  **Half-width of MCI for Min and Max Safe TU Speed**	Covered by SpecSysReq[009]	CLUG 2.0 define 500km/h as maximum speed.
SR_R14	The resolution for TU speed shall be 0.1 m/s.	Covered by SpecSysReq[008]	
SR_R15	The TLOBU shall provide the outputs specified in this function every 200 ms.	Covered by SpecSysReq[032]	CLUG 2.0 define a 10hz frequency.
SR_R108	The outputs of the function shall be estimated less than 200 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	CLUG 2.0 define a 100ms period.
SR_R109	The outputs of this function shall meet the safety targets defined in D2.4 'Preliminary Hazard Analysis': • TFFR ≤ 5E-10/h • Max SDT = 24h • No single failure • SIL4	Not covered	CLUG 2.0 D2.4 does not define quantitative values toward safety requirements.
SR_R143	In case compliance to SR_R12 cannot be accomplished within the required safety requirement defined in SR_R109, the Minimum	Covered by SpecSysReq[066]	Simplified in CLUG 2.0. Whatever the

	and Maximum TU Speed output shall as a conservative estimate comply to the safety requirement defined in SR_R109.		case, safety shall be guaranteed.
INFO	SR_143 means that the true speed shall always be bound by the confidence interval for TU Speed. And in challenging conditions where the accuracy requirements might not be fulfilled, the Min and Max Safe TU Speed interval shall continue to ensure compliance to the safety requirement SR_R109.	Covered by SpecSysReq[011]	Simplified in CLUG 2.0. Whatever the case, safety shall be guaranteed.
INFO	TU speed is always a positive value; when the TU is moving in reverse, the TU Actual Movement Direction will be 'reverse' and TU speed will therefore indicate the speed in the reverse direction.	Covered by SpecSysReq[008]	
INFO	The Minimum and Maximum Safe TU speed shall be estimated as an interval around the reported speed (Estimated TU Speed), within which the speed of the train is bound.	Covered by SpecSysReq[008]	

15.1.1.3 Minimum and Maximum Safe Accurate Front End Position

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-15'	Trace to CLUG 2.0 system requirement	Comment
SR_R102	The TLOBU shall provide: • estFE Position • minSFE and maxSFE	Not covered	CLUG 2.0 does not identify the need of a safe accurate train front end.
SR_R103	The half-width of the MCI is 0.5 m for speeds below 40 km/h then the distance run in 1 second at speeds higher than 40 km/h up to 600 km/h.  **Half-width of MCI for Min and Max Safe Accurate Front End**	Not covered	CLUG 2.0 does not identify the need of a safe accurate train front end.
SR_R104	The resolution for estFE, Safe Minimum and Maximum Front End shall be 0.1 m.	Not covered	CLUG 2.0 does not identify the need of a safe accurate

			train front end.
SR_R105	The TLOBU shall provide the outputs specified in this function every 100 ms.	Not covered	CLUG 2.0 does not identify the need of a safe accurate train front end.
SR_R106	The outputs of this function shall be estimated less than 100 ms before the beginning of the sending of the corresponding output.	Not covered	CLUG 2.0 does not identify the need of a safe accurate train front end.
SR_R107	The outputs of this function shall meet the safety targets defined in D2.4 'Preliminary Hazard Analysis': • TFFR ≤ 5E-8/h • Max SDT = 24h	Not covered	CLUG 2.0 does not identify the need of a safe accurate train front end.
SR_R144	In case compliance to SR_R103 cannot be accomplished within the required safety requirement defined in SR_R107, the minSFE and maxSFE output shall as a conservative estimate comply to the safety requirement defined in SR_R107.	Not covered	CLUG 2.0 does not identify the need of a safe accurate train front end.
INFO	SR_144 means that the true position shall always be bound by the confidence interval (i.e., minSFE and maxSFE). And in challenging conditions where the accuracy requirements might not be fulfilled, the Min and Max Safe Front End interval shall continue to ensure compliance to the safety requirement SR_R107.	Not covered	CLUG 2.0 does not identify the need of a safe accurate train front end.
INFO	The minSFE and maxSFE shall be estimated as a confidence interval around the reported position (estFE), within which the front end of the train is located.	Not covered	CLUG 2.0 does not identify the need of a safe accurate train front end.

15.1.1.4 Safe TU Along-track Acceleration

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-07'	Trace to CLUG 2.0 system requirement	Comment
SR_R16	The TLOBU shall provide: • Estimated TU Along-track acceleration • Minimum and Maximum TU Along-track acceleration	Covered by SpecSysReq[012]	CLUG 2.0 follow the definitions of the subset 026. Under and over estimation is provided instead of the minimum and maximum TU acceleration.
SR_R19	The resolution for TU along-track acceleration shall be 0.01 m/s^2.	Covered by SpecSysReq[012]	
SR_R20	The TLOBU shall provide the outputs specified in this function every 200 ms.	Covered by SpecSysReq[032]	CLUG 2.0 define a 10hz frequency.
SR_R135	The outputs of the function shall be estimated less than 200 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	CLUG 2.0 define a 100ms period.
SR_R110	The outputs of this function shall meet the safety targets defined in D2.4 'Preliminary Hazard Analysis': • TFFR ≤ 5E-10/h • Max SDT = 24h • No single failure • SIL4	Not covered	CLUG D2.4 does not define quantitative values toward safety requirements.
NOTE	No performance requirements have been specified for this function.	Not applicable	SpecSysReq[013] and SpecSysReq[014]define performance requirement toward 1D acceleration.
INFO	The Minimum and Maximum Safe TU along-track acceleration shall be estimated as an interval around the reported along-track acceleration (Estimated TU along-track acceleration), within which the along-track acceleration of the train is bound.	Covered by SpecSysReq[015]	

15.1.1.5 Track Selective Positioning

<table>
<tr><th>CLUG (1) System Requirement ID</th><th>CLUG (1) System Requirements for System Function ‘SFUNC-10’</th><th>Trace to External-User Requirement</th><th>Comment</th></tr>
<tr><td>SR_R21</td><td>The TLOBU shall provide:
TrackEdge ID
Status of track selectivity determination</td><td>Covered by SpecSysReq[001]</td><td></td></tr>
<tr><td>SR_R145</td><td>Valid outputs for the Status of track selectivity determination are as follows:
<table>
<tr><th>Valid output</th><th>Description of the output</th></tr>
<tr><td>Unknown</td><td>No TrackEdge ID can be provided by the TLOBU e.g., during start-up phase of the TLOBU.</td></tr>
<tr><td>Safe to use</td><td>TrackEdge ID output by this function complies with safety target defined in SR_R112.</td></tr>
<tr><td>Not safe to use</td><td>TrackEdge ID output by this function is unable to comply with safety target defined in SR_R112.</td></tr>
</table></td><td>Not applicable</td><td></td></tr>
<tr><td>SR_R23</td><td>The TLOBU shall provide the outputs specified in this function every 200 ms.</td><td>Covered by SpecSysReq[032]</td><td>CLUG 2.0 define a 10hz frequency.</td></tr>
<tr><td>SR_R111</td><td>The outputs of the function shall be estimated less than 200 ms before the beginning of the sending of the corresponding output.</td><td>Covered by SpecSysReq[033]</td><td>CLUG 2.0 define a 100ms period.</td></tr>
<tr><td>SR_R112</td><td>The outputs of this function shall meet the safety targets defined in D2.4 ‘Preliminary Hazard Analysis’:
TFFR ≤ 5E-10/h
Max SDT = 24h
No single failure
SIL4</td><td>Not covered</td><td>CLUG D2.4 does not define quantitative values toward safety requirements.</td></tr>
<tr><td>NOTE</td><td>The function is expected to determine TrackEdge ID and Status only using digital maps and on-board sensor data input to this function.</td><td>Covered by SpecSysReq[001]</td><td></td></tr>
</table>

NOTE	The output "Status of the track selectivity determination" is only defined for evaluating the performance of the function in the CLUG (1) project. The safety reactions necessary when a future standalone failsafe TLOBU outputs 'Not safe to use' flag is outside the scope of CLUG (1) project.	Not applicable	Need not identified in CLUG 2.0.

15.1.1.6 Actual Movement Direction

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-13'	Trace to CLUG 2.0 system requirement	Comment
SR_R24	The TLOBU shall provide: • TU Actual Movement Direction	Covered by SpecSysReq[001]	
SR_R25	Valid outputs for the actual movement direction of the train are "nominal", "reverse" and "unknown".	Covered by SpecSysReq[001]	
SR_R26	The TLOBU shall provide the outputs specified in this function every 200 ms.	Covered by SpecSysReq[032]	CLUG 2.0 define a 10hz frequency.
SR_R113	The outputs of the function shall be estimated less than 200 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	CLUG 2.0 define a 100ms period.
SR_R114	The outputs of this function shall meet the safety targets defined in D2.4 'Preliminary Hazard Analysis': • TFFR ≤ 5E-10/h • Max SDT = 24h • No single failure • SIL4	Not covered	CLUG D2.4 does not define quantitative values toward safety requirements.

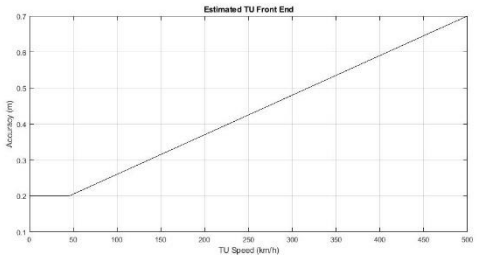
15.1.1.7 System Diagnostics

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-14'	Trace to CLUG 2.0 system requirement	Comment
SR_R146	The TLOBU shall provide a health flag with every system output.	Partially covered by SpecSysReq[066] and SpecSysReq[050]	CLUG 2.0 does not explicit the need of a health flag.
SR_R147	Valid outputs for the health flag of each function are "OK" and "NOT OK". The health flag shall be set to "OK" when the system function of the TLOBU is working as expected. The health flag shall be set to "NOT OK" when the system function of the TLOBU is not working as expected and the output shall be considered erroneous.	Not covered	CLUG 2.0 does not explicit the need of a health flag.
SR_R148	As long as the TLOBU outputs are correctly declared as invalid, the effect will be a detrimental impact on availability, not safety (D2.4 'Preliminary Hazard Analysis').	Partially covered by SpecSysReq[066] SpecSysReq[050] SpecSysReq[067]	CLUG 2.0 does not explicit the need of a health flag.

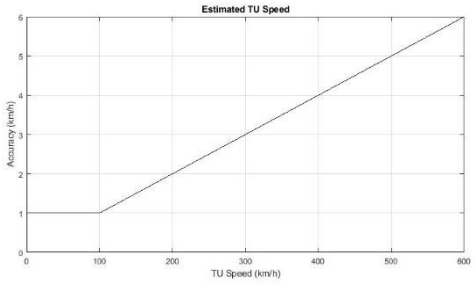
15.1.2 Non-Safety Related Functions (incl. Functions with Basic Integrity)

15.1.2.1 estFE Position

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-02'	Trace to CLUG 2.0 system requirement	Comment
SR_R27	The TLOBU shall provide: • estFE Position • Formal accuracy of the estFE Position	Covered by SpecSysReq[001]	
SR_R28	As defined in Subset-036 Section 4.2.10.3, after a balise passage, the estFE Position shall be determined at an accuracy of 0.20 m for speeds below 40 km/h, then (0.15 m + 0.0011*v) for speeds from 40 km/h until 500 km/h.	Covered by SpecSysReq[005] SpecSysReq[006]	CLUG 2.0 does not refer to a speed accuracy model but refer to a two static values accuracy model.

	 **Performance Requirement for estFE Position**		
SR_R29	As defined in Subset-036 Section 4.2.10.3, the accuracy defined in SR_R28 shall be met for at least 99.8%.	Not covered	CLUG 2.0 does not identify an availability goal toward the 2 sigma standard deviation.
SR_R149	The outputs of this function shall meet the safety targets defined in D2.4 'Preliminary Hazard Analysis': • Basic integrity • Max SDT = 24h	Not covered	CLUG D2.4 does not define the needs toward safety requirements.
NOTE	No performance requirements have been defined for the outputs of the function when no balises are read.	Not covered	CLUG 2.0 does not identify an availability goal toward the 2 sigma standard deviation.
SR_R152	In the cases where no balises are read, the function is still expected to output the estFE Position.	Not covered	CLUG 2.0 does not identify a special case toward the non-detection of balise.
SR_R31	The resolution for estFE Position shall be 0.01 m.	Covered by SpecSysReq[001]	
SR_R32	The TLOBU shall provide the outputs specified in this function every 100 ms.	Covered by SpecSysReq[032]	
SR_R115	The outputs of the function shall be estimated less than 100 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	
INFO	A range has been not defined for estFE Position. Rationale: The range depends on the length of the TrackEdge and therefore no limits have been defined for the CLUG project.	Not covered	CLUG 2.0 does not identify a special need toward the range of the estFE.

15.1.2.2 Estimated TU Speed

CLUG- (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-05'	Trace to CLUG 2.0 system requirement	Comment
SR_R33	The TLOBU shall provide: • Estimated TU Speed • Formal accuracy of the Estimated TU Speed	Covered by SpecSysReq[008]	
SR_R34	The Estimated TU Speed shall be estimated with an accuracy of ± 1 km/h for speeds from 0 km/h to 100 km/h and ± 1% *v for speeds from 100 km/h to 600 km/h  **Performance Requirement for Estimated TU Speed**	Covered by SpecSysReq[010]	
SR_R36	The resolution for estFE Position shall be 0.01 m/s.	Covered by SpecSysReq[008]	
SR_R37	The TLOBU shall provide the outputs specified in this function every 100 ms.	Covered by SpecSysReq[032]	
SR_R116	The outputs of the function shall be estimated less than 100 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	
SR_R150	The outputs of this function shall meet the safety targets defined in D2.4 'Preliminary Hazard Analysis': • Basic integrity • Max SDT = 24h	Not covered	CLUG D2.4 does not define the needs toward safety requirements.
NOTE	NOTE: TU speed is always a positive value; when the TU is moving in reverse, the actual movement direction will be "reverse" and TU speed will therefore indicate the speed in the reverse direction.	Covered by SpecSysReq[008]	

15.1.2.3 Estimated TU Along-track Acceleration

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-08'	Trace to External-User Requirement	Comment
SR_R38	The TLOBU shall provide: • Estimated TU Along-track acceleration • Formal accuracy of the Estimated TU Along-track acceleration	Covered by SpecSysReq[012]	
SR_R41	The resolution for estFE Position shall be 0.01 m/s^2	Covered by SpecSysReq[012]	
SR_R42	The TLOBU shall provide the outputs specified in this function every 100 ms.	Covered by SpecSysReq[032]	
SR_R117	The outputs of the function shall be estimated less than 100 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	
SR_R151	The outputs of this function shall meet the safety targets defined in D2.4 'Preliminary Hazard Analysis': • Basic integrity • Max SDT = 24h	Not covered	CLUG D2.4 does not define the needs toward safety requirements.
NOTE	No Performance Requirements have been defined for Estimated TU Along-track acceleration.	Not applicable	SpecSysReq[013] and SpecSysReq[014]define performance requirement toward 1D acceleration.

15.1.2.4 Estimated TU 3D Position

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-03'	Trace to CLUG 2.0 system requirement	Comment
SR_R43	The TLOBU shall provide: • Estimated TU 3D Position • Formal accuracy of the Estimated TU 3D Position	Covered by SpecSysReq[016]	
SR_R49	The TLOBU shall provide the outputs specified in this function every 100 ms.	Covered by SpecSysReq[032]	
SR_R118	The outputs of the function shall be estimated less than 100 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	
NOTE	No Performance Requirements have been defined for Estimated TU 3D Position.		SpecSysReq[017] define performance requirement toward 3D position.

15.1.2.5 Estimated TU 3D Velocity

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-06'	Trace to CLUG 2.0 system requirement	Comment
SR_R50	The TLOBU shall provide: • Estimated TU 3D Velocity • Formal accuracy of the Estimated TU 3D Velocity	Covered by SpecSysReq[018]	
SR_R56	The TLOBU shall provide the outputs specified in this function every 100 ms.	Covered by SpecSysReq[032]	
SR_R119	The outputs of the function shall be estimated less than 100 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	
NOTE	No Performance Requirements have been defined for Estimated TU 3D Velocity.		SpecSysReq[019] define performance requirement toward 3D velocity.

15.1.2.6 Estimated TU 3D Acceleration

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-09'	Trace to CLUG 2.0 system requirement	Comment
SR_R57	The TLOBU shall provide: • Estimated TU 3D Acceleration • Formal accuracy of the Estimated TU 3D Acceleration	Covered by SpecSysReq[020]	
SR_R63	The TLOBU shall provide the outputs specified in this function every 50 ms.	Covered by SpecSysReq[032]	CLUG 2.0 define a 10hz frequency.
SR_R120	The outputs of the function shall be estimated less than 50 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	CLUG 2.0 define a 100ms period.
NOTE	No Performance Requirements have been defined for Estimated TU Acceleration.		SpecSysReq[021] define performance requirement toward 3D acceleration.

15.1.2.7 Yaw, Pitch and Roll Angles

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-16'	Trace to CLUG 2.0 system requirement	Comment
SR_R121	The TLOBU shall provide: • Estimated Yaw, Pitch and Roll Angles • Formal accuracy of the Estimated Yaw, Pitch and Roll Angles	Covered by SpecSysReq[022]	
SR_R122	The TLOBU shall provide the outputs specified in this function every 50 ms.	Covered by SpecSysReq[032]	CLUG 2.0 define a 10hz frequency.
SR_R123	The outputs of the function shall be estimated less than 50 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	CLUG 2.0 define a 100ms period.
NOTE	No Performance Requirements have been defined for Estimated Yaw, Pitch and Roll Angles.		SpecSysReq[023] define performance requirement toward attitude.

15.1.2.8 Yaw, pitch and roll rates

CLUG (1) System Requirement ID	CLUG (1) System Requirements for System Function 'SFUNC-12'	Trace to CLUG 2.0 system requirement	Comment
SR_R68	The TLOBU shall provide: • Estimated Yaw, Pitch and Roll rates • Formal accuracy of the Estimated Yaw, Pitch and Roll rates	Covered by SpecSysReq[022]	
SR_R74	The TLOBU shall provide the outputs specified in this function every 50 ms.	Covered by SpecSysReq[032]	CLUG 2.0 define a 10hz frequency.
SR_R124	The outputs of the function shall be estimated less than 50 ms before the beginning of the sending of the corresponding output.	Covered by SpecSysReq[033]	CLUG 2.0 define a 100ms period.
NOTE	No Performance Requirements have been defined for Estimated Yaw, Pitch and Roll rates.		Not covered in CLUG 2.0.

15.2 Non-functional requirements

CLUG (1) System Requirement ID	CLUG (1) Requirement	Trace to CLUG 2.0 system requirement	Comment
INFO	To reuse an existing certification based on a standard which is not prescribed, it shall be demonstrated that the alternative standard provides results that are equivalent to or better than those obtained by using the standards.	Covered by SpecSysReq[056]	CLUG D2.4 does not define requirements toward cross acceptance. SpecSysReq[056] cover the whole certification process.
INFO	The standards stated in chapter can be replaced by equivalent standards and norms.	Covered by SpecSysReq[056]	CLUG D2.4 does not define requirements toward cross acceptance. SpecSysReq[056] cover the whole certification process.
SR_R141	The categories and classes of requirements stated by the standards shall be chosen in regard to the applicability of the TLOBU and the conditions relevant to the chosen technology.	Covered by SpecSysReq[056]	CLUG D2.4 does not define requirements toward cross acceptance. SpecSysReq[056] cover the whole certification process.

15.2.1 Design and Development

CLUG (1) System Requirement ID	CLUG (1) Requirement	Trace to CLUG 2.0 system requirement	Comment
INFO	defines the methods which need to be used in order to provide software which meets the demands for safety integrity.	Covered by SpecSysReq[056]	SpecSysReq[056] cover the whole certification process without getting into detail.
SR_R77	The TLOBU shall be developed to the methods and requirements defined using the SILs defined in Chapter for each system function. For system functions requiring basic integrity as their safety target and system functions without safety integrity level requirements, level 0 shall be considered.	Covered by SpecSysReq[056]	SpecSysReq[056] cover the whole certification process without getting into detail.
INFO	defines the requirements for the approval of safety-related electronic systems in railway signalling technology.	Covered by SpecSysReq[056]	SpecSysReq[056] cover the whole certification process without getting into detail.
SR_R79	The TLOBU shall be developed to the requirements specified. A structured safety justification document, known as the Safety Case shall be included in D3.2 “RAMS Analysis Report”.	Covered by SpecSysReq[056]	SpecSysReq[056] cover the whole certification process without getting into detail.
INFO	specifies the process and the technical requirements for the development of Software for programable electronical systems in railway applications.	Covered by SpecSysReq[056]	SpecSysReq[056] cover the whole certification process without getting into detail.
SR_R81	The TLOBU shall comply to the requirements specified using the SILs defined for each system function. For system functions requiring basic integrity as their safety target and system functions without safety integrity level requirements, level 0 shall be considered.	Covered by SpecSysReq[056]	SpecSysReq[056] cover the whole certification process without getting into detail.
SR_R139	The TLOBU shall be designed according of the requirements specified in [15] .	Not covered]	Antenna requirements shall be considered taking into account the LOC-OB design.
SR_R140	The TLOBU shall be designed according of the requirements specified in [16] .	Not covered	Earthing shall be considered taking into account the LOC-OB design.

15.2.2 Start-up Time/Initialisation

CLUG (1) System Requirement ID	CLUG (1) Requirement	Trace to CLUG 2.0 system requirement	Comment
SR_R82	The TLOBU shall reach full operational capability including for safety-related applications within 600 s after powering up.	Covered by SpecSysReq [029] & [030]	
SR_R125	The TLOBU shall be able to initialize itself and provide the localisation report for safety applications also when no initial position and track ID is provided as an input.	Covered by SpecSysReq [030]	
INFO	ETCS defines the cold movement detector (CMD). When a stored position and TrackEdge ID is available, the same may be provided as an input to the TLOBU during initialization. The definition and realization of a CMD is not in the scope of CLUG (1).	SpecSysReq [029] & [030]	
INFO	In the case, the TLOBU is unable to reach full operational capability within the defined initialization period defined in SR_R82, the system shall be considered to be in degraded mode. In this case, operational measures have to be defined and taken. The definition of these measures is not in the scope of CLUG (1).	SpecSysReq [031] & [048]	

15.2.3 Reliability, Availability and Maintainability

CLUG (1) System Requirement ID	CLUG (1) Requirement	Trace to CLUG 2.0 system requirement	Comment
SR_R83	The TLOBU shall follow the reliability, availability and maintainability processes and comply to the reliability, availability and maintainability requirements specified in EN61703.	Covered by SpecSysReq[056]	SpecSysReq[056] cover the whole certification process without getting into detail.
INFO	The targets defined in this section apply to a single train unit assuming operation on mainline and absence of wayside equipment.		
SR_R126	Availability Target The TLOBU shall meet a (asymptotical) mean intrinsic availability (Ai) ≥ 99,998% The intrinsic availability is defined as availability provided by the design under ideal conditions of operation and maintenance (delays associated with maintenance, such as logistic	Covered by SpecSysReq[049]	

	and administrative delays, are excluded). The (asymptotical) mean availability is defined in [68] EN 61703.		
SR_R127	Reliability Target – "Immobilizing" category This category applies to defects/failures of TLOBU that require the train to stop immediately and cannot continue with no evident or built-in mitigation possible. Defect/failures requiring the train to terminate service or prohibiting service start are also part of this category. The TLOBU shall meet a total rate target ≤ 1.0E-6/h for all failures (incl. combined ones) leading to the "immobilizing" category.	Covered by SpecSysReq[047]	
SR_R128	Reliability Target – "Operation impacting" category (1) This category applies to defects/failures of TLOBU that cause an additional delay ≥ 60 s to the train service (the train can continue the commercial operation until the end of service). The TLOBU's design shall meet a total rate ≤ 4E-6/h for all failure (incl. combined ones) leading to the "operation impacting" category. Note: 60 s corresponds to a time buffer considered in timetable definition at DB.	Covered by SpecSysReq[047] SpecSysReq[048]	
SR_R129	Reliability Target – "Operation impacting" category (2). 90% of the operation impacting failures (failure rate) shall not cause an additional delay ≥ 6 minutes to the train service. Note: A delay ≥ 6 minutes corresponds to a commercial delay according to DB definition	Covered by SpecSysReq[047] SpecSysReq[048]	
SR_R130	Reliability Target – "Operation transparent" category. This category applies to defects / failures of TLOBU that cannot be noticed or is train service transparent (causing no or an	Covered by SpecSysReq[047] SpecSysReq[048]	

	additional delay < 60 s to the train service). The TLOBU shall meet a total rate ≤ 1.5E-5/h for all failures leading to the "operation transparent" category.		
SR_R131	Reliability Critical Item Single component failures of TLOBU leading to "immobilizing" or "operation impacting" category shall be classified as Reliability Critical Item.	Not covered	This requirement is linked to a methodology.
SR_R132	Maintainability Target The TLOBU's design and maintenance concept shall meet a MTTR ≤ 1 h. The MTTR is defined in EN 61703. The administrative delay Logistic Delay shall not be considered. The time elapsed to restore during service online (incl. reset, reconfiguration) and all architecture-related corrective maintenance tasks shall be considered.	Covered by SpecSysReq[054]	

15.2.4 Safety

CLUG (1) System Requirement ID	CLUG (1) Requirement	Trace to CLUG 2.0 system requirement	Comment
SR_R133	The development of the TLOBU shall follow the safety processes and comply to the safety requirements stated in EN 50126-1 and -2.	Covered by SpecSysReq[056]	SpecSysReq[056] cover the whole certification process without getting into detail.
SR_R134	The single component failure (incl. common mode failure) of a TLOBU leading to hazard related to a “catastrophic” or a “critical” severity level shall be classified as Safety Critical Item.	Covered by SpecSysReq[056]	SpecSysReq[056] cover the whole certification process without getting into detail.
SR_R84	The TLOBU shall comply to the safety requirements (incl. TFFR) defined to each function in D2.4 “Preliminary Hazard Analysis”.	Not covered explicitly	WP3 is in charge of the safety analysis and the definition of safety requirements.

15.2.5 Security

CLUG (1) System Requirement ID	CLUG (1) Requirement	Trace to CLUG 2.0 system requirement	Comment
SR_R153	Security Levels of the TLOBU shall be derived in accordance with [20] IEC 62443-3-3.	Covered by SpecSysReq[058]	CLUG 2.0 refer to CLC/TS 50701:2021
SR_R86	The TLOBU shall comply to IT security requirements defined in [12] IEC 62443-3-3 for the Security Levels derived as required in SR_R153.	Covered by SpecSysReq[058]	CLUG 2.0 refer to CLC/TS 50701:2021

15.2.6 Communication

CLUG (1) System Requirement ID	CLUG (1) Requirement	Trace to CLUG 2.0 system requirement	Comment
SR_R87	The TLOBU shall comply to the requirements for category 3 transmission systems to provide safety-related communication between safety related equipment.	Covered by SpecSysReq[035]	

15.2.7 GNSS Spoofing and Jamming

CLUG (1) System Requirement ID	CLUG (1) Requirement	Trace to CLUG 2.0 system requirement	Comment
SR_R88	The TLOBU shall be able to detect a GNSS spoofing attempt that impacts the TLOBU and inform the users of the same.	Not covered explicitly	CLUG 2.0 having an agnostic approach, GNSS specific issue are not identified explicitly.
SR_R89	The TLOBU shall be able to detect GNSS jamming attacks that impacts the TLOBU and inform the users of the same.	Not covered explicitly	CLUG 2.0 having an agnostic approach, GNSS specific issue are not identified explicitly.

15.2.8 Environmental Conditions

CLUG (1) System Requirement ID	CLUG (1) Requirement	Trace to CLUG 2.0 system requirement	Comment
SR_R90	The environmental conditions within Europe are given at which the TLOBU shall function as specified.	Covered by SpecSysReq[059]	CLUG 2.0 refer to 97s0665. 97s0665 factorise the needs toward environmental requirements in the ETCS system.
SR_R91	The TLOBU shall function as specified in the presence of electromagnetic phenomena defined in EN 61703:2016, ISO 8855:2011 and 50121 part 3-2.	Covered by SpecSysReq[059]	CLUG 2.0 refer to 97s0665. 97s0665 factorise the needs toward environmental requirements in the ETCS system.
SR_R92	The electromagnetic energy emission of the TLOBU shall comply to the requirements specified in EN 61703:2016, ISO 8855:2011 and 50121 part 3-2.	Covered by SpecSysReq[059]	CLUG 2.0 refer to 97s0665. 97s0665 factorise the needs toward environmental requirements in the ETCS system.
SR_R93	The TLOBU shall function as specified under shock and vibration conditions defined.	Covered by SpecSysReq[059]	CLUG 2.0 refer to 97s0665. 97s0665 factorise the needs toward environmental requirements in the ETCS system.
SR_R137	The TLOBU shall be REACH compliant.	Covered by SpecSysReq[061]	
SR_R138	The TLOBU shall be (Restriction of Hazardous Substances) compliant.	Covered by SpecSysReq[061]	

15.2.9 Fire Protection

CLUG (1) System Requirement ID	CLUG (1) Requirement	Trace to CLUG 2.0 system requirement	Comment
Info	EN specifies fire protection measures for railway vehicles and verification methods for these measures.	Covered by SpecSysReq[060]	
SR_R136	The TLOBU shall comply with the requirements and measures defined.	Covered by SpecSysReq[060]	

15.2.10 Operating Conditions

CLUG (1) System Requirement ID	CLUG (1) Requirement	Trace to CLUG 2.0 system requirement	Comment
INFO	EN 50155 covers the operating conditions, the design requirements, the documentation and testing of electronic equipment as well as the hardware and software requirements.	Covered by SpecSysReq[059]	CLUG 2.0 refer to 97s0665. 97s0665 factorise the needs toward environmental requirements in the ETCS system
SR_R94	The TLOBU shall comply to the requirements specified in EN 50155.	Covered by SpecSysReq[059]	CLUG 2.0 refer to 97s0665. 97s0665 factorise the needs toward environmental requirements in the ETCS system
SR_R95	The identified requirements shall be met for all operating conditions of different loco traction systems (e.g., slip and slide).	Covered by SpecSysReq[059] SpecSysReq[054]	

15.2.11 Reference Frame

System Requirement ID	Requirement	Trace to CLUG 2.0 system requirement	Comment
SR_R99	The TLOBU shall output the TU 3D Position (Function SFUNC-2) with reference to WGS84 reference frame.	Not covered	CLUG 2.0 refer to ETRS89

16 APPENDIX B: 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		

17 APPENDIX C: 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	Standby (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

18 APPENDIX D: CLUG 2.0 WP2 Glossary

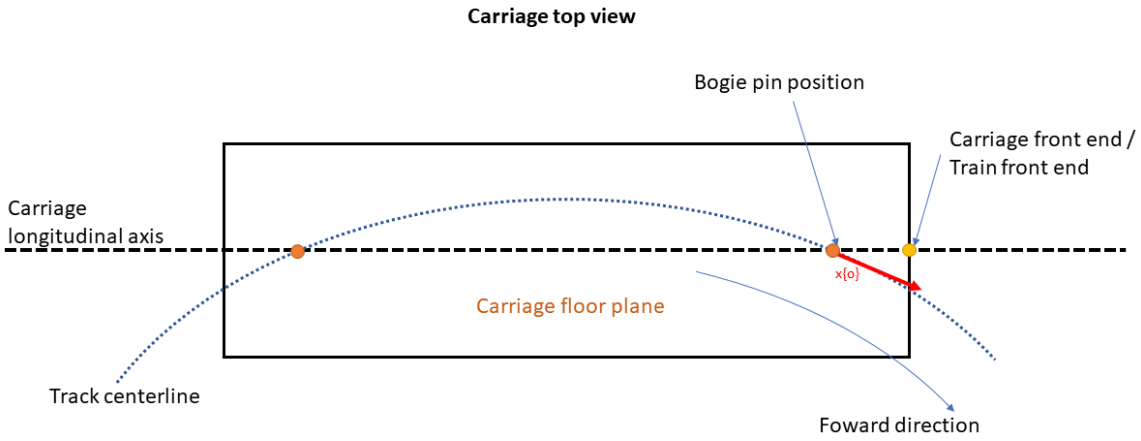
This appendix is aimed at ensuring terminology alignment and common understanding throughout CLUG 2.0 WP2 documentation. Terms definitions are already captured and hence referenced to:

- 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).



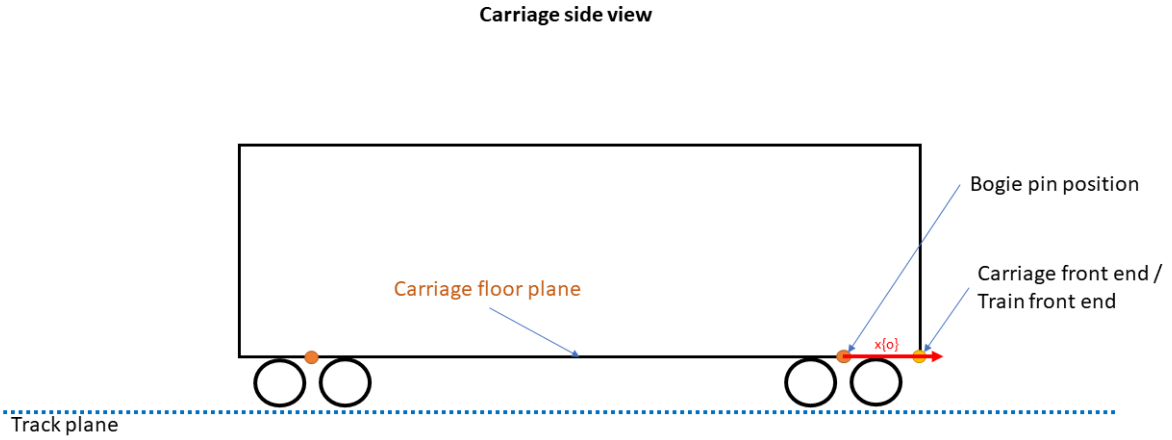


Figure 2 - 1D reference frame represented by the x-axis of the bogie frame $\{o\}$.

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]).

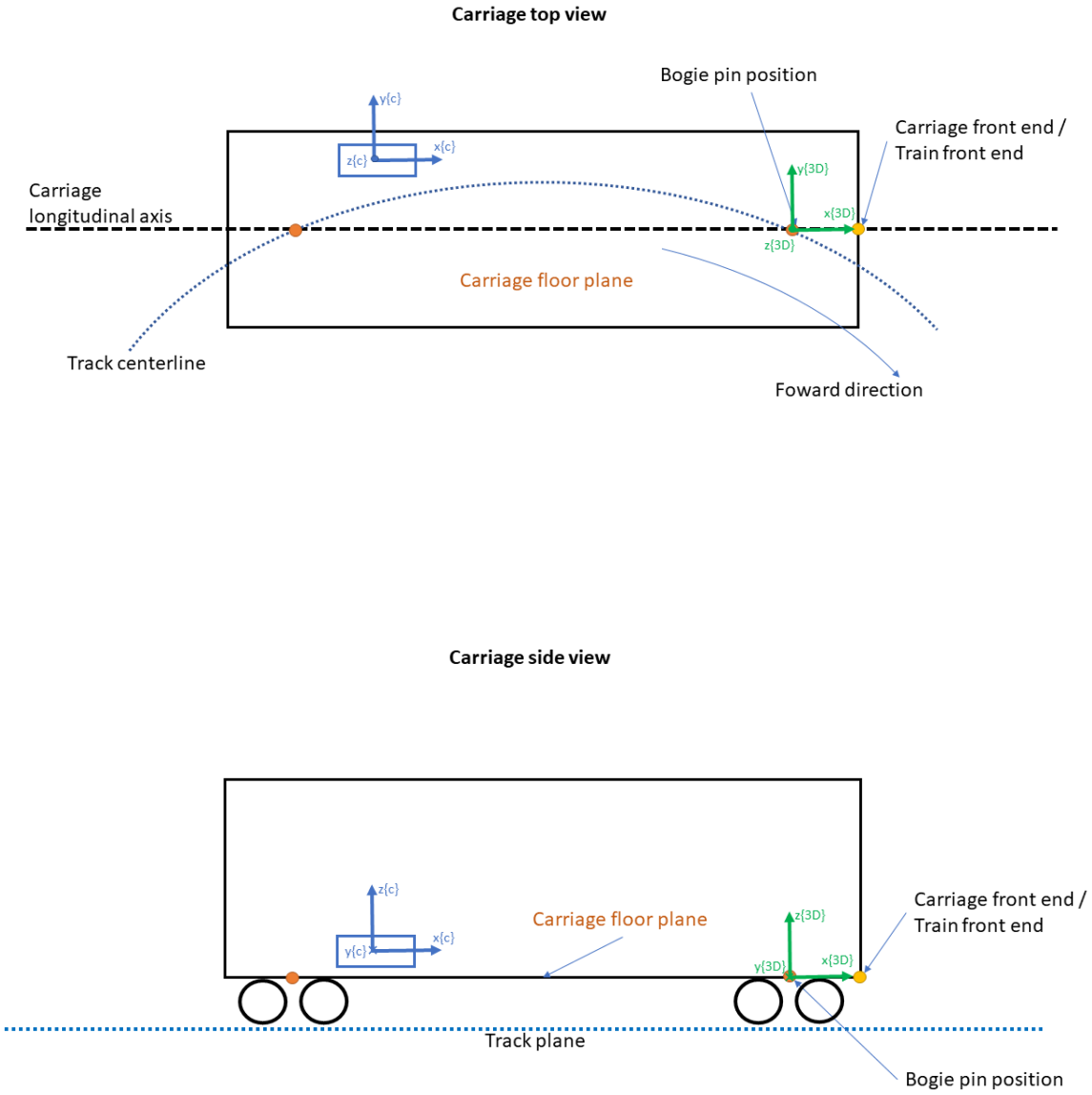


Figure 3 - 3D reference frame and carriage frame $\{c\}$.

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 3).

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 4). During straight paths, $\{o\}$ is oriented as $\{t\}$.

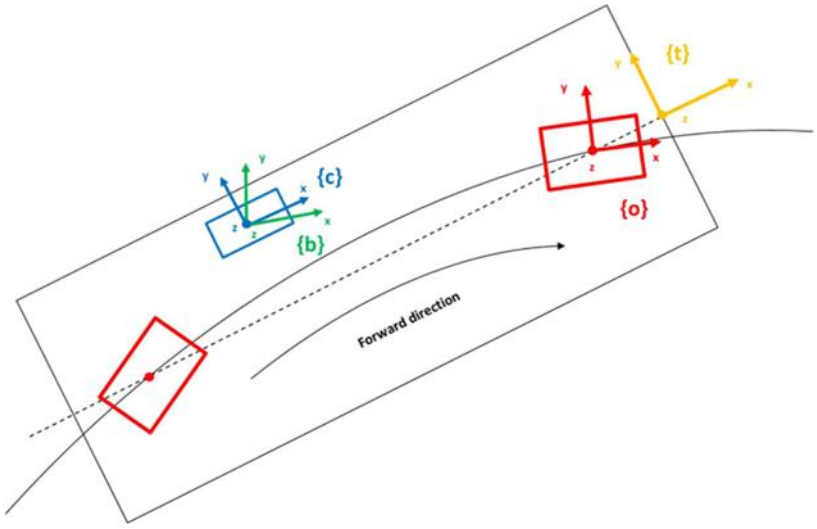


Figure 4 - On-board reference frames: front train $\{t\}$, bogie $\{o\}$ and carriage $\{c\}$ reference frames (Ref [17]).

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 3). 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 Users 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 2).

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.

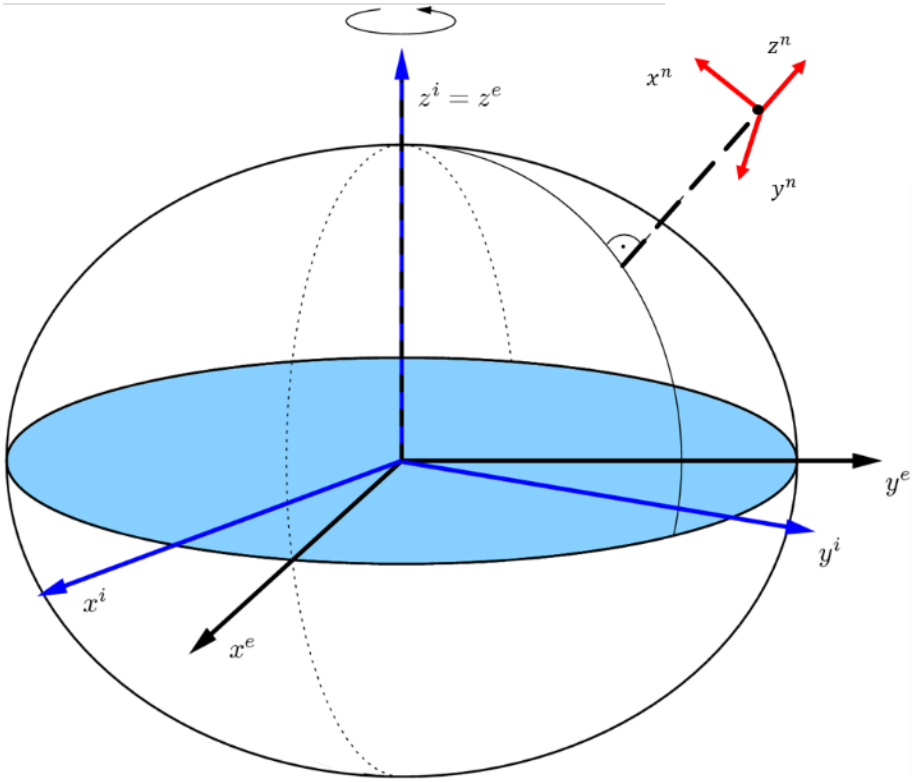


Figure 5 - Reference frames with respect to the earth centre.

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 6 and Figure 7 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.

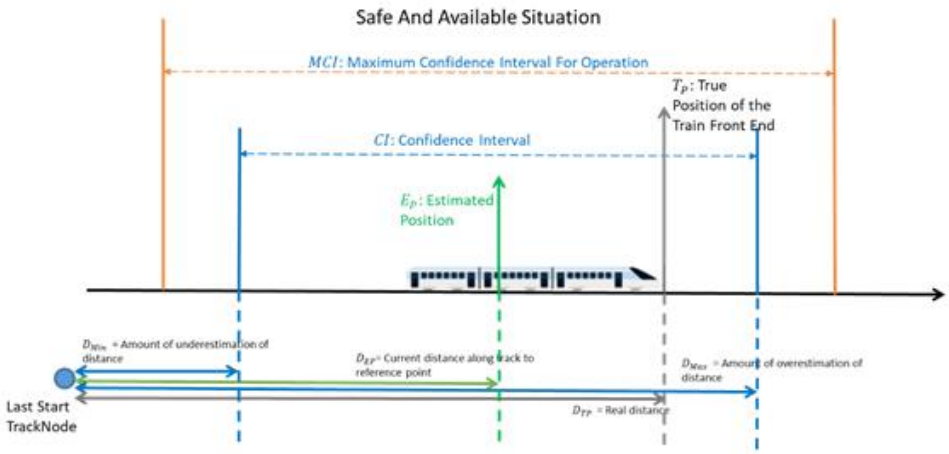


Figure 6 - Safe and available situation. Estimated position, computed Confidence Interval versus specified Maximum Confidence Interval.

Figure 7 - 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 8: 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 8 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 9: 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.

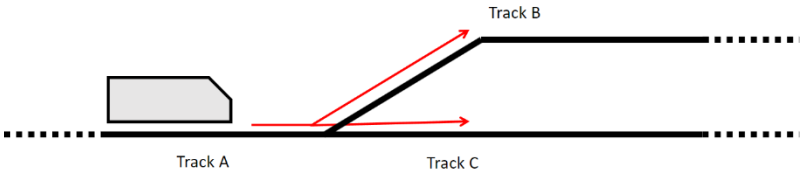


Figure 8 - Train on parting tracks.

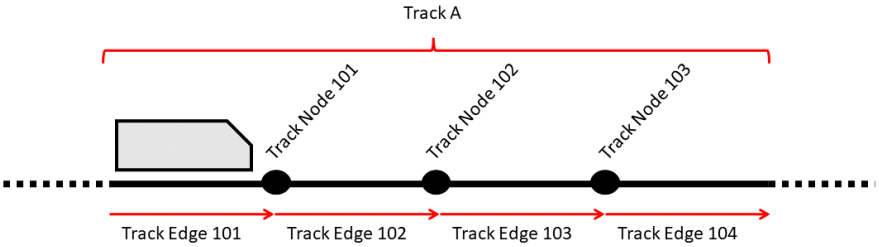


Figure 9 - Train on single track.

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 2 and Figure 3).

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 2 and Figure 4).

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 2).

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 3).

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

19 APPENDIX E: Requirements to be fulfilled by the CLUG2 demonstrator.

Req ID	Requirement	Relevance for demonstration Testing
SpecSysReq[001]	The 1D localisation dataset toward the train front end provided by LOC-OB shall include: - Reference location id - Train orientation - Position qualifier (w.r.t. to the reference location) - Estimated distance - Underestimation of the estimated distance - Overestimation of the estimated distance - Track edge id - Validity timestamp	Yes.
SpecSysReq[002]	LOC-OB shall provide the track edge ID where the train front end position is.	Yes.
SpecSysReq[003]	The absolute value of the Overestimation related to the estimated distance and the absolute value of the Underestimation related to the estimated distance shall be lower than ten meters. surrounding: - An operational stop or speed limitation. - A stop in train station. Surrounding shall be interpreted as +- 500m of a stopping point.	Yes.
SpecSysReq[004]	The absolute value of the Overestimation related to the estimated distance and the absolute value of the Underestimation related to the estimated distance shall be lower than sixty meters anywhere the SpecSysReq[003] requirement is not requested.	Yes.
SpecSysReq[005]	The absolute error of the estimated distance to the reference location shall not exceed 1.25m, for at least 95% of the cases, surrounding: - An operational stop or speed limitation - A stop in train station. Surrounding shall be interpreted as +- 500m of a stopping point.	Yes.
SpecSysReq[006]	The absolute error of the estimated distance calculated by LOC-OB shall not exceed 4m (for at least 95% of the cases), anywhere the SpecSysReq[005] requirement is not requested.	Yes.
SpecSysReq[007]	The train front end true position shall be included in the LOC-OB computed confidence interval towards the train front end position within the most constraining user exported THR.	Yes.

	Train true position is within [(Reference location id + Estimated distance - Overestimation of the estimated distance); (Reference location id + Estimated distance + Underestimation of the estimated distance)].	
SpecSysReq[008]	The 1D speed (along the track) dataset provided by LOC-OB shall include: - Movement direction - Estimated train speed - Underestimation train speed - Overestimation train speed - Validity timestamp	Yes.
SpecSysReq[009]	The confidence interval calculated by LOC-OB (Underestimation of the estimated train speed - Overestimation of the estimated train speed) toward estimated speed shall be better than 2 km/h for speeds lower than 30 km/h, and increasing linearly up to 12 km/h for speeds between 30 km/h and 500 km/h.	Yes.
SpecSysReq[010]	The absolute error of the estimated train speed provided by LOC-OB shall not exceed ± 1 km/h for speeds from 0 km/h to 100 km/h and ± 1% * v for speeds from 100 km/h to 500 km/h for at least 95% of the cases.	Yes.
SpecSysReq[011]	The train true speed shall be lower than the LOC-OB computed max safe speed (Estimated train speed + Underestimation train speed) within the most constraining user exported THR.	Yes.
SpecSysReq[012]	The 1D acceleration (along the track) dataset provided by LOC-OB shall include: - Estimated train acceleration - Underestimation train acceleration - Overestimation train acceleration - Validity timestamp	Yes.
SpecSysReq[013]	The computed confidence interval (Underestimation train acceleration - Overestimation train acceleration) toward the estimated train acceleration shall not exceed 0.2 m/s2.	Yes.
SpecSysReq[014]	The absolute error of the estimated train acceleration shall not exceed 0.05 m/s2 for at least 95% of the cases.	Yes.
SpecSysReq[015]	The train true acceleration shall be included in the LOC-OB computed confidence interval toward the estimated train acceleration within the most constraining user exported THR.	Yes.
SpecSysReq[016]	The 3D train position dataset provided by LOC-OB shall include: - 3D Position - 3D Position uncertainty - Coordinate reference system - Validity timestamp	Yes.

SpecSysReq[017]	The absolute error of the estimated 3D position shall not exceed 1,25 m for at least 95% of the cases.	Yes.
SpecSysReq[018]	The 3D train velocity dataset provided by LOC-OB shall include: - 3D Velocity - 3D Velocity uncertainty - Validity timestamp	Yes.
SpecSysReq[019]	The absolute error of the estimated 3D train velocity shall not exceed 2 km/h on each axis of the 3D reference frame (refer to definitions) for at least 95% of the cases.	Yes.
SpecSysReq[020]	The 3D train acceleration dataset provided by LOC-OB shall include: - 3D Acceleration - 3D Acceleration uncertainty - Validity timestamp	Yes.
SpecSysReq[021]	The absolute error of the estimated 3D train acceleration shall not exceed 0.05 m/s2 on each axis in the 3D reference frame (refer to definitions) for at least 95% of the cases.	Yes.
SpecSysReq[022]	The train attitude (rotational angles) dataset provided by LOC-OB shall include: - Attitude - Attitude uncertainty - Angular rate - Angular rate uncertainty - Validity timestamp	Yes.
SpecSysReq[023]	The absolute error of the estimated attitude (rotational angles) shall not exceed 0,1° for yaw, and 0,5° for pitch and roll for at least 95% of the cases.	Yes.
SpecSysReq[024]	The dataset toward estimated distance travelled provided by LOC-OB shall include: - Estimated distance travelled - Estimated distance max - Estimated distance min - Validity timestamp	Yes.
SpecSysReq[025]	Only if safety is not to be compromised, LOC-OB shall not provide a sudden variation of the position and the speed confidence intervals that leads to brake intervention or trip (TR) mode. The increase of the confidence interval shall allow the train to adapt its behaviour to avoid emergency braking.	Yes.
SpecSysReq[027]	LOC-OB, from the train power on, shall initialise itself and provide the outputs with no human supervision.	Yes.
SpecSysReq[028]	After being powered up and its initialisation stage ended, LOC-OB shall provide data continuously.	Yes.

SpecSysReq[029]	After the LOC-OB is powered-on, it shall fulfil entire operational capability in less than 1 minute when initial position is valid under the following conditions: 1. Initial position is known (e.g., last known position is saved before LOC-OB is switched-off). 2. Track edge id is known (e.g., last track edge id is saved before LOC-OB is switched-off). 3. Cold Movement Detection (CMD) doesn't indicate a train movement while the train has been powered off.	Yes.
SpecSysReq[030]	After the LOC-OB is powered-on, it shall fulfil entire operational After the LOC-OB is powered-on, it shall fulfil entire operational capability in less than 10 minutes when initial position is not valid under any of the following conditions: 4. Initial position is unknown (e.g., last known position is not saved before LOC-OB is switched-off). 5. Track edge id is unknown (e.g., last track edge id is not saved before LOC-OB is switched-off). 6. CMD indicates a train movement during the train is powered off.	Yes.
SpecSysReq[031]	In case the LOC-OB cannot reach full operational capability after the system is powered on (e.g., Unknown track segment / track edge), estimated speed and travelled distance since the LOC-OB is powered on shall always be provided.	No.
SpecSysReq[032]	LOC-OB dataset time validity shall not exceed 200 ms when transferred to users.	Yes.
SpecSysReq[033]	LOC-OB shall provide the processed dataset with a frequency at least equal to 10Hz.	Yes.
SpecSysReq[034]	LOC-OB shall embed a safe and secure mechanism to detect delays and time incoherencies within the most constraining user exported THR.	No.
SpecSysReq[035]	LOC-OB, user equipment and provider equipment shall use data exchange mechanisms in accordance with the safety, security and interoperability requirements.	No.
SpecSysReq[036]	LOC-OB shall provide its dataset in compliance with the future TSI through the SCI - Vehicle Locator (SCI-VL) interface.	No.
SpecSysReq[037]	If needed, LOC-OB shall acquire the Digital Map in accordance with the future TSI through the SCI - Map Repository On-Board (SCI-REP-OB) interface.	No.
SpecSysReq[038]	If available and needed by LOC-OB, LOC-OB shall acquire the train routing information (Movement authority, journey profile or switch information etc) in accordance to the future TSI through the SCI - Route Control (SCI-RC) interface.	No.

SpecSysReq[039]	If available and needed, LOC-OB shall comply with the future TSI concerning the use the Augmentation Data (definition of the dataset and exchange mechanism) through the SCI - Augmentation (SCI-AUG) interface.	No.
SpecSysReq[040]	If available and needed by LOC-OB, LOC-OB shall comply with the future TSI concerning the use of Train integrity status. (Definition of the dataset and exchange mechanism) through the SCI - Train Control Management System (SCI-TCMS) interface.	No.
SpecSysReq[041]	If existing, LOC-OB shall acquire the train static configuration from the common on-board Configuration Data Storage (CDS) component through the SCI - Configuration Data Storage (SCI-CDS) interface. Otherwise, specific static configuration information shall be managed as an internal component of LOC-OB.	No.
SpecSysReq[042]	If needed, LOC-OB shall acquire the dynamic train configuration, as active cab, train length, rigid definition of the primary moving direction, or definition of trains front end from Train Control Management System (TCMS) through the SCI - Operational Data Storage (SCI-ODS) interface.	No.
SpecSysReq[043]	If needed and available, LOC-OB shall acquire the EUB Telegram in accordance with the future TSI through the SCI - Physical ETCS Transponder Service (SCI-PETS) interface.	No.
SpecSysReq[044]	If needed, LOC-OB shall use the LRBG reference provided by ETCS through the SCI - Vehicle Supervisor (SCI-VS) interface.	No.
SpecSysReq[045]	If needed, LOC-OB shall use the reference points defined in the Digital Map through the SCI-VS interface.	No.
SpecSysReq[046]	If available and needed, LOC-OB shall comply with the future TSI concerning the use of Cold Movement information. (Definition of the dataset and exchange mechanism).	No.
SpecSysReq[047]	The LOC-OB hardware shall comply with the overall CCS-OB reliability as defined in Ref [57] Chapter 2. Minor failure: λ <1,25 10-4/h. Reduced service failure: λ < 3,3 10-6/h. Immobility failure: λ < 3,7 10-7/h.	Yes.
SpecSysReq[048]	If the confidence intervals are larger than the acceptable position confidence interval (position), maximum acceptable speed confidence interval (speed) or maximum acceptable acceleration confidence interval (acceleration) for a cumulative 60 seconds (or more) for two hours, the time is accounted in the overall LOC-OB unavailability.	Yes.
SpecSysReq[049]	The LOC-OB shall have an overall availability of 99,998% during operation.	No.

SpecSysReq[050]	LOC-OB shall manage useful data toward maintenance in an internal log memory and through the SCI - Monitoring, Diagnostic, Configuration, Maintenance On-Board (SCI-MDCM-OB) interface.	No.
SpecSysReq[051]	LOC-OB shall be designed as a generic application (cf.EN50126 [5] [6]).	No.
SpecSysReq[052]	LOC-OB shall be designed to ease software updates (including security patches) by avoiding complex workshop procedures requiring bench testing.	No.
SpecSysReq[054]	The LOC-OB's design and maintenance concept shall meet a Mean Time To Restore (MTTR) ≤ 1h.	No.
SpecSysReq[055]	Preventive maintenance or periodic sensor calibration period of the overall LOC-OB shall exceed 2 years.	No.
SpecSysReq[056]	The safety of the LOC-OB shall be ensured and demonstrated according to the Common Safety Methods (cf. Ref [34]) and the EN 50126 standard (cf. Ref [5] and Ref [6]).	No.
SpecSysReq[057]	If needed, calibration procedure(s) shall fulfil with the safety requirement.	No.
SpecSysReq[058]	LOC-OB shall fulfil requirements and recommendations for cybersecurity as specified in CLC/TS 50701 (cf. Ref [36]) with the purpose to demonstrate that the system is up to date from a cybersecurity perspective and that it meets and maintains the target level of security for the entire system life cycle.	No.
SpecSysReq[059]	LOC-OB components shall comply with applicable environmental standards.	Yes.
SpecSysReq[060]	LOC-OB components shall comply with the Ref [42] standard: Railway applications - Fire protection on railway vehicles. The latest edition shall apply.	No.
SpecSysReq[061]	LOC-OB components shall comply with the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) and RoHS2 directives. The latest edition shall apply.	No.
SpecSysReq[066]	If LOC-OB cannot guarantee safe operation due to internal safety process faults (for ex: safe computer failure): LOC-OB shall not provide any information to the users.	No.
SpecSysReq[067]	LOC-OB shall log overall availability issues and specific relevant events as timestamped events.	No.
SpecSysReq[068]	If LOC-OB is unable to produce a data within the awaited THR due to insufficient information to guarantee safe results (one or several sensor failure or unavailability), LOC-OB shall provide a default invalid value for the data concerned and shall provide all other data as specified.	No.

SpecSysReq[069]	LOC-OB computed localisation data shall be considered unsafe if: • The LOC-OB (including all sensors) is not located in the front of the train (cab) AND • The train consists of coupled wagons, locomotives, etc. AND • Train integrity is not confirmed	No.
SpecSysReq[070]	The track edge ID provided by LOC-OB shall refer to the track edge occupied by the train front end real position within the most constraining user exported THR.	No.
SpecSysReq[071]	LOC-OB shall take into consideration each sensor specific challenging environmental condition and each sensor failure mode to perform in all situations not considered as incredible or Improbable.	Yes.
SpecSysReq[072]	If the LOC-OB is not providing data at the defined rate, the LOC-OB is considered as unavailable during this time.	Yes.

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