Grant agreement No 101082624

CLUG Demonstration of Readiness for Rail – CLUG 2.0

D2.1 OPERATIONAL NEEDS AND SYSTEM CAPABILITIES OF LOCALISATION ON-BOARD SYSTEM

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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 main objective of this deliverable is to analyse operational needs and operational context to derive the system capabilities needed of a train on-board localisation system. It also targets to specify a set of high-level user requirements for a localisation system that fulfils the operational needs of its railway users. These high-level user requirements are the basis for the system definition, design and evaluation.

To define the high-level user requirements for the localisation system a black-box approach was used. This approach focuses on analysing the functionalities needed of a localisation system without peering into internal structures or technical solutions.

The steps that were taken to define the high-level user requirements are as follows:

- Identify the users that need localisation information. The main users are Infrastructure Managers and Railway Undertakings.
- Identify the functions of each system in the wider system of interest which have needs towards localisation.
- Identify the operational needs based on the functions of each system. Operational needs are classified as safety and non-safety relevant.
- Define the system capabilities of the localisation system required to fulfil the operational needs.
- Specify the set of functional and non-functional high-level user requirements for a localisation system that needs to fulfil the operational needs of its railway users.

For some of the identified systems that require localisation information such as Digital Register, Perception, Hazard Identification and Evaluation, assumptions had to be made because these are still under development at European level.

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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 Introduction

1.1 Objectives of the CLUG 2.0 Project

CLUG stands for Certifiable Localisation Unit using GNSS in the railway environment.

The CLUG 2.0 project will continue with the work started in the H2020-project CLUG (1), specifying a proposal for a future on-board localisation unit with the following characteristics:

- on-board multi-sensor safe localisation system consisting of a navigation core combining GNSS, Inertial Measurement Unit (IMU) and digital map information among others,
- continuous on-board localisation providing safe and non-safe localisation parameters, notably position, speed, movement direction and other dynamics of the train,
- localisation system that is operational and interoperable across the entire European rail network,
- localisation system that is compatible with European Railway Traffic Management System (ERTMS) TSI current status and future evolutions.

It is not in scope of CLUG 2.0 to develop a certifiable product, but rather to consolidate and complete the specification of the system as well as demonstrating the feasibility and the technological readiness of the specified Localisation On-Board (LOC-OB) system.

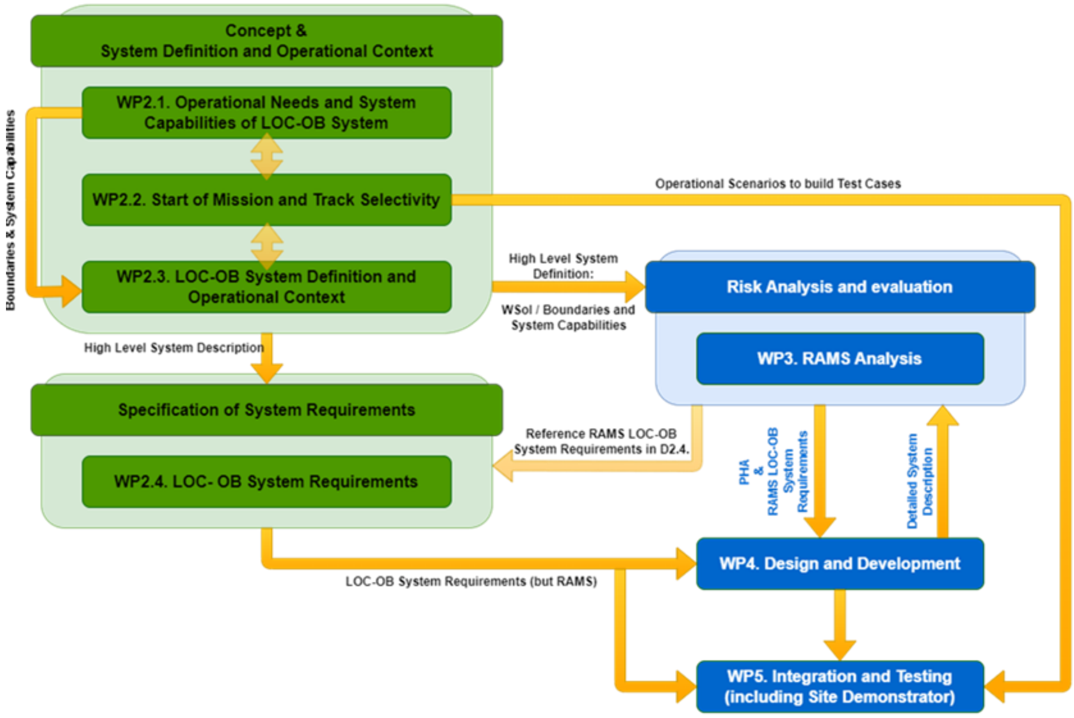


Figure 1 - Logical decomposition of WP2 and interrelationship with the rest of WPs.

The objective of WP2 "LOC-OB System Definition and Requirements Specification" is consolidating and completing the LOC-OB system definition and requirements specification, including the definition and requirements to accomplish localisation needs during start of mission and for track selectivity. WP2 is subdivided in the following deliverables:

- D2.1 Operational Needs and System Capabilities for LOC-OB, Ref [1]
- D2.2 Start of Mission and Track Selectivity, Ref [2]
- D2.3 LOC-OB System Definition and Operational Context, Ref [3]
- D2.4 LOC-OB System Requirements, Ref [4]

WP2 deliverables intend to follow the structure and topics to be covered in phases 1, 2 and 4 of system definition according to Figure 2. While deliverables D2.1, D2.2 and D2.3 cover the topics related to phases 1 and 2, D2.4 covers phase 4 by defining the set of LOC-OB system requirements. Note: Phase 3 (Risk analysis and evaluation) shall be covered in WP3.

In D2.1 the target is to define the high-level user requirements for the LOC-OB. The requirements are further developed after system analysis in D2.3 (cf. Ref [3]), defining the LOC-OB system boundaries and external interfaces based on the required system capabilities identified from the user functions and the required supporting information to ensure the provision of these system capabilities.

A parallel analysis w.r.t track selectivity and start of mission is conducted in D2.2 (cf. Ref [2]) to understand the challenges and potential requirements.

Finally, the LOC-OB System Requirements in D2.4 (cf. Ref [4]) collects and consolidate all analyses and assumptions made in the set of unique LOC-OB system requirements.

As an important remark, CLUG 2.0 is a research project which does not have as goal developing a certifiable product. For this reason, it is neither the intention to describe all necessary content as defined in Ref [5] nor to conduct all CENELEC phases.

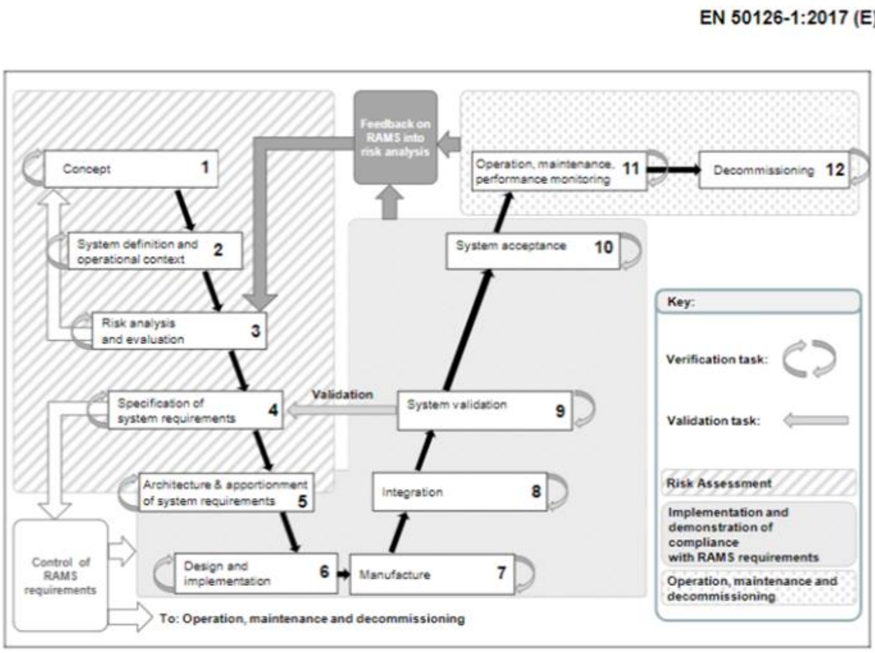


Figure 2 - V-cycle representation from Ref [5].

Previous work performed in other initiatives (RCA, OCORA, Localisation Working Group (LWG), X2RAIL, CLUG (1)… (APPENDIX B: CLUG 2.0 WP2 References)) has been considered as input and referenced where applicable.

1.2 Scope of the document

The purpose of this document is specifying the set of high-level user requirements fulfilling the needs of the railway users towards a localisation system.

The high-level user requirements specification defines the main targets for the localisation system, constituting the basis for the system definition, design and evaluation.

The structure of the current document "D2.1 Operational Needs and System Capabilities of LOC-OB System" is defined as follows:

- Chapter 2 identifies the railway users and details the functions of the systems within the wider system of interest which have needs towards the localisation system to collect the operational needs from the user´s towards localisation.
- Chapter 3 translates the identified needs into the localisation system capabilities required to fulfil these needs.
- Chapter 4 identifies the potential constraints with regards to current European Train Control System (ETCS) system and with regards to the target CLUG 2.0 system and analyses potential variants to overcome those constraints.
- Chapter 5 specifies the set of high-level user requirements to be used as base for the localisation system definition.
- Appendix A collects and presents the results of different studies on the impact of accuracy in the overall railway capacity.

1.3 Methodology

The methodological steps to identify a comprehensive set of high-level user requirements to LOC-OB have been applied as follows:

1. Identify and classify the users requiring localisation information, i.e., systems or subsystems which require localisation information to fulfil their own functionalities (localisation user functions). The main railway users are Infrastructure Managers (IM) and Railway Undertakings (RU), being represented by the trackside and on-board systems in the LOC-OB Wider System of Interest (WSoI).
2. Identify the functions of the systems in the wider system of interest which have a need towards localisation.
3. Identify the operational needs (type of information) that the functions of the systems, belonging to the wider system-of-interest, have towards localisation. The operational needs derived from these functions are classified as safety relevant and non-safety relevant.
4. Define the localisation system capabilities required to fulfil the identified operational needs (e.g., localisation, speed, acceleration, movement direction…). The system capabilities will be provided as input for the functional LOC-OB architecture definition in Ref [3].

5. Specify the set of functional high-level user requirements capturing the identified operational needs.
6. Definition of the expected localisation information quality in the set of non-functional (performance) high level user requirements.
7. Considering the operational and environmental conditions under which the localisation information is required and reflect it in the set of non-functional high level user requirements. Collect potential external requirements such as economic constraints and modularity, compatibility and interchangeability requirements in the set of non-functional high level user requirements.

To identify the set of high-level user requirements to LOC-OB, assumptions had to be made on the operational needs of the functions of the systems in the WSoI and the system capabilities of the LOC-OB. These assumptions are in line with the current knowledge but are subject for change because of the following reasons:

- The definition of a standardised Control and Command and Signalling on-board (CCS-OB) Ref [49].
- The results that will be provided by the proof of concept designed in CLUG 2.0 WP4.
- New needs that are inherited with other ongoing research and development projects: Digital Register, Perception, Hazard Identification and Evaluation.

The defined operational needs, system capabilities and high-level user requirements serve as input for future projects as well. The assumptions taken need to be further analysed and they need to be validated or invalidated by future R&D projects.

In the frame of CLUG 2.0 WP6 more specifically the document of D6.6 the potential differences from the WP2 assumptions will be documented.

2 Railway Operational Needs

2.1 Railway users

Trackside and on-board systems, operated by the involved railway users, are identified as stakeholders of the LOC-OB system which shall support those systems to perform the allocated functions, based on their functional needs. Industry partners who contribute to the system design and technology demonstrators are also identified as possible stakeholders.

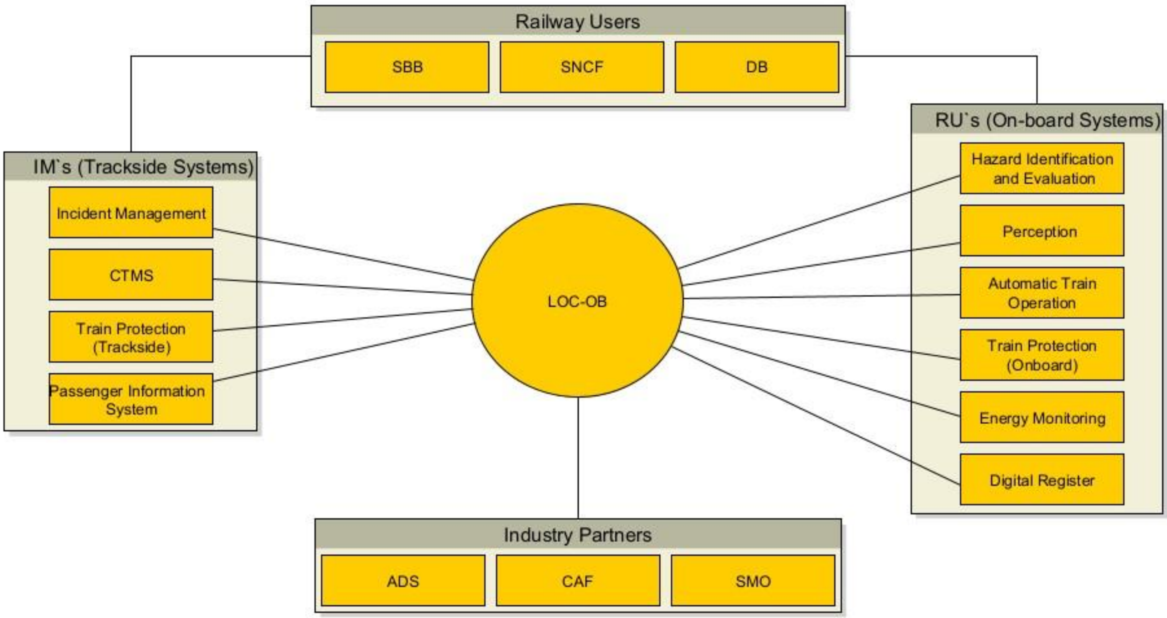


Figure 3 - Stakeholder Map of LOC-OB system.

2.1.1 Wider System of Interest

The LOC-OB system will implement the localisation functionalities. It will be integrated into a larger system, the WSoI.

The purpose of the WSoI is to operate and, for instance, move trains which includes the supporting functions to plan, control and protect the train movements in the environment of railway operation.

The WSoI defined in Figure 4 contains the systems which require information provided by the LOC-OB as investigated within the CLUG 2.0 project to support their own functions and that have their respective functional and non-functional requirements on the output provided by the LOC-OB. Note: the WSoI description will be completed in Ref [3] by including the systems providing the supporting information required by LOC-OB to perform its expected functionalities.

Please note that the Wider System of Interest as shown here is not a System Architecture. It represents a relationship between a provider of information (here: LOC-OB) and the users of the information (the other systems shown here). A relationship does not imply that there is a direct interface between the two systems.

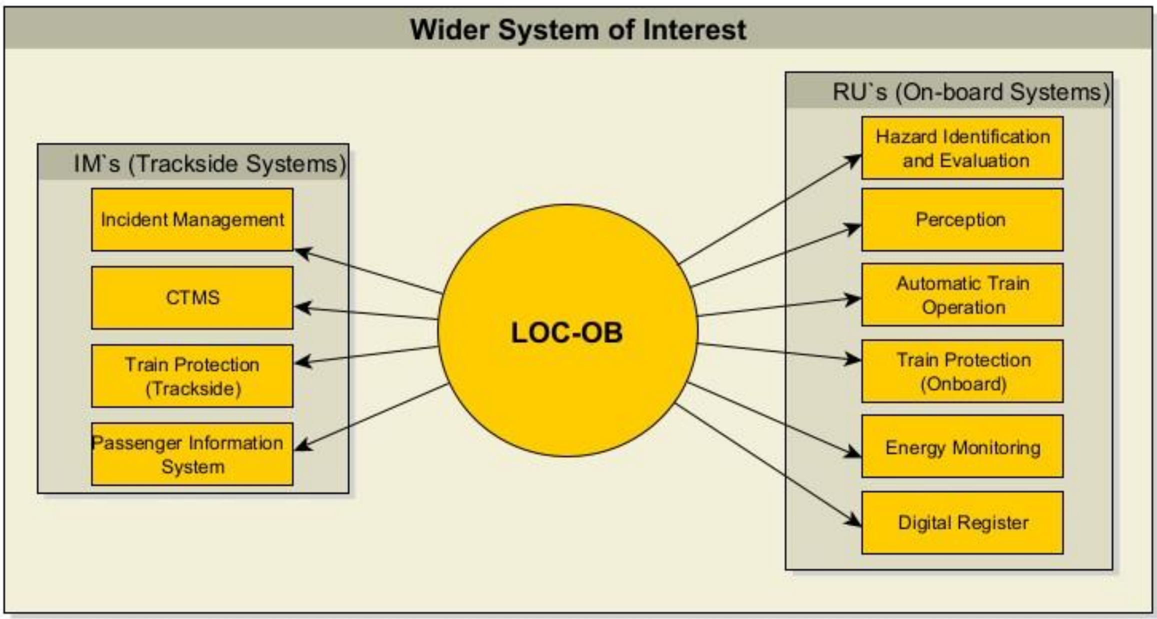


Figure 4 - LOC-OB Wider System of Interest.

2.1.2 User Functions of the Wider System of Interest

To support the identification of the operational needs of the systems of the WSoI to LOC-OB, the relevant system user functions are extracted and shown in Figure 5.

This diagram shows the high-level functional context in the scope of CLUG 2.0.

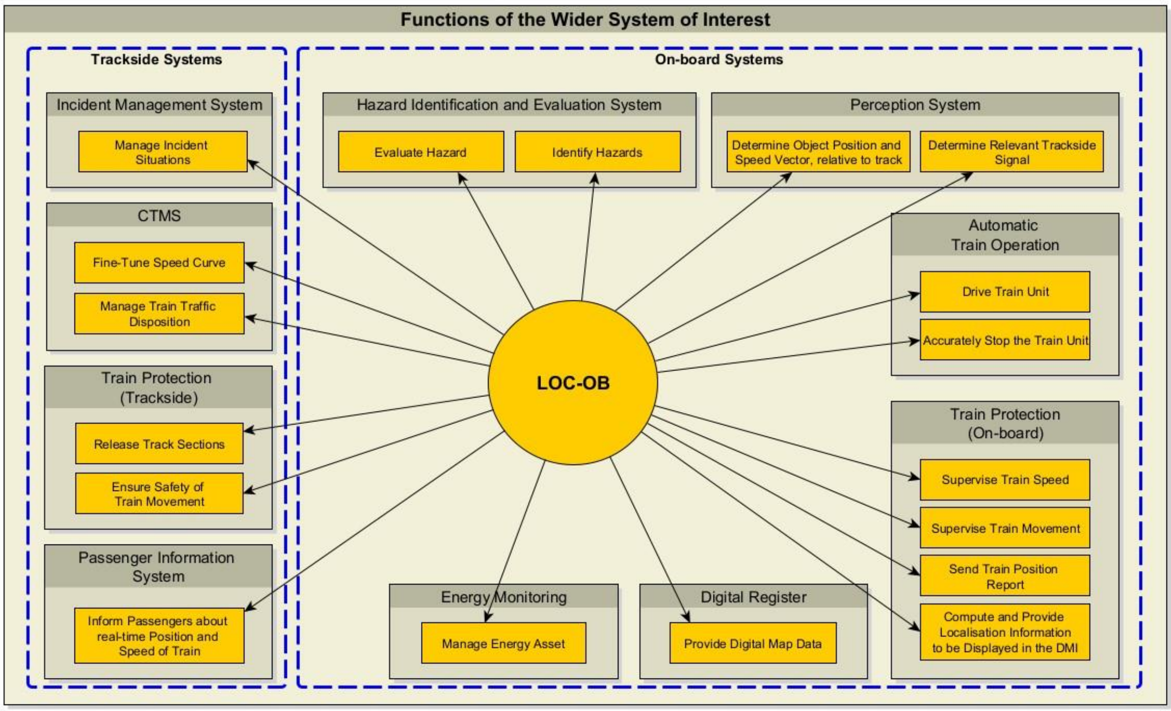


Figure 5 - LOC-OB User Functions of Wider System of Interest.

The following sections contain high level descriptions of the LOC-OB information required by each function of the Wider System of Interest.

2.2 Operational Needs

The localisation system in this context is intended to provide localisation information to other systems. Different concepts of Localisation information are defined by Ref [28], Ref [7] and Ref [17] and are collected in CLUG 2.0 WP2 glossary (cf. Appendix D). The specific localisation information (position, speed, acceleration, …) required by each user function is detailed and defined as the LOC-OB system capabilities in the next chapter.

2.2.1 Capacity and Traffic Management System (CTMS)

2.2.1.1 Purpose

Capacity and Traffic Management purpose is optimizing the rail operations. It controls the movement of trains and reacts to deviations from the traffic plan by making decisions on waiting times, train sequences, track changes or reroutes, and communicating these decisions to the protection system. Capacity and Traffic Management provides information about real-time train movements via interfaces to other systems and operator staff.

2.2.1.2 User Functions

CTMS detects deviations from the plan and decides upon necessary reactions.

2.2.1.3 Operational Needs

OpNeed [1] Capacity and Traffic Management needs train localisation information and track edge id to react to deviations from the traffic plan by fine-tuning the operational speed profile.

Safety Assessment: "non safety relevant"

OpNeed [2] Capacity and Traffic Management needs train localisation information and track edge id to manage train traffic disposition.

Safety Assessment: "non safety relevant"

2.2.2 Train Protection Trackside

2.2.2.1 Purpose

Train Protection Trackside purpose is safely managing the track occupancy, including defining and locking route (safety envelope), granting a movement authority within the safety envelope and releasing route sections which were already passed by the Train Unit (TU).

2.2.2.2 User Functions

To ensure the safe train movement, Train Protection Trackside first checks that the requested route can be made safe, and if so, transmits the corresponding actuation commands to the track elements to lock the safety envelope. Then it provides the movement authority within the safety envelope to the train.

Once the train has passed sections of the route, the Train Protection Trackside releases them.

The CLUG 2.0 WP2 assumption is that the Train Protection Trackside functions use the localisation information provided by the LOC-OB, including the determined track edge id. It is assumed that this information is provided with the required safety level to the Train Protection Trackside to cover the case when only LOC-OB information is used to ensure safety of the train movement and/or release route sections.

2.2.2.3 Operational Needs

OpNeed [3] Train Protection Trackside needs safe train localisation information and track edge id to release route sections.

Safety Assessment: "safety relevant"

OpNeed [4] Train Protection Trackside needs safe train localisation information to ensure the safety of the train movement (e.g., management of mode, providing Movement Authority (MA)).

Safety Assessment: "safety relevant"

2.2.3 Passenger Information System (PIS)

2.2.3.1 Purpose

PIS purpose is providing passengers with real-time information about train times and deviations from the timetable.

2.2.3.2 User Functions

PIS informs passenger about the real-time location of the train.

2.2.3.3 Operational Needs

OpNeed [5] PIS needs train localisation information to display real-time information on train movement.

Safety Assessment: "non safety relevant"

2.2.4 Automatic Train Operation (ATO)

2.2.4.1 Purpose

ATO purpose is automating the operation of trains by executing functions that traditionally are carried out by a driver. The functionalities taken over by the ATO from the driver depend on the grade of automation.

2.2.4.2 User Functions

The LOC-OB is assumed to operate in an overall system with a grade of automation up to GoA2. The starting, driving and stopping functionalities are assumed to be automated (relying also on protection system) whilst a driver is required in the cab for other functionalities such as detecting obstacles on the track, commanding doors or handling emergency situations.

ATO continuously calculates the optimum speed profile based on the timetable, infrastructure and track information and adapts the traction and brake commands. This also includes stopping the train unit at a planned location.

2.2.4.3 Operational Needs

OpNeed [6] ATO needs train localisation information and track edge id to drive the TU.

Safety Assessment: “non safety relevant”

OpNeed [7] ATO needs train localisation information and track edge id to stop the TU within specified range of positions.

Safety Assessment: “non safety relevant”

2.2.5 Train Protection On-Board

2.2.5.1 Purpose

Train Protection On-Board purpose is assuring that a TU does not pass the safety envelope provided by Train Protection Trackside and intervening when the train exceeds the safety envelope.

2.2.5.2 User Functions

Train Protection On-Board supervises TU speed and movements by ensuring that the TU is within the safety envelope and determines in a safe and accurate way if brake intervention is required.

2.2.5.3 Operational Needs

OpNeed [8] Only in case safety is not in concern the train front end position confidence interval provided for the Train Protection On-board is needed to be less or equal to the travelled distance to avoid unnecessary brake intervention or trip (TR) mode by the following train.

Safety Assessment: “non safety relevant”

OpNeed [9] Train Protection On-Board needs safe train localisation information to supervise train movement, train speed.

Safety Assessment: “safety relevant”

OpNeed [10] Train Protection On-Board needs train localisation information to allow the driver or ATO to stop the train at the intended stopping point.

Safety Assessment: “non safety relevant”

OpNeed [11] Only in case safety is not in concern the Train Protection On-board needs that the train front end position underestimation is less than the distance to the emergency brake intervention or service brake intervention curves, and the speed underestimation is less than the margin to the speed curve to avoid brake intervention or trip (TR) mode.

Safety Assessment: "non safety relevant"

OpNeed [12] Train Protection On-Board needs safe train localisation information to be able to send a position report.

Safety Assessment: "safety relevant"

OpNeed [13] The Train Protection On-Board needs safe train localisation information to compute and provide the localisation information to be displayed on the DMI.

Safety Assessment: "safety relevant"

2.2.6 Incident Management

2.2.6.1 Purpose

Incident Management purpose is to assist the operator in the evaluation of the situation and to restore normal service operation as fast as possible and minimizing the impact on business operations, ensuring that agreed levels of service quality are maintained.

2.2.6.2 User Functions

Incident Management evaluates incidents and decides on appropriate reaction as well as manages actions to solve an incident situation. It is assumed that the incident Management will benefit from receiving localisation information to react to incidents more efficiently. For example, in case of derailment the TU might report its position for the Incident Management which in turn can react much faster to resolve the incident.

2.2.6.3 Operational Needs

OpNeed [14] Incident Management needs train localisation information, 3D train localisation information and the track edge id to manage incident situations.

Safety Assessment: "non safety relevant"

2.2.7 Hazard Identification and Evaluation

2.2.7.1 Purpose

The functionalities clustered by Hazard Identification and Evaluation are not yet defined, so a revision is needed when a clear definition is in place. It is assumed that its purpose is to continuously monitor objects on or near the track, evaluating the hazard they are posing and reporting the identified hazards to the on-board systems. To accomplish its purpose and implement its functions (assumed to be safety relevant up to SIL2) the Hazard Identification and Evaluation system is assumed to receive inputs from different systems such as Perception, Digital Register and LOC-OB.

2.2.7.2 User Functions

It is assumed that the Hazard Identification and Evaluation system identifies and evaluates potential hazardous objects with the help of the Perception system. Identifies the location of the hazardous objects and reports the result of its evaluation to other on-board systems to react on it.

For example, one of the scenarios which is assumed to be covered by the Hazard Identification and Evaluation is: A tree is detected which is evaluated as an object interfering with the pantograph. Based on this information the TCMS might be triggered to lower the pantograph.

Another example is that a hazardous object is identified on the track, which will be reported to the on-board protection system, which in turn decides on the proper action, such as triggering the brakes.

2.2.7.3 Operational Needs

OpNeed [15] Hazard Identification and Evaluation needs safe train localisation information, 3D train localisation information, vehicle attitude and track edge id to evaluate hazard.

Safety Assessment: "safety relevant"

OpNeed [16] Hazard Identification and Evaluation needs safe train localisation information, 3D train localisation information and vehicle attitude to identify hazardous conditions.

Safety Assessment: "safety relevant"

2.2.8 Perception

2.2.8.1 Purpose

Perception is a potential future system for applications such as driverless operation in open environments. Functionalities to be performed by Perception are still under discussion due to the lack of harmonized applications (not agreed at European level). The user functions listed below are based on assumptions and those will need revision once the system is agreed at European level.

Perception system purpose is perceiving the train´s surroundings to support and assist the driver in monitoring the environment in front of the train, including the detection and status of trackside signage, and detecting (potentially) hazardous objects.

2.2.8.2 User Functions

The assumption for the Perception system is that its accountabilities end with detecting objects relative to the train unit, being next steps, such as assign objects to the map, identifying and evaluating a hazard assigned to Hazard Identification and Evaluation system. Perception computes the position of objects relative to the track where a train unit is.

It is assumed that the Perception system will also identify the relevant trackside signage.

2.2.8.3 Operational Needs

OpNeed [17] Perception needs safe train localisation information and track edge id to detect and identify track, objects, and occupancies.

Safety Assessment: "safety relevant"

OpNeed [18] Perception needs safe train localisation information, 3D localisation information, attitude and track edge id to determine the relevant trackside signage and their status.

Safety Assessment: "safety relevant"

2.2.9 Digital Register (DR)

2.2.9.1 Purpose

Digital Register system is currently under discussion at European level. Since it is strongly related to the CCS-OB architecture it expected to evolve. Assumptions are made below on the needs of Digital Register towards LOC-OB.

DR purpose is providing the Digital Map as a central data source for infrastructure data to support and enable the new systems of digital railway operation, including on-board localisation, without trackside absolute positioning indicators.

2.2.9.2 User Functions

The assumption for CLUG 2.0 is that DR only needs the 1D position (including movement direction) to provide the relevant reliable map (being DR system in charge of checking and ensuring that the provided map part is relevant).

DR provides position relevant reliable map data to other systems.

2.2.9.3 Operational Needs

OpNeed [19] DR needs train localisation information and track edge id to download the relevant map.

Safety Assessment: "non safety relevant"

2.2.10 Energy Monitoring

2.2.10.1 Purpose

Energy Monitoring is responsible for continuously measuring the power consumption to optimize the load globally in the network by short-time control of energy consumers e.g., the air-conditioning system.

2.2.10.2 User Functions

Energy Monitoring system requires position and time information.

2.2.10.3 Operational Needs

OpNeed [20] The Energy Monitoring system needs train localisation information to manage energy asset.

Safety Assessment: "non safety relevant"

3 LOC-OB System Capabilities

3.1 System Capabilities

The localisation system shall be able to address system capabilities based on operational needs, providing the required localisation information to every user function in the WSoI defined in Section 2.1.2.

SysCap [1] Provide 1D Train Front End Position

SysCap [2] Provide 1D Train Speed

SysCap [3] Provide 1D Train Acceleration

SysCap [4] Provide Train Movement Direction

SysCap [5] ***Intentionally deleted***

SysCap [6] Provide Vehicle Attitude (yaw, pitch and roll)

SysCap [7] Provide 3D Position

SysCap [8] Provide 3D Speed

SysCap [9] Provide 3D Acceleration

SysCap [10] Provide Track Edge ID

3.2 System Capabilities allocation to users and Operational Needs

System	Function	Operational Need	SysCap [1] **Provide 1D Train Front End Position**	SysCap [2] **Provide 1D Train Speed**	SysCap [3] **Provide 1D Train Acceleration**	SysCap [4] **Provide Train Movement Direction**	SysCap [6] **Provide Vehicle Attitude**	SysCap [7] **Provide 3D Position**	SysCap [8] **Provide 3D Speed**	SysCap [9] **Provide 3D Acceleration**	SysCap [10] **Provide Track Edge ID**
CTMS	**Fine-tune speed profile**	**[1]**	**x**	**x**		**x**					**x**
	Manage Train Traffic Disposition	**[2]**	**x**	**x**		**x**					**x**
Train Protection Trackside	**Release Track Sections**	**[3]**	**x**								**x**
	Ensure Safety of Train Movement	**[4]**	**x**			**x**					
PIS	**Inform Passengers about real-time Position and Speed of Train**	**[5]**	**x**	**x**		**x**		**x**			
ATO	**Drive Train Unit**	**[6]**	**x**	**x**	**x**	**x**					**x**

System	Function	Operational Need	SysCap [1] **Provide 1D Train Front End Position**	SysCap [2] **Provide 1D Train Speed**	SysCap [3] **Provide 1D Train Acceleration**	SysCap [4] **Provide Train Movement Direction**	SysCap [6] **Provide Vehicle Attitude**	SysCap [7] **Provide 3D Position**	SysCap [8] **Provide 3D Speed**	SysCap [9] **Provide 3D Acceleration**	SysCap [10] **Provide Track Edge ID**
	Accurately Stop the Train Unit	**[7]**	**x**	**x**	**x**	**x**					**x**
Train Protection On-board	**Supervise Train Speed**	**[8]**	**x**								
		[11]	**x**	**x**		**x**					
	Supervise Train Movement	**[9]**	**x**	**x**	**x**	**x**					
		[10]	**x**	**x**	**x**	**x**					
	Send Train Position Report	**[12]**	**x**	**x**		**x**					
	Compute and Provide Localisation Information to be displayed on the DMI	**[13]**	**x**	**x**		**x**					

System	Function	Operational Need	SysCap [1] **Provide 1D Train Front End Position**	SysCap [2] **Provide 1D Train Speed**	SysCap [3] **Provide 1D Train Acceleration**	SysCap [4] **Provide Train Movement Direction**	SysCap [6] **Provide Vehicle Attitude**	SysCap [7] **Provide 3D Position**	SysCap [8] **Provide 3D Speed**	SysCap [9] **Provide 3D Acceleration**	SysCap [10] **Provide Track Edge ID**
Incident Management	**Manage Incident Situations**	**[14]**	**x**	**x**	**x**	**x**		**x**	**x**	**x**	**x**
Hazard Identification and Evaluation	**Evaluate Hazard**	**[15]**				**x**	**x**	**x**	**x**	**x**	**x**
	Identify Hazard	**[16]**				**x**	**x**	**x**	**x**	**x**	
Perception	**Determine Object Position and Speed Vector, relative to track**	**[17]**		**x**			**x**				**x**
	Determine Relevant Trackside Signage	**[18]**	**x**				**x**	**x**			**x**
Digital Register	**Provide Digital Map Data**	**[19]**	**x**			**x**		**x**			**x**

System	Function	Operational Need	SysCap [1] **Provide 1D Train Front End Position**	SysCap [2] **Provide 1D Train Speed**	SysCap [3] **Provide 1D Train Acceleration**	SysCap [4] **Provide Train Movement Direction**	SysCap [6] **Provide Vehicle Attitude**	SysCap [7] **Provide 3D Position**	SysCap [8] **Provide 3D Speed**	SysCap [9] **Provide 3D Acceleration**	SysCap [10] **Provide Track Edge ID**
Energy Monitoring	**Manage Energy Asset**	**[20]**	**x**								

Table 1 - System Capabilities allocation to users and Operational Needs.

4 LOC-OB Constraints

4.1 Identified LOC-OB Constraints

4.1.1 Constraints based on TSI

This chapter describes constraints to the LOC-OB exported from the current ETCS implementation and existing TSI.

4.1.1.1 LOC-OB Functionality and Performance

In accordance with existing Ref [28] the actual train position is defined as a relative train position as distance to the last relevant balise group (LRBG), defined as track reference point. The balise reader as part of the today`s localisation functionality is currently implemented in the European Train Control System – On-Board (ETCS-OB) unit. The new intended LOC-OB unit would require taking over localisation functionality from the current ETCS-OB unit. Also, the generation and transmission of the train position report is currently allocated to ETCS-OB as per Ref [28] and will be affected by the functional reallocation of localisation functions to LOC-OB.

The current definition/computation of position report imposes certain limitations (cf. Ref [11]):

- The provisioning of position reports is non-continuous, including unavailability due to communication problems.
- Position report frequency.
- Position report latency.
- Train integrity report frequency.
- Time, confidence interval and location inaccuracy.
- Wake up the train from power-off with invalid, unknown or known but not trustworthy position information.

Open issues (challenges):

In the future, the position report shall be triggered not only as per Ref [28] Chapter 3 but also based on performance and operation of the LOC-OB (e.g., speed dependent) to improve frequency, latency and accuracy.

The future LOC-OB system needs to use a reduced number of balises, be fully operational from ETCS Level 2 on achieving at least the same performance as per Ref [30], while in ETCS Level 0, ETCS Level 1 and national train control, lower performances are acceptable.

The assumption for the LOC-OB system considered within CLUG 2.0 project is that it will provide continuously the localisation information required to produce the position report, while Automatic Train Protection (ATP) will continue producing the position report relying not only on the balise telegram provided by the balise reader but also using other information to trigger the dispatching of a new report such as time, speed or operation information.

The future LOC-OB might need to implement new functionalities (e.g., to support “cab anywhere supervision”) and performance requirements (e.g., waking-up from power-off initialization time), which would require support information as input to LOC-OB.

4.1.1.2 LOC-OB Architecture

In today´s system the localisation functionalities are part of the monolithic ETCS. One of the main goals for the future LOC-OB system is to separate the localisation functions from the core ETCS and transfer them to the LOC-OB unit. Therefore, all ETCS internal functional interfaces between localisation functions and user functions become external system interfaces and need attention for the interface specification from LOC-OB to other systems of the WSoI.

Open issue (challenges):

The required standardised interfaces to be defined in TSI depend eventually on the selected high-level architecture, including which inputs and functionalities are required from the LOC-OB which includes decisions as whether the balise reader shall remain in the ETCS-OB or belong to LOC-OB or whether a cold movement detector (CMD) is required and, in case, whether this functionality should be implemented inside or outside the LOC-OB.

In Ref [3], the LOC-OB external interfaces and functionalities are defined, describing the considered assumptions on the required functionalities and surrounding systems.

4.1.2 Constraints based on GNSS and IMU implementation w.r.t. current TSI (gap)

This chapter describes additional constraints to LOC-OB, introduced by new technology as GNSS and IMU. Existing TSI might be changed in order to enable new technology implementation.

4.1.2.1 LOC-OB Functionality and Performance

One of the main reasons for GNSS and IMU implementation is to reduce the number of balises. Today`s train unit localisation is realised by a relative distance to the LRBG, which is the known trackside reference point (Ref [28]). GNSS based localisation determines the relative position to track by mapping absolute geo position data to a reference track topology. Therefore, the potential sources for the trackside localisation reference points need to be extended to other reference systems than LRBG`s by changing the relevant TSI (revision of Ref [28] required).

All accuracy requirements, measured against the LRBG, must be fulfilled by LOC-OB.

GNSS and IMU technologies might be unavailable or provide insufficient accuracy under certain scenarios, hence support information might be required to back-up and improve accuracy of LOC-OB based on GNSS and IMU.

4.1.2.2 LOC-OB Architecture

As localisation functionality today is integrated in the ETCS specification, the functional interfaces between localisation function and user functions are internal. A new LOC-OB unit containing the localisation functions requires dedicated physical, functional and communication interfaces between the systems of the WSoI and LOC-OB. Those interface specifications must be defined in TSI to ensure modularity.

4.2 Potential solutions for LOC-OB based on not mandatory supportive information

Given the constraints described in the above sections some of the supportive information of the LOC-OB are not mandatory. The impact of the supportive information is analysed and described how it affects the solution of the LOC-OB.

The following supportive information is considered not mandatory:

- Train Integrity Status
- Cold Movement Detection
- Eurobalise telegram and Last Relevant Balise group
- Digital Map On-board

GNSS augmentation data Train Integrity Management System (TIMS) To perform its functionalities the LOC-OB needs as input the position of the sensors and antenna (Static Train Configuration), side of the train front end (Dynamic Train Configuration).

To provide full functionalities to all its users the LOC-OB needs to be mounted on the leading cab. When the LOC-OB is not mounted on the leading cab a reduced functionality (1D localisation information) can be provided to its users if the train integrity status information from TIMS is an input for the LOC-OB.

4.2.1.1 Cold Movement Detection (CMD)

When using a CMD device it can be confirmed whether the last stored position is valid after waking up from no power (NP) mode. This can shorten the time required till the LOC-OB provides a valid position. Another option to ensure availability and reliability of the localisation information right after start-up is maintaining LOC-OB system always ON (e.g., using a dedicated battery).

4.2.1.2 Reference location for localisation

The LOC-OB needs a reference location from which it can estimate safely the current train localisation information. Current ETCS provides this information with regards to the last relevant balise group. However, as raised in Section 4.1.2.1, LOC-OB is meant to function with a reduced number of balises hence alternative positions (e.g., points in digital map, track edge nodes…) might need to be input as reference locations to LOC-OB system.

4.2.1.3 Digital Map On-Board (DM-OB) and Train Routing Information

When reducing the number of balises to meet the business case, a new and most preferable, continuously available reference position for localisation needs to be defined. Reference points defined in the input map data can be used as reference location points.

Given the limitations in terms of availability and accuracy of GNSS and IMU sensors in certain scenarios (cf. Section 4.3, Ref [2]) the digital map together with the routing information could be used as input to the fusion algorithm to improve the LOC-OB positioning performance. A dedicated study will be performed within CLUG 2.0 WP3 to analyse the potential safety risks set by LOC-OB using the route information from trackside to compute localisation information.

4.2.1.4 Augmentation

When using GNSS for train unit positioning, augmentation data (e.g., EGNOS) is required to improve information integrity and accuracy.

5 Railway HL Users Requirements

5.1 Introduction

The high-level users' requirements defined in Section 5.3 constitute the collection of the functional and non-functional needs from users´ localisation information identified in Section 2.2.

The set of LOC-OB system requirements is defined in Ref [4]. LOC-OB System Requirements (functional and non-functional, excluding Reliability, Availability, Maintainability and Safety (RAMS)) will be derived from the set of high-level users' requirements defined in Section 5.3.

In order to consolidate the set of railway high-level users' requirements towards the LOC-OB system defined in previous projects and initiatives the following documents are considered:

From CLUG (1) project: D2.1 High-Level Mission Requirements Definition (cf. Ref [22])

From LWG: LOC-OB System Definition and Operational Context (cf. Ref [17])

From X2RAIL-2 project: D3.8 Stand Alone System Requirements Specification for Fail-Safe Train Positioning (Ref [20])

5.2 Requirements Categorization

The high-level users' requirements on LOC-OB are divided into the following categories:

- Functional
- Non-functional:
    - Performance
    - Economic constraints
    - Interoperability
    - Modularity
    - Compatibility
    - Operational and Environmental conditions
    - RAMSS

Functional requirements are those concerning a result or behaviour that shall be provided by a function or system.

Performance requirements are those boundary value and accuracy requirements of functional parameters.

Economic constraint requirements are those external requirements imposing a restriction on the maximum overall system cost.

Interoperability requirements are those requirements ensuring interoperability within the railway system of the European Union and its affiliate members.

Modularity requirements are reflecting the goals of CLUG 2.0 to define an enhanced, modular on-board localisation subsystem integrated with the ETCS.

Compatibility requirements are those requirements reflecting the need of ensuring backward compatibility with ETCS (at least L2).

Operational and Environmental conditions requirements are those requirements reflecting the conditions under which LOC-OB system shall perform.

RAMSS requirements are reliability, availability, maintainability, safety and security-related requirements. The LOC-OB system should, as a minimum, maintain the safety level of today´s ETCS-OB system.

5.3 High Level User Requirements (towards LOC-OB)

The documents considered and mentioned in the Section 5.1 serve as guideline for defining the functional and non-functional high-level user requirements for the LOC-OB. This includes the definition of train position information that needs to be provided, the integrity, accuracy requirements of the provided information as well as performance and RAMSS requirements of the LOC-OB.

5.3.1 Methodology

To facilitate the identification of requirements and their attributes, a generic template is defined as shown below.

Req ID	*A unique identifier is assigned to each requirement:* UR[00X].
Requirement	*Definition of the requirement itself. It shall be considered as the mandatory inputs to be fulfilled in the following phases.*
Rationale	*Explanation to support the understanding of the requirement. The rationale is not constrained and can contain text, links to other chapters, links to documents etc.*
Category	*Tag used to classify the requirement. Categories are defined in Section 5.2.*
Traceability	*Traceability to operational needs (OpNeed(X)), system capabilities (SysCap [X]) or reference to general standards to be followed by railway applications.*

5.3.2 High level functional requirements

Req ID	UR[001]
Requirement	LOC-OB shall provide 1D localisation information: - Acceleration (estimated, underestimation, overestimation). - Speed (estimated, underestimation, overestimation). - Position (estimated, underestimation, overestimation). - Train movement direction - Train orientation - Side of the position from/to reference location - Track Edge Id.
Rationale	1D localisation information is relative to the along-track reference frame and to a reference location. Localisation information contains at least train positioning values, speed and acceleration values to be used at least by the Train Protection system.
Category	Functional
Traceability	SysCap[1]; SysCap[2]; SysCap[3]; SysCap[4]; SysCap[10]

Req ID	UR[002]
Requirement	LOC-OB shall provide acceleration, velocity and position in a common 3D reference system.
Rationale	Hazard Identification and Evaluation functions have been identified as user of 3D localisation information in order to provide hazard information to on-board systems such as protection and TCMS (cf. Section 2.2.7.2).
Category	Functional
Traceability	SysCap[7]; SysCap[8]; SysCap[9]

Req ID	UR[003]
Requirement	LOC-OB shall provide vehicle attitude in a common 3D reference frame
Rationale	Hazard Identification and Evaluation, Perception systems are based on camera analysis and require this type of data.
Category	Functional
Traceability	SysCap[6]

Req ID	UR[004]
Requirement	After being powered up and its initialisation stage ended, LOC-OB shall provide data continuously.
Rationale	LOC-OB is a data provider.
Category	Functional
Traceability	SysCap[1] to SysCap[10]

Req ID	UR[005]
Requirement	Even if LOC-OB is not able to provide the train position, speed shall be provided by LOC-OB in order to move the train.
Rationale	Even if delivering only speed it has a major impact on the train capabilities in terms of automation, staff responsible driving is still possible. The speed displayed at the DMI is provided by LOC-OB. The Driver needs speed information to move the train. To be noticed that the distance ran since power-on is used by some Specific Transmission Module (STM) to supervise the train movement in addition to speed.
Category	Functional
Traceability	SysCap[2]

5.3.3 High level non-functional requirement

Req ID	UR[006]
Requirement	LOC-OB shall provide localisation information with an accuracy that fulfils the existing and future users' application needs (estimated position/speed, min/max safe front end) as specified in the operational needs.
Rationale	ATO is assumed to be the most demanding LOC-OB user in terms of accuracy. Since no standardisation toward ATO is yet available, assumptions will be made considering available results from relevant projects. Driver or ATO shall be able to approach a signal, a sign at an on-sight distance in accordance with the national driving rules. The detailed requirement for the accuracy of the localisation information can be found in Ref [4].
Category	Performance
Traceability	SysCap[1] to SysCap[10]

Req ID	UR[007]
Requirement	LOC-OB shall provide localisation information in adequacy with the temporal constraints of the existing and future users' application needs as specified in the operational needs.
Rationale	Temporal constraints can refer (but not only) to the management of the processing and transmission delays and the detection of temporal obsolescence. ATO is assumed to be the most demanding LOC-OB user in terms of data freshness. Since no standardisation toward ATO is yet available, assumptions will be made considering available results from relevant projects.
Category	Performance
Traceability	SysCap[1] to SysCap[10]

Req ID	UR[009]
Requirement	If safety is not in concern, LOC-OB, between two successive localisation information, shall not provide a variation of the confidence interval that leads to brake intervention or trip (TR) mode.
Rationale	In the case the increase of the overestimation is too large, the train's minimum safe rear end can be seen as moving backwards with respect to the travelling direction. The following train can then trig brake intervention or trip (TR) mode if the two trains are close to each other. In the case the increase of the underestimation is too large while the train is approaching an LoA or EoA, the train can trig brake intervention or trip (TR) mode.
Category	Performance
Traceability	OpNeed [8]; OpNeed [11]

Req ID	UR[010]
Requirement	When compared to the current ERTMS baseline, the same performances shall be achieved by LOC-OB using a significantly reduced number of balises.
Rationale	From CR1368 Enhanced on-board localisation.
Category	Performance / Economic constraints
Traceability	§ 4.1.1

Req ID	UR[011]
Requirement	If safety is not in concern, the absolute maximum allowed value of the LOC-OB confidence interval shall be lower compared to baseline ETCS BL3 R2 [SS041].
Rationale	The values of the confidence interval are derived from capacity studies or operational rules. The maximum allowed value of the confidence interval is one of the measures that affect the capacity of the line.
Category	Performance / Economic constraints
Traceability	§ 4.1.1

Req ID	UR[012]
Requirement	LOC-OB shall guarantee all its functionalities for trains running up to 500km/h.
Rationale	To be noticed that 600km/h is sometimes defined in the ETCS environment. The maximum speed value defined in Ref [30] is 500km/h.
Category	Performance / Compatibility
Traceability	§ 4.1.1

Req ID	UR[013]
Requirement	LOC-OB shall add economic benefits (opex and capex) to IM and RU in comparison to Ref [30] odometry definition.
Rationale	Replacing the current odometry / positioning of ETCS with 1D reference to balises by a LOC-OB based on e.g., GNSS, IMU, onboard track map etc. shall only be done if the business case is positive for IMs and RUs.
Category	Economic constraints
Traceability	§ 4.1.1

Req ID	UR[014]
Requirement	LOC-OB shall be designed as an independent constituent of the Control Command and Signalling On-Board (CCS-OB) with standardised interfaces.
Rationale	Defining the LOC-OB as an independent constituent will ease integration in different designs and implementations. LOC-OB should also be separately upgradeable with minimum effort toward certification update of the complete ETCS On-Board Unit (OBU).
Category	Modularity
Traceability	§ 4.1.1

Req ID	UR[015]
Requirement	LOC-OB shall be a constituent separated from the core ETCS through a standardised interface.
Rationale	The interoperability constraints are defined through Technical Specification of Interoperability. A new iteration of the current TSI is ongoing.
Category	Interoperability
Traceability	§ 4.1.1

Req ID	UR[016]
Requirement	LOC-OB being an electronic embedded component, LOC-OB shall comply with applicable environmental standards.
Rationale	Ref [37] constituent and can be useful as a guidance. LOC-OB shall achieve all performance targets in the railway environment met in Europe.
Category	Operational and environmental conditions
Traceability	Ref [30]

Req ID	UR[018]
Requirement	LOC-OB shall achieve all performance targets under the following train behaviour or surrounding environment: - All types of physical environments such as station areas surrounded by high buildings, forests, etc. - all types of Rail infrastructure (e.g., tunnels, bridges, with or without catenary, concrete track, ballast track, etc). - Under all types of train acceleration/deceleration conditions - Under train jerk conditions - Under coasting mode - Under slip/slide conditions - Under sparks with overhead line - Under ballast throw - Under steep ramp/slope - Under small radius curve
Rationale	The system is designed to be used under nominal mode of train operation.
Category	Operational and environmental conditions
Traceability	Ref [30]

Req ID	UR[019]
Requirement	LOC-OB shall achieve backward compatibility with ETCS L2 defined in Ref [30].
Rationale	A train equipped with the LOC-OB shall be operated on the existing ETCS line (BL3R2) without any additional engineering work or added features.
Category	Compatibility
Traceability	§ 4.1.1

Req ID	UR[020]
Requirement	The safety of the LOC-OB shall be ensured and demonstrated according to the Common Safety Methods [ERA CSM] and the [EN 50126] standard.
Rationale	LOC-OB is a safety related constituent, Common Safety Methods (cf. Ref [34]) and the EN 50126 standard (cf. Ref [5]) shall be applied.
Category	RAMSS
Traceability	Ref [30]

Req ID	UR[021]
Requirement	LOC-OB shall not degrade safety toward odometry as defined in the ETCS BL3 R2.
Rationale	Current ERTMS standard on safety (cf. Ref [31]) has to be kept as valid.
Category	RAMSS
Traceability	§ 4.1.1

Req ID	UR[022]
Requirement	The true train position shall be always inside the confidence interval.
Rationale	The confidence interval determines the part of the track that guarantees where the possible true train front end position is.
Category	RAMSS
Traceability	SysCap [1]

Req ID	UR[023]
Requirement	The true train speed shall be always inside the confidence interval.
Rationale	The confidence interval describes a lower and upper boundary of the true train speed. To be noticed that the lowest possible speed may not be critical in terms of safety.
Category	RAMSS
Traceability	SysCap [2]

Req ID	UR[024]
Requirement	The true train acceleration shall be always inside the confidence interval.
Rationale	The confidence interval describes a lower and upper limit/boundary of the train true acceleration. It could be used to determine the braking distance (cf. Ref [28]).
Category	RAMSS
Traceability	SysCap [3]

Req ID	UR[025]
Requirement	Each localisation information shall fulfil safety target requirements in accordance with the user's application requirements.
Rationale	User applications can export safety requirements on the information to fulfil their safety requirements. WP3 will provide the safety constraints towards LOC-OB.
Category	RAMSS
Traceability	Ref [30]

Req ID	UR[026]
Requirement	The LOC-OB shall fulfil requirements and recommendations for cybersecurity as specified in [CLC/TS 50701:2021] with the purpose to demonstrate that the system is up to date from a cybersecurity perspective and that it meets and maintains the target level of security for the entire system life cycle.
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 should be accessible according to users and roles.
Category	RAMSS
Traceability	Ref [30]

6 Conclusions

This document created in the scope of the CLUG 2.0 project is the continued work of the CLUG (1) project, so it is based on the results achieved in CLUG (1) but also previous projects in X2Rail-5, RCA, OCORA. The target of the document was to collect the set of high-level user requirements that fulfil the needs of railway users towards a localisation system.

In conclusion during the analysis of the railway users that need localisation information two main users were identified: Infrastructure Managers and Railway Undertakings. The users were represented by their trackside and on-board systems in the LOC-OB Wider System of Interest. During the analysis of the operational needs of these systems it has been shown that some assumptions need to be made for these systems in order to define the system capabilities of the LOC-OB.

The goal is that all localisation information that is needed by the identified railway users will be provided by the LOC-OB. The new solution would introduce new technologies (e.g., GNSS and IMU) for localisation into the railway system. It needs to be confirmed if this goal is achievable in the next phases of the project during the system design, development and testing of the LOC-OB.

Some of the identified systems that require localisation information are still under development within the European frame such as Digital Register, Perception and Hazard Identification and Evaluation. Therefore, additional assumptions had to be made on the function performed by these systems.

Based on the constrains identified while analysing the current European Train Control System (ETCS) and the target system of CLUG 2.0 it has been shown that some functionalities regarding localisation will be provided by the ETCS-OB (e.g., Define reference location, provide position report). Other functionalities were identified as LOC-OB system capabilities.

Therefore, based on the analysis performed and assumptions taken the high-level functional and non-functional requirements were derived which define the main targets of the localisation system. These requirements are the basis for the system definition proposed in D2.2, D2.3 and D2.4, the system design in WP4 and evaluation in WP5.

7 APPENDIX A: Localisation accuracy impact on line capacity

7.1 Introduction

Due to the increasing demands of ETCS railway operations, the requirements for the localisation system on the on-board side become more challenging as well. Among other things, ETCS monitors the maximum permitted speed (considering the ETCS braking curves) and, from ETCS Level 2 Trackside application with no or reduced train detection, the system also manages continuous track vacancy detection. Here the train position accuracy becomes increasingly important, since it influences where a train is required to initiate braking, may accelerate and when the track can be released.

In general, the position of the train in ETCS operation is determined with respect to the LRBG. If the train passes a balise, the exact position (depending on the balise installation tolerance, i.e., “Q_LOCACC”) of the train is known at this point. Between two balises, the position must be estimated by the train itself. Regardless of which technology (e.g., odometry sensors or GNSS) that is used for this purpose, the determined position is always subject to uncertainty, e.g., due to measurement inaccuracy.

Initially, the terms “confidence interval“, “over/under reading amount” (or odometry error) and “distance measurement inaccuracy” need to be defined and differentiated, as they are all related to the train’s position accuracy and thus often get confused. The distance measurement inaccuracy is defined here as the actual inaccuracy of the estimated position of the train front end, hence the distance between the actual and the estimated position of the train front end (c.f. both illustrations from below in Figure 7). It must be noted that the actual value of the distance measurement inaccuracy is not readily known but can be estimated and must not be larger than the permitted odometry inaccuracy. The confidence interval provides the range in which the true train front end is located with high probability and is composed of the maximum measurement deviation (i.e., the maximum expectable measurement inaccuracy) and the balise installation tolerance (i.e., “Q_LOCACC”). Figure 6 visualizes the determination of the confidence interval. Note here, for safety reasons, a brake intervention is triggered as soon as the max safe front end passes the ETCS intervention curve. Figure 7 shows the braking intervention for different confidence intervals and distance measurement inaccuracies.

The purpose of this appendix is to investigate the impact of confidence interval different models and sizes on capacity and operational quality. All relevant information was taken from the article written by van Hövell et al. (cf. Ref [61]) unless otherwise stated. Please note that in the following, to remain consistent with the wording from the references, the confidence interval is defined by the odometry error. This odometry error can be replaced by the error of other localisation methodologies to determine the confidence interval. As described by the authors of Ref [60], different modelling for the confidence interval must be used for novel sensor technologies (e.g., GNSS or IMU). For example, the confidence interval determined using GNSS can become smaller again depending on the GNSS reception, even if no balise is crossed. This confidence interval can also change when the vehicle is stationary. If, in comparison, only odometry sensors are used to determine the confidence interval, the confidence interval grows monotonously and does not change even when stationary.

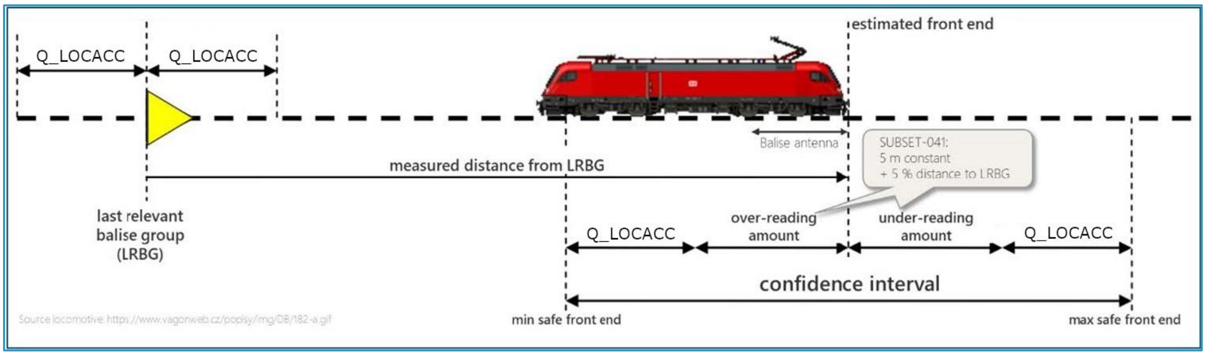


Figure 6 - Determination of the confidence interval according to Ref [28].

Note that in Figure 6 "Q_LOCACC" refers to the balise installation tolerance and that the combination of "Q_LOCACC" and "over-reading amount is stated as L_DOUBTOVER and the combination of "Q_LOCACC" and "under-reading amount" is stated as L_DOUBTUNDER.

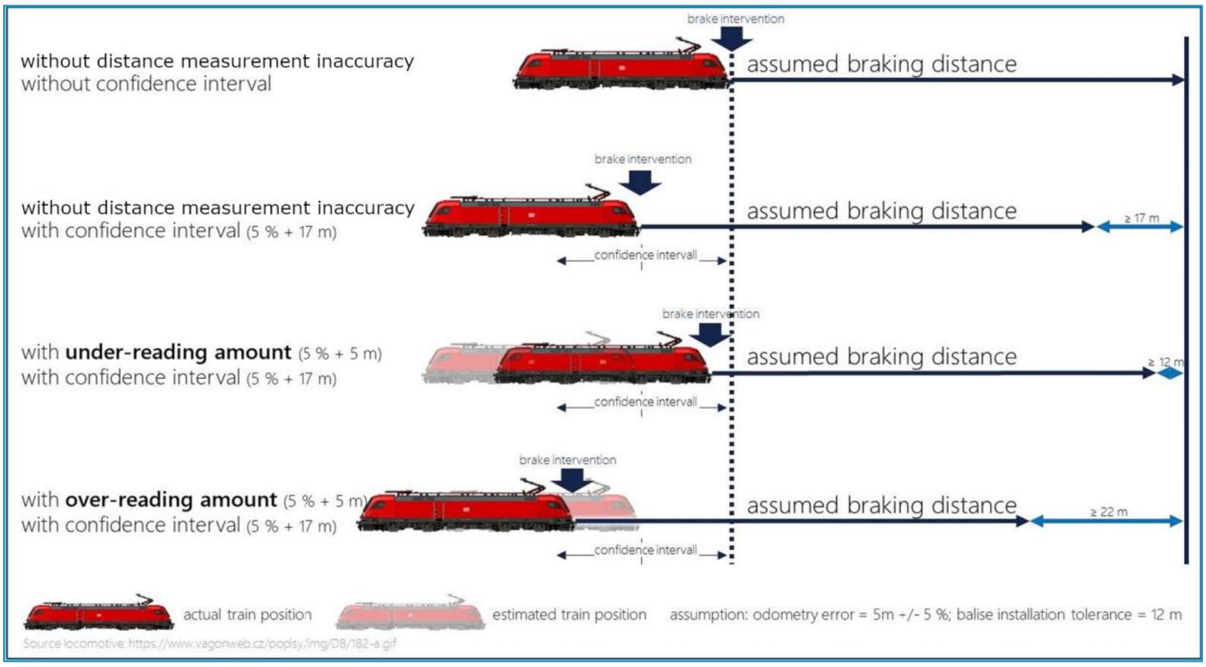


Figure 7 – Influence of the distance measurement inaccuracy and the confidence interval on the ETCS braking curve.

Note that the timing of the brake intervention in Figure 7 depends only on the estimated train position. As soon as the max safe front end (c.f. Figure 6) passes the vertical line, the train is braked.

7.2 Localisation accuracy requirements

7.2.1 Current accuracy definition: TSI Subsets 026 and 041

The accuracy to be achieved by the on-board localisation system of a train is defined in Ref [30]. For every measured distance s the accuracy shall be better or equal to $\pm(5\,m + 5\,\% \cdot s)$, i.e., the over reading amount and the under reading amount shall be equal to or lower than $(5\,m + 5\,\% \cdot s)$. Note that this requirement for accuracy includes the error of detecting the positions of the balises. Also in case of malfunctioning the on-board equipment shall evaluate a safe confidence interval.

As defined in Ref [28] the confidence interval model increases in relation to the distance travelled from the LRBG and depends on the Q_LOCACC until it is reset when another Balise Group (BG) becomes the LRBG.

7.2.2 CLUG (1) accuracy requirements

In the preceding project CLUG (1), half of the Mission Confidence Interval for Operations (MCI) was set to $10\,m$ if the speed of the train is below $36\,\frac{km}{h}$.For speeds greater than $36\,\frac{km}{h}$ and up to $600\,\frac{km}{h}$, the size of the confidence interval increases linearly according to Figure 8 (cf. Ref [59]).

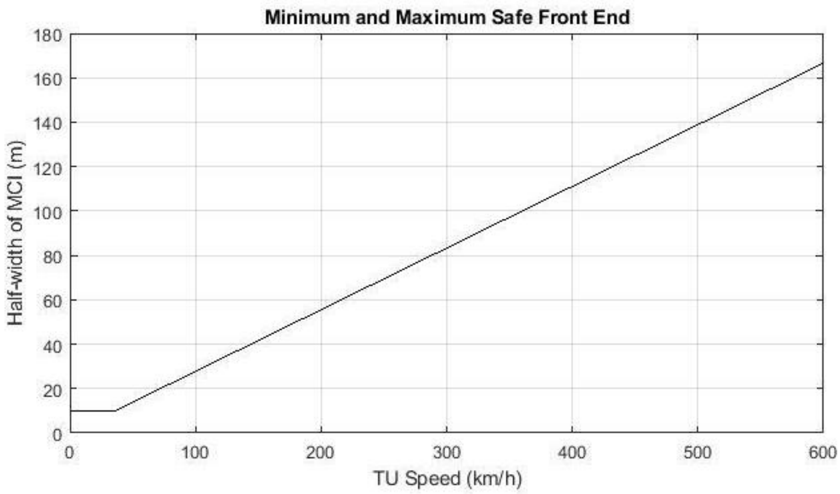


Figure 8 – Half-width of MCI for Min and Max Safe Front End.

7.3 Capacity effects

7.3.1 Background

This section is intended to discuss the influence of the confidence interval on the capacity, respectively the influence on the average minimum headway times. The headway is the time difference between two trains following each other on the same track. In the following, the minimum headway time (MHT) is the smallest achievable time difference between two trains and the average MHT is defined here as the average of all MHTs weighted with the probability of occurrence of a certain train type. The confidence interval can trigger the following effects on capacity:

- Since ETCS triggers a braking intervention as soon as the max safe front end passes the ETCS intervention curve, a larger confidence interval can have a negative effect on the travel time. In other words, the train is braked "too early" by ETCS, which increases the travel time.

- A larger confidence interval leads to an earlier pre-occupancy of the ahead track section since the occupancy is determined based on the max safe front end (c.f. ETCS Level 2 Trackside application with and without train detection). Consequently, a larger distance between the trains must be maintained, which leads to a lower capacity and higher MHTs.
- If a track is released with the assistance of on-board sensor systems (as in ETCS Level 2 Trackside application with no or reduced train detection), a larger confidence interval at the rear end has a negative influence. The travelled track section (regardless of whether it is a moving block or a fixed track section) is released in ETCS Level 2 Trackside application with no or reduced train detection at the earliest when the min safe rear end has passed the section, and when a new position report is sent. In other words, the travelled track section is released with a delay, which leads to a loss of capacity. An additional delay can be caused by the processing time of the on-board system, by a transmission delay and by the processing time of the trackside technology.
- The min safe rear end is also used to determine the point at which the train is allowed to accelerate in case of a max line speed increase. For example, if a train has passed a switch at low speed, the train may not accelerate until the min safe read end has passed the switch area. In other words, the train accelerates with a delay which leads to a longer travel time and hence to a loss of capacity.
- The confidence interval has a significant influence when it is large in relation to the breaking distance. This is the case when a train reaches a station at low speed. If the confidence interval is large, the train will brake too early, which has a negative impact on the capacity of the line. When travelling at high speed on an open track, the breaking distance is usually much larger compared to the confidence interval, and thus has only a small influence on the capacity compared to the breaking distance. Figure 7 shows the interaction of confidence interval and braking distance.

7.3.2 Methodology

Different localisation procedures can be used for dimensioning the confidence interval. The effects of the following procedures on the capacity are compared in this section:

1. **Distance dependent confidence interval**
   This confidence interval refers to the odometry error and is composed of a constant value and a distance-dependent component. According to Ref [30], the accuracy shall be better or equal to: $5\ m \pm 5\ \% \cdot d$. Here, d is the distance to the LRBG.
2. **Speed dependent confidence interval**
   This confidence interval considers, in addition to a constant value, a velocity-dependent component, e.g.: $MAX(10\ m;\ 1\ s \cdot v_{train})$.
3. **Constant confidence interval**
   This confidence interval refers to an exclusively constant odometry error. It is a simple modelling interval and is compared against the other two methods described to verify their overvalue.

In total, the 21 variants, listed in Table 2, are evaluated. The variants of the distance-dependent confidence interval were simulated without additional balises (basic state) and with additional balises. In the basic state (c.f. ETCS Level 2), the balises have an average distance of $500\ m$ and a maximum distance of $1450\ m$. The variants of the speed dependent confidence interval were simulated without trackside train detection and with trackside train detection. As already mentioned, this has an impact on capacity, since in the case without trackside train detection, the min safe rear position is used for track release.

Confidence interval	Variant						
Distance dependent	$10\ m \pm 5\ \%$		$5\ m \pm 5\ \%$		$5\ m \pm 2\ \%$		$1\ m \pm 2\ \%$
($4 \cdot 2$ variants)	With and without additional positioning balises[1]						
Speed dependent	$MAX(10\ m; 1\ s \cdot v_{train})$		$MAX(5\ m; 1\ s \cdot v_{train})$		$MAX(10\ m; 1\ s \cdot v_{line})$		
($3 \cdot 2$ variants)	With and without trackside train detection[2]						
Constant	$40\ m$	$35\ m$	$20\ m$	$10\ m$	$5\ m$	$1\ m$	$0\ m$
(7 variants)							

Table 2 – Summary of the variants considered with respect to the capacity analysis. Note v_line is the maximum permitted speed on the line, while v_train is the actual train speed.

7.3.3 Assumptions

To analyse the effects of the various confidence intervals on capacity, the following assumptions were made in the underlying simulation:

- In most simulated variants, the balise installation tolerance (Q_LOCACC) was not explicitly considered, as this is already mapped by the varied constant components of the confidence intervals.
- No distance measurement inaccuracy is assumed, consequently the Estimated Front End (estFE) equals the actual front end (c.f. Figure 7 second from top).
- The estimated rear end is calculated as a function of the estFE (with the aid of the train length, while train integrity is assumed). Note that the confidence interval at the rear end equals the confidence interval at the front end.
- The average MHT is used as a metric to determine the effect of confidence intervals on the capacity. To determine the average MHT, the underlying infrastructure (c.f. Section 7.3.4) is divided into sectional route nodes. A subsectional route node is the area around a railway junction which may be occupied by only one train, e.g., a switch area. The subsectional route node with the highest occupancy rate is decisive for determining the average MHT. For all

[1]The number and position of balises correspond in the basic state (i.e., without additional balises) to an ETCS Level 2 layout with an average distance between balises of 500 m.

[2] Due to the underlying ETCS Level 2 Trackside application with no or reduced train detection architecture, all scenarios regard trainside track liberation besides trackside train detection is explicitly mentioned.

possible train sequences in operation, the MHT is now determined within this sectional route node. The average MHT is then the average of all MHTs weighted by the probability of occurrence of the corresponding train sequence.

- For the simulation, an ETCS Level 2 Trackside application with no or reduced train detection configuration with moving blocks is assumed, whereby the number of balises in the basic state totals 89.

7.3.4 Confidence Interval Effects on Capacity

The following capacity analysis is based on the queueing theory and refers to a generic infrastructure and operational program, whereby the operational program (c.f. Figure 11) and infrastructure (c.f. Figure 9) were developed by VIA-Con and SBB (I.NAT). In Figure 10 the decisive sectional route node for this scenario is depicted, with all trains passing through this node being considered in the analysis.

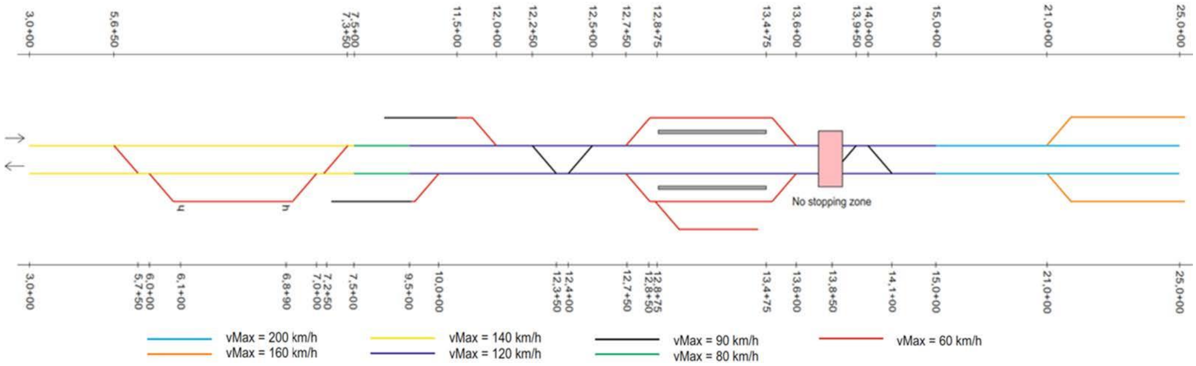


Figure 9 – Generic infrastructure developed by VIA-Con and SBB (I.NAT) with associated maximum line speed used for the evaluation.

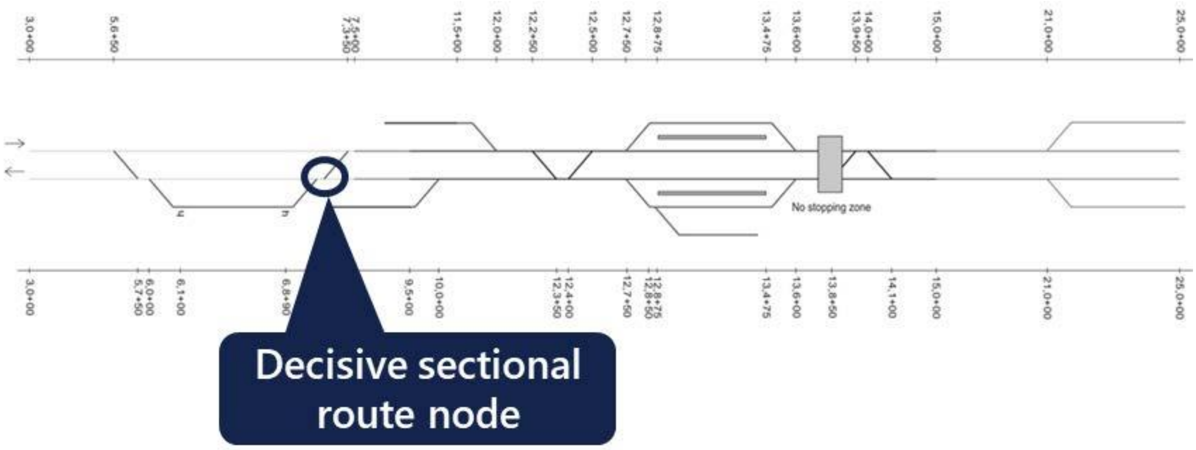


Figure 10 – Decisive sectional route node for which the average MHT for the underlying operational program is determined.

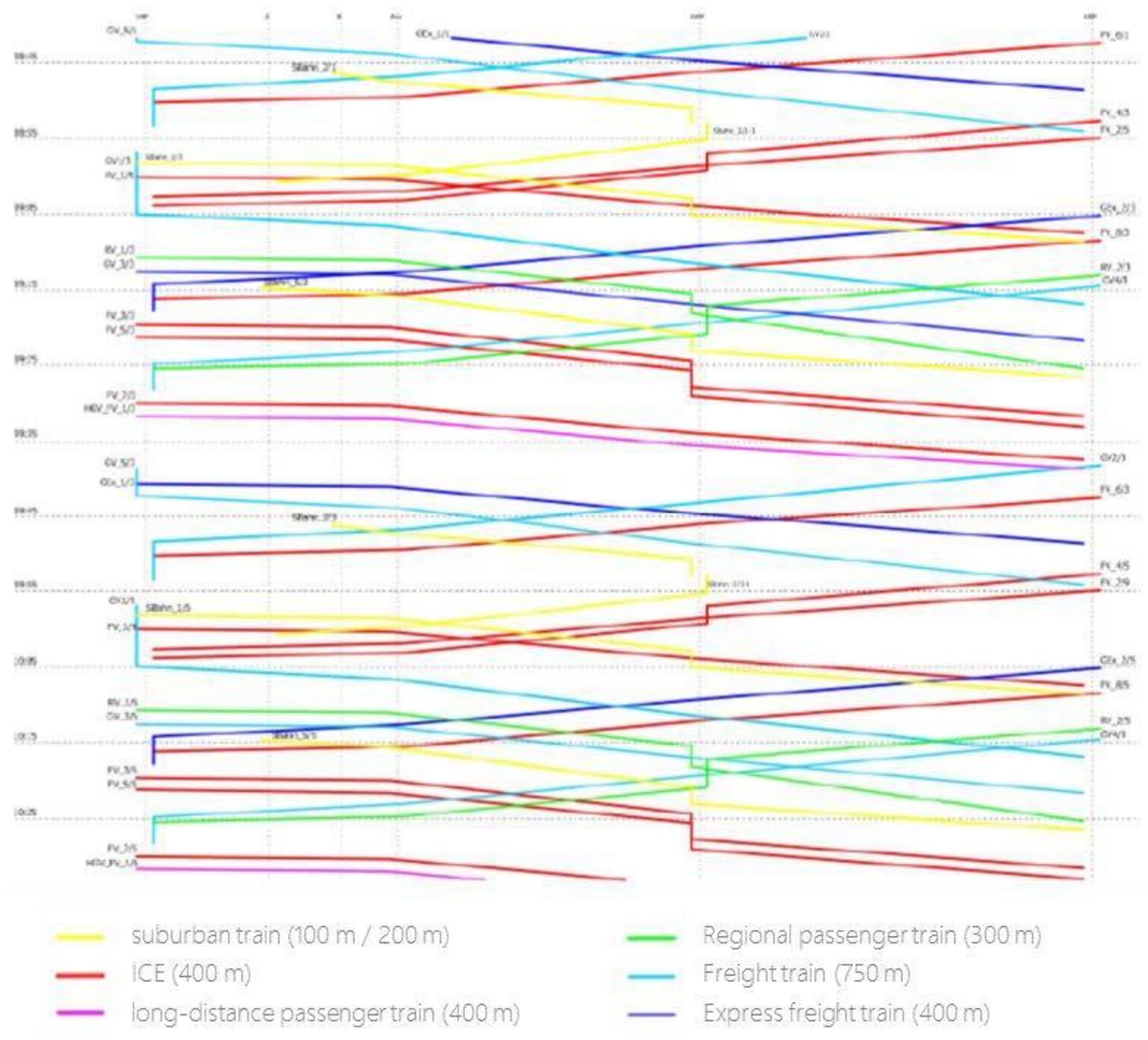


Figure 11 – Generic operational program developed by VIA-Con and SBB (I.NAT) with a duration of four hours.

First, the results are examined exemplarily on a train sequence of a long freight train, with low braking force and a following Intercity-Express (ICE) (c.f. Figure 12). The freight train has a length of $750\ m$ with a braking percentage of 65 and the ICE a length of $400\ m$ with a braking percentage of 198. The results are shown in Figure 12, where the pre-occupation, the trajectory and the release are plotted versus time for both trains, each for the corresponding scenario. Note that for this example only the confidence intervals with a constant value of $5\ m$ are examined.

Compared to the constant confidence interval, the MHT of the speed dependent confidence interval ($MAX(5\ m; 1s \cdot v_{train})$; without trackside train detection) increases by $2\ s$. This is caused by an earlier pre-occupation and later release of the sectional route node. Using the distance-dependent confidence interval ($5\ m \pm 5\ \%$; without additional positioning balises), the MHT increases by $17\ s$ compared to the constant confidence interval. Using four additional positioning balises, the difference to the constant confidence interval can be reduced to $5\ s$, although it must be pointed out here that this does not correspond to the objective of ETCS Level 2 Trackside application with no or reduced train detection. In this case, the additional positioning balises were installed at relevant positions near the decisive sectional route node (c.f. Figure 12), thus reducing the occupancy time of the corresponding switch point. Note that both trains run on the generic infrastructure in Figure 9 from right to left and the ICE overtakes the freight train after the decisive sectional route node. The additional balises used depending on the scenario are marked with a grey border.

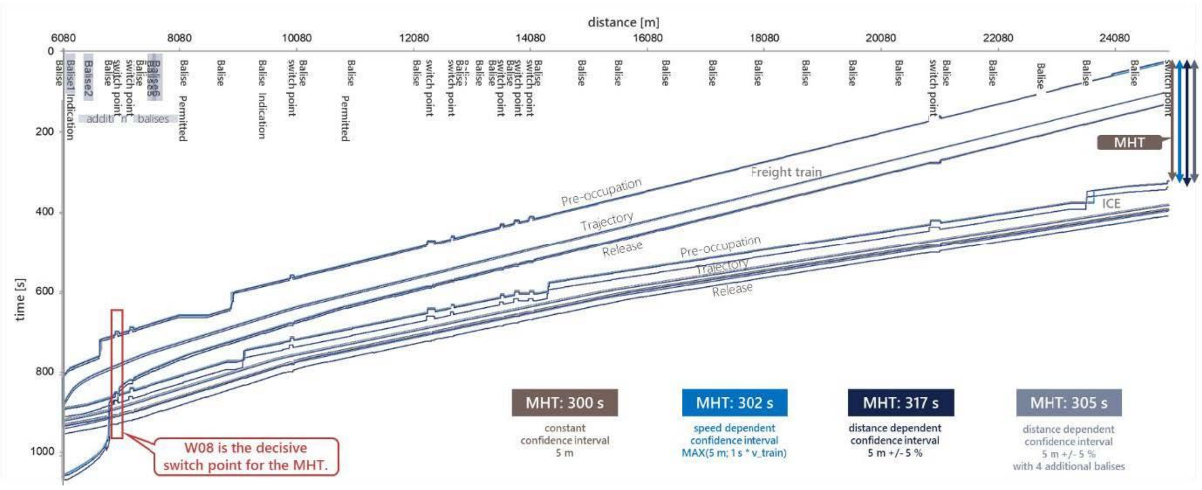


Figure 12 – MHT in comparison to different confidence intervals with constant value of 5 m for a train sequence of a $750\ m$ long freight train with 65 braking percentages and a $400\ m$ long ICE with 198 braking percentages.

Now the average MHTs of all variants (c.f. Table 2) using the entire generic operational program (c.f. Figure 11) are compared. The results for the MHTs of all variants, apart from the line speed dependent variants, are shown in Figure 13. Results for the line speed-dependent variants are shown separately in Figure 14.

The worst result is achieved by the constant confidence interval of $40\ m$, closely followed by the distance-dependent confidence interval ($10\ m \pm 5\ \%$), whereas also in this case the results can be significantly improved by 8 additional positioning balises. The average MHTs of the speed-dependent confidence intervals change only slightly by varying the constant component (c.f. Figure 14). In this case, the existence of trackside train detection has only a minor influence, i.e., the MHT can only be reduced by 0.6 percent if the track is released based on trackside equipment.

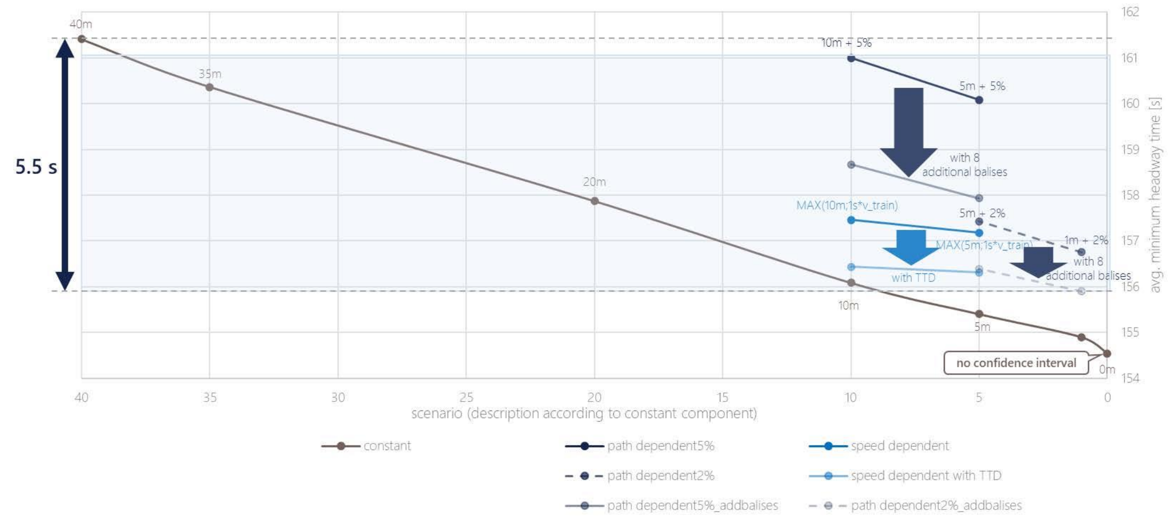


Figure 13 - Results of the MHTs for all variants of the confidence intervals listed in Table 2, except for the line speed-dependent variants, which are shown separately in Figure 14.

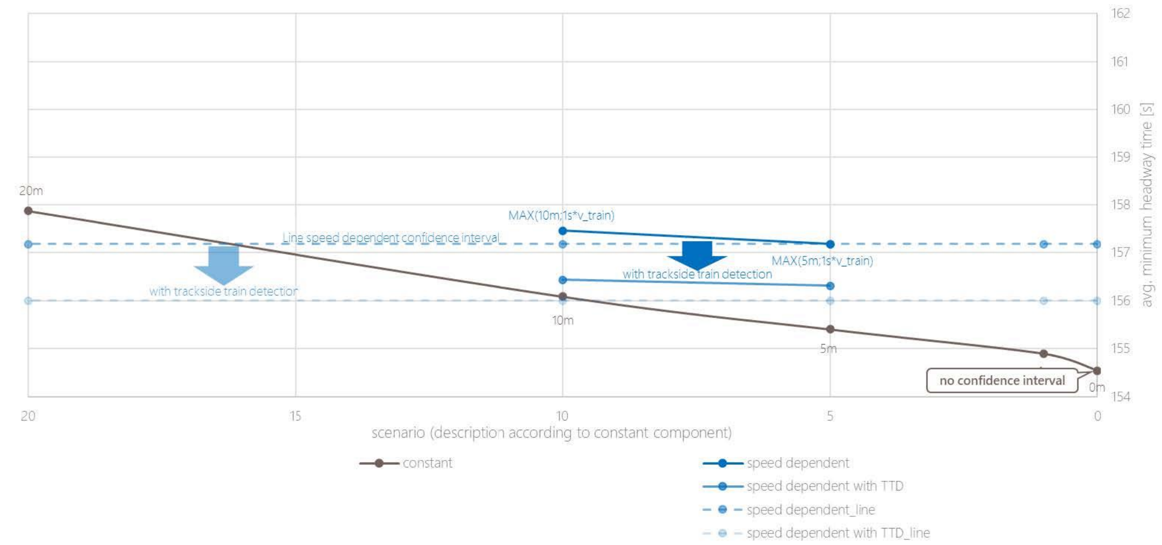


Figure 14 - Results of the MHTs for all speed-dependent variants of the confidence intervals listed in Table 2. For comparison, the results for the constant confidence intervals are plotted additionally.

7.3.5 Summary

In summary, all distance and speed-dependent variants can be represented in terms of performance as a constant confidence interval between $10\ m$ and $40\ m$ and have a maximum effect of $5.5\ s$ or $3\ \%$ on the average MHT (c.f. blue marked area in Figure 13). In general, the results of the speed-dependent confidence intervals are better than those of the distance-dependent variants. However, with additional positioning balises the results of the distance-dependent variants can significantly improve, whereby it must be noted that this does not correspond to the objective of ETCS Level 2 Trackside application with no or reduced train detection. Also, the results of the speed-dependent variants can be slightly improved if the track occupancy detection is realized via trackside train detection, nevertheless this also does not correspond to the objectives of ETCS Level 2 Trackside application with no or reduced train detection.

7.4 Impact on Operational Quality

7.4.1 Methodology

This section is intended to discuss the impact of the confidence interval on the operational quality, respectively the influence on the delay. As discussed in the previous section, a larger confidence interval can lead to higher MHTs, hence increased running times. These increased running times lead either to reduced running time reserves or to delays if there is not enough reserve time. To investigate the influence of the different confidence intervals on the operational quality, four representative scenarios (c.f. Table 3) are compared with each other by means of an operational simulation.

To simulate the effect of the different confidence intervals, an operation with interruptions must be simulated. For this purpose, random delay values are added to the regular timetable, which can be reduced with sufficient reserve times. Through anticipatory conflict detection and conflict resolution, conflicts between trains can be avoided by means of disposition options such as modified routes, speeds and stopping times. In most cases, however, this leads to secondary delays, i.e., subsequent delays that result from delays of preceding trains. The simulation software used is "Leistungsuntersuchung Knoten und Strecken®", which tries to be comparable to reality as possible.

Scenario	Represented variant	Capacity effect
$0\ m$ confidence interval	No confidence interval	Reference scenario
$10\ m$ confidence interval	All speed dependent confidence intervals with TTD	1 % longer avg. MHT
	$1\ m \pm 2\ \%$ distance dependent confidence interval with additional balises	
$20\ m$ confidence interval	$1\ m \pm 2\ \%$ distance dependent confidence interval without additional balises	2 % longer avg. MHT
	$5\ m \pm 2\ \%$ distance dependent confidence interval with additional balises	
$40\ m$ confidence interval	$10\ m \pm 5\ \%$ distance dependent confidence interval without additional balises	4 % longer avg. MHT

Table 3 - Selected scenarios for operational simulation, which represent all variants of the different localisation procedures regarding their capacity effect. The scenario with no confidence interval serves here as a reference scenario.

7.4.2 Assumptions

To analyse the effects of the various confidence intervals on operational quality, the following assumptions were made in the underlying simulation:

- Due to the line characteristics (e.g., medium line utilization) and a balanced ratio of different train types, the Herzogenrath-Aachen-Köln line serves as a suitable investigation area.

- For the operational simulation, the current timetable is used, and the simulation covers a period of four hours (from 7 am to 11 am). Here the delay probability and dimension of delay is based on the high default values per train category in Germany.
- For each scenario, 150 simulation runs are performed.
- As the simulation software used does not yet support ETCS Level 2 Trackside application with no or reduced train detection and with Moving Blocks, an ETCS Level 2 with very short blocks is assumed to approximate ETCS Level 2 Trackside application with no or reduced train detection and with Moving Blocks. Note here that the block length between stations has limited influence anyway due to high speeds. The block lengths between stations were set at $70\ m$ and around switch points at $5\ m$. Due to the short block length, the signals are only a few meters behind the stopping positions.
- The influence of open and closed exit signals will also be investigated. For this purpose, the simulation is carried out with the following two assumptions:
    a. At all stations, the exit signal is closed when a stopping train enters the station. This has a negative effect on the journey time, as the ETCS supervision curve is active at the stop entry. In other words, a train is braked too early due to a too large confidence interval (c.f. Figure 7).
    b. At smaller stations (i.e., all stations within the investigation area besides Cologne and Aachen main station), the exit signal is open when a passenger train enters. Note that this assumption is more realistic.

7.4.3 Confidence Interval Effects on Operational Quality

Note that the statistical significance of the results has already been proven in the underlying study (c.f. Ref [61]).

First, the influence of open, or closed, exit signals on the scenarios in Table 3 is to be examined. The running time of the train RB20 from Stolberg to Herzogenrath was investigated. For the simulation, the latest timetable at that time was used with respect to the reserve times. Figure 15 lists the results for the four scenarios, in case of closed exit signals at all stations. Figure 16 shows the running time for the $40\ m$ confidence interval in the case of partly open exit signals at the stations.

As can be seen, even the largest confidence interval in the case of open exit signals affects the running time by only $2\ s$ (c.f. Figure 16). In the case of closed exit signals at all stations, the timetable can only be maintained for the reference scenario and the $10\ m$ confidence interval. For the other scenarios, the running time increases by $10\ s$ or $33\ s$ (c.f. Figure 15). The results can be explained by the fact that only in the case of closed exit signals does a large confidence interval has a negative influence on the running time. For closed exit signals the ETCS supervision curve becomes restrictive and since in this simulation it is assumed that the signals are placed directly behind the stations, the train is braked too early (c.f. Figure 7) because the EoA is located directly behind the station. In the case of open exit signals, the EoA is far enough away from the station so that the ETCS supervision curve is not active.

confidence interval 0 m

RB20_KST_KHERZ/10
Traktion: 643-3.0, 643-3.0
135.20 t, 69.20 m, 150 BrH, 0 km/h
Trassenlänge: 24753 m, Fahrzeit: 32:10

Running time 32:10 min

station	stopping time	arrival	departure	running time allowances
KST G	01:00 / 01:00	08:16:33	08:17:33	100.00
KST P	00:43 / 00:42	08:19:10	08:19:53	110.00
K 907	- / -	08:21:23	08:21:23	109.10
K 954	- / -	08:21:27	08:21:27	114.60
K 909	- / -	08:22:20	08:22:20	114.30
K 952	- / -	08:23:01	08:23:01	100.00
K912	- / -	08:23:06	08:23:06	111.50
K 911	- / -	08:23:18	08:23:18	100.00
K972S	- / -	08:23:25	08:23:25	100.00
KEIL	00:42 / 00:42	08:23:58	08:24:40	110.60
KAREG	- / -	08:26:56	08:26:56	100.00
KAREP	00:42 / 00:42	08:28:06	08:28:48	100.90
KA	00:42 / 00:42	08:31:13	08:31:55	100.00
K0401	- / -	08:33:54	08:33:54	100.00
KASZ	00:42 / 00:42	08:34:34	08:35:16	100.00
E002A	- / -	08:35:26	08:35:26	100.00
KAW P	00:42 / 00:42	08:37:21	08:38:03	100.00
KAW G	- / -	08:39:11	08:39:11	100.00
KRIC	- / -	08:40:51	08:40:51	100.00
KKOS	00:42 / 00:42	08:43:11	08:43:53	100.00
E 803	- / -	08:45:17	08:45:17	100.00
E 850	- / -	08:45:17	08:45:17	100.00
KHEZ	00:42 / 00:42	08:48:01	08:48:43	100.00

Reference scenario

confidence interval 10 m

RB20_KST_KHERZ/10
Traktion: 643-3.0, 643-3.0
135.20 t, 69.20 m, 150 BrH, 0 km/h
Trassenlänge: 24753 m, Fahrzeit: 32:10

Running time 32:10 min

= 0 s

station	stopping time	arrival	departure	running time allowances
KST G	01:00 / 01:00	08:16:33	08:17:33	100.00
KST P	00:43 / 00:42	08:19:10	08:19:53	110.00
K 907	- / -	08:21:23	08:21:23	109.10
K 954	- / -	08:21:27	08:21:27	114.60
K 909	- / -	08:22:20	08:22:20	114.30
K 952	- / -	08:23:01	08:23:01	100.00
K912	- / -	08:23:06	08:23:06	111.50
K 911	- / -	08:23:18	08:23:18	100.00
K972S	- / -	08:23:25	08:23:25	100.00
KEIL	00:42 / 00:42	08:23:58	08:24:40	110.60
KAREG	- / -	08:26:56	08:26:56	100.00
KAREP	00:42 / 00:42	08:28:06	08:28:48	100.90
KA	00:42 / 00:42	08:31:13	08:31:55	100.00
K0401	- / -	08:33:54	08:33:54	100.00
KASZ	00:42 / 00:42	08:34:34	08:35:16	100.00
E002A	- / -	08:35:26	08:35:26	100.00
KAW P	00:42 / 00:42	08:37:21	08:38:03	100.00
KAW G	- / -	08:39:11	08:39:11	100.00
KRIC	- / -	08:40:51	08:40:51	100.00
KKOS	00:42 / 00:42	08:43:11	08:43:53	100.00
E 803	- / -	08:45:17	08:45:17	100.00
E 850	- / -	08:45:17	08:45:17	100.00
KHEZ	00:42 / 00:42	08:48:01	08:48:43	100.00

confidence interval 20 m

RB20_KST_KHERZ/10
Traktion: 643-3.0, 643-3.0
135.20 t, 69.20 m, 150 BrH, 0 km/h
Trassenlänge: 24753 m, Fahrzeit: 32:20

Running time 32:20 min

+ 10 s

station	stopping time	arrival	departure	running time allowances
KST G	01:00 / 01:00	08:16:33	08:17:33	100.00
KST P	00:42 / 00:42	08:19:11	08:19:53	110.60
K 907	- / -	08:21:22	08:21:22	109.10
K 954	- / -	08:21:26	08:21:26	114.60
K 909	- / -	08:22:19	08:22:19	114.30
K 952	- / -	08:23:00	08:23:00	100.00
K912	- / -	08:23:06	08:23:06	109.80
K 911	- / -	08:23:17	08:23:17	100.00
K972S	- / -	08:23:25	08:23:25	100.00
KEIL	00:42 / 00:42	08:24:00	08:24:42	109.00
KAREG	- / -	08:26:55	08:26:55	100.00
KAREP	00:42 / 00:42	08:28:09	08:28:51	100.00
KA	00:42 / 00:42	08:31:16	08:31:58	100.00
K0401	- / -	08:33:57	08:33:57	100.00
KASZ	00:42 / 00:42	08:34:39	08:35:21	100.00
E002A	- / -	08:35:31	08:35:31	100.00
KAW P	00:42 / 00:42	08:37:27	08:38:09	100.00
KAW G	- / -	08:39:18	08:39:18	100.00
KRIC	- / -	08:40:58	08:40:58	100.00
KKOS	00:42 / 00:42	08:43:20	08:44:02	100.00
E 803	- / -	08:45:26	08:45:26	100.00
E 850	- / -	08:45:26	08:45:26	100.00
KHEZ	00:42 / 00:42	08:48:11	08:48:53	100.00

confidence interval 40 m

RB20_KST_KHERZ/10
Traktion: 643-3.0, 643-3.0
135.20 t, 69.20 m, 150 BrH, 0 km/h
Trassenlänge: 24753 m, Fahrzeit: 32:43

Running time 32:43 min

+ 33 s

station	stopping time	arrival	departure	running time allowances
KST G	01:00 / 01:00	08:16:33	08:17:33	100.00
KST P	00:42 / 00:42	08:19:15	08:19:57	106.10
K 907	- / -	08:21:23	08:21:23	109.10
K 954	- / -	08:21:27	08:21:27	114.60
K 909	- / -	08:22:20	08:22:20	114.30
K 952	- / -	08:23:01	08:23:01	100.00
K912	- / -	08:23:06	08:23:06	106.30
K 911	- / -	08:23:18	08:23:18	100.00
K972S	- / -	08:23:26	08:23:26	100.00
KEIL	00:42 / 00:42	08:24:04	08:24:46	105.40
KAREG	- / -	08:26:55	08:26:55	100.00
KAREP	00:42 / 00:42	08:28:13	08:28:55	100.00
KA	00:42 / 00:42	08:31:23	08:32:05	100.00
K0401	- / -	08:34:05	08:34:05	100.00
KASZ	00:42 / 00:42	08:34:52	08:35:34	100.00
E002A	- / -	08:35:44	08:35:44	100.00
KAW P	00:42 / 00:42	08:37:44	08:38:26	100.00
KAW G	- / -	08:39:35	08:39:35	100.00
KRIC	- / -	08:41:15	08:41:15	100.00
KKOS	00:42 / 00:42	08:43:42	08:44:24	100.00
E 803	- / -	08:45:48	08:45:48	100.00
E 850	- / -	08:45:48	08:45:48	100.00
KHEZ	00:42 / 00:42	08:48:34	08:49:16	100.00

Figure 15 - Running time for different confidence intervals of the train RB20 from Stolberg to Herzogenrath with closed exit signals at every stop.

confidence interval 40 m

RB20_KST_KHERZ/10
Traktion: 643-3.0, 643-3.0
135.20 t, 69.20 m, 150 BrH, 0 km/h
Trassenlänge: 24753 m, Fahrzeit: 32:12

Running time 32:12 min

+ 2 s

station	topping time	arrival	departure	running time allowances
KST G	01:00 / 01:00	08:16:33	08:17:33	109.60
KST P	00:44 / 00:42	08:19:10	08:19:54	110.20
K 907	- / -	08:21:22	08:21:22	109.10
K 954	- / -	08:21:26	08:21:26	114.60
K 909	- / -	08:22:19	08:22:19	114.30
K 952	- / -	08:23:00	08:23:00	100.00
K912	- / -	08:23:06	08:23:06	106.30
K 911	- / -	08:23:17	08:23:17	100.00
K972S	- / -	08:23:26	08:23:26	100.00
KEIL	00:42 / 00:42	08:24:04	08:24:46	105.40
KAREG	- / -	08:26:55	08:26:55	133.30
KAREP	00:42 / 00:42	08:28:05	08:28:47	100.00
KA	00:42 / 00:42	08:31:16	08:31:58	100.00
K0401	- / -	08:33:58	08:33:58	106.40
KASZ	00:42 / 00:42	08:34:33	08:35:15	100.00
E002A	- / -	08:35:26	08:35:26	109.00
KAW P	00:42 / 00:42	08:37:20	08:38:02	100.00
KAW G	- / -	08:39:11	08:39:11	100.00
KRIC	- / -	08:40:51	08:40:51	110.00
KKOS	00:42 / 00:42	08:43:10	08:43:52	100.20
E 803	- / -	08:45:16	08:45:16	100.00
E 850	- / -	08:45:16	08:45:16	100.00
KHEZ	00:42 / 00:42	08:48:03	08:48:45	100.00

Figure 16 - Running time for $40\ m$ confidence interval of the train RB20 from Stolberg to Herzogenrath with partly open exit signals.

Note for Figure 15 and Figure 16, that today's timetable regarding reserve times was used in the simulation.

Next, the influence of the different scenarios from Table 3 on the delay will be examined. Therefore, the average delay progression of all trains running partly on the same path in the same direction is considered. Figure 17 shows the results for the case of closed exit signals at all stations and Figure 18 shows the results for the case of partly open exit signals at the stations. The size of the confidence interval has a significant influence here, as it does on the capacity (c.f. Section 7.3). In the case of closed exit signals, the average delay for the $40\ m$ confidence interval at the last station increases by $30\ s$, or 12 percent, compared to the reference scenario. In the case of open exit signals at small stations, the influence of the confidence interval can be significantly reduced. Here, the average delay for the $40\ m$ confidence interval at the last station increases by only $11\ s$, or 4 percent.

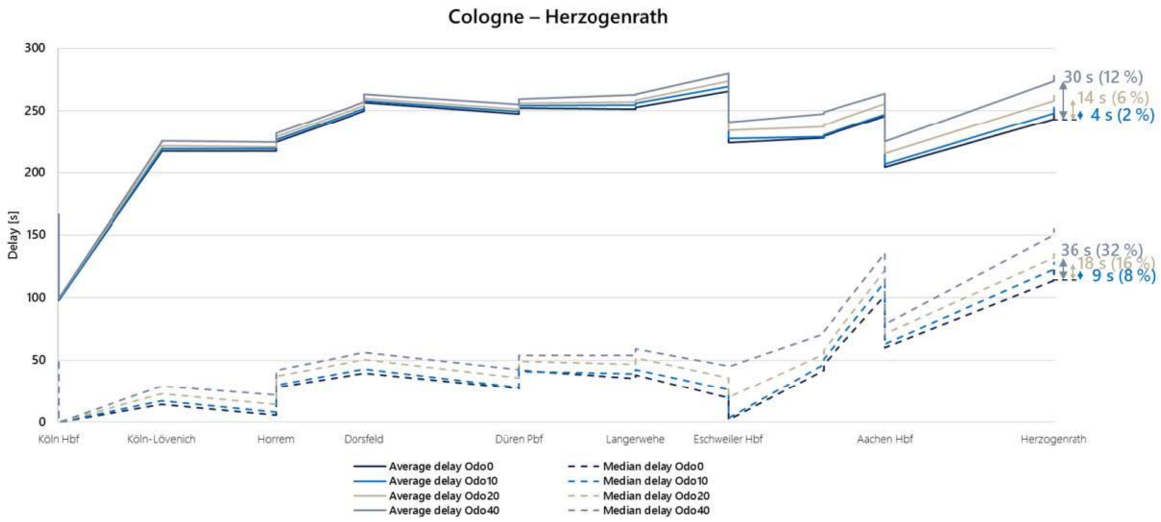


Figure 17 - Average and median of the delay progression for all trains from Cologne to Herzogenrath for the scenarios from Table 3 with closed exit signals.

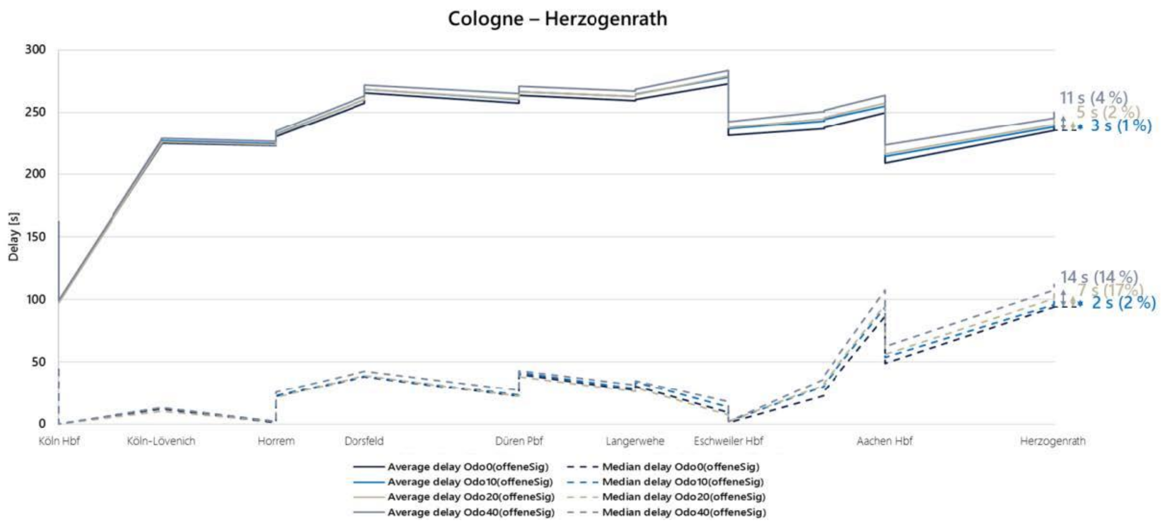


Figure 18 - Average and median of the delay progression for all trains from Cologne to Herzogenrath for the scenarios from Table 3 with party open exit signals.

Finally, the influence of different confidence intervals on three metrics for operational quality will be investigated. The "$5\ min$ punctuality" (or "$3\ min$ punctuality") defines a train journey as punctual if it is not more than $5:59$ minutes (or $3:59$ minutes) late. The average arrival delay refers to all stops of all trains travelling the same route. Table 4 shows the results for the metrics in the case of closed exit signals and Table 5 in the case of partly open exit signals. Again, as in the previous evaluations, the advantage of open exit signals is evident. The operational quality with open exit signals improves significantly compared to the scenarios with closed exit signals.

Operational Quality	$0\ m$ confidence interval	$10\ m$ confidence interval	$20\ m$ confidence interval	$40\ m$ confidence interval
$3\ min$ punctuality	$63.6\ \%$	$-0.7\ \%$ points	$-1.8\ \%$ points	$-3.4\ \%$ points
$5\ min$ punctuality	$78.9\ \%$	$-0.2\ \%$ points	$-0.8\ \%$ points	$-1.7\ \%$ points
Average arrival delay	$226.6\ s$	$+2\ \%$	$+4\ \%$	$+8\ \%$

Table 4 - Operational quality in relative comparison to the reference scenario regarding assumption with closed exit signals.

Operational Quality	$0\ m$ confidence interval	$10\ m$ confidence interval	$20\ m$ confidence interval	$40\ m$ confidence interval
$3\ min$ punctuality	$64.3\ \%$	$-0.3\ \%$ points	$-0.5\ \%$ points	$-1.4\ \%$ points
$5\ min$ punctuality	$78.6\ \%$	$-0.1\ \%$ points	$-0.2\ \%$ points	$-0.7\ \%$ points
Average arrival delay	$227.1\ s$	$+1\ \%$	$+2\ \%$	$+5\ \%$

Table 5 - Operational quality in relative comparison to the reference scenario regarding assumption with partly open exit signals.

7.5 Conclusions

As shown in the previous sections, the length of the confidence interval can have a major influence on the capacity and the operational quality of a line.

A larger confidence interval leads to longer journey times, as the ETCS braking intervention takes effect earlier or the track is released later. Consequently, secondary delays increase.

Note here that this effect only occurs when the EoA is directly behind a stopping position. On an open track at high speed, the size of the confidence interval does not have much influence, as the braking distance is much larger than the confidence interval anyway.

It is possible to mitigate this negative effect by entering an open signal station. However, especially at larger stations this is usually not possible, therefore the confidence interval should be kept as small as possible.

This can be achieved by a speed-dependent confidence interval as proposed in CLUG (1) (cf. Section 7.2.2), whereby according to Section 7.3.4 a speed-dependent confidence interval can also be modelled as a constant confidence interval (c.f. Figure 14). Note that this assumption (speed dependent confidence interval can be approximated as a constant confidence interval) can only be ensured here for the underlying generic infrastructure as per Figure 9.

Moreover, the confidence interval assumed in the timetable should not be smaller than the actual confidence interval to prevent delays. SNCF report study (cf. Ref [60]) concludes that the confidence interval with a length of $80\ m$ represents a threshold value. All confidence intervals larger than this have a significant impact on the capacity and operational quality of a line.

This appendix shows that by improving localisation system, therefore e.g., a reduced confidence interval can make a positive contribution to the overall capacity and operational quality of the railway transport system. For this purpose, and considering the previous analysis and conclusions, there would be two options depending on the available trackside information as LOC-OB input:

1) If trackside information (i.e., the information on proximity to a closed signal) is available and can be safely used to compute the confidence interval, a two constant value model is proposed for CLUG 2.0, based on the proximity to a closed signal:
   - Confidence interval = $80\ m$ at open tracks
   - Confidence interval = $10\ m$ close to closed signals (EoA)
2) If trackside information is not available or cannot be safely used, the proposal is using for CLUG 2.0 the same speed-dependent confidence interval model as proposed for CLUG (1).

8 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][3]	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][3]	FDS-2022-01	Estimation Impact Performance ce l'erreur de localisation	1.4	28/02/2023
[61][3]	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

[3] Confidential. Not publicly available.

[79]	IEEE Transactions on Instrumentation and Measurement	RTK-LoRa: High-Precision, Long-Range, and Energy-Efficient Localization for Mobile IoT Devices https://www.researchgate.net/publication/346658103_RTK-LoRa_High-Precision_Long-Range_and_Energy-Efficient_Localization_for_Mobile_IoT_devices	-	04/12/2020

9 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 Equipment
MHT	Minimum Headway Time
MI-HMI	Maintenance - HMI
minSFE	Minimum Safe Front End
MLM	Mode and Level Manager
MNT	Maintenance Terminal
MOL	Mobile Object Locator
MOT	Mobile Object Transactor
MT	Movement Authority Transactor
MTTR	Mean Time To Restore
NL	Non-Leading (ETCS mode)

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

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

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

10 APPENDIX D: CLUG 2.0 WP2 Glossary

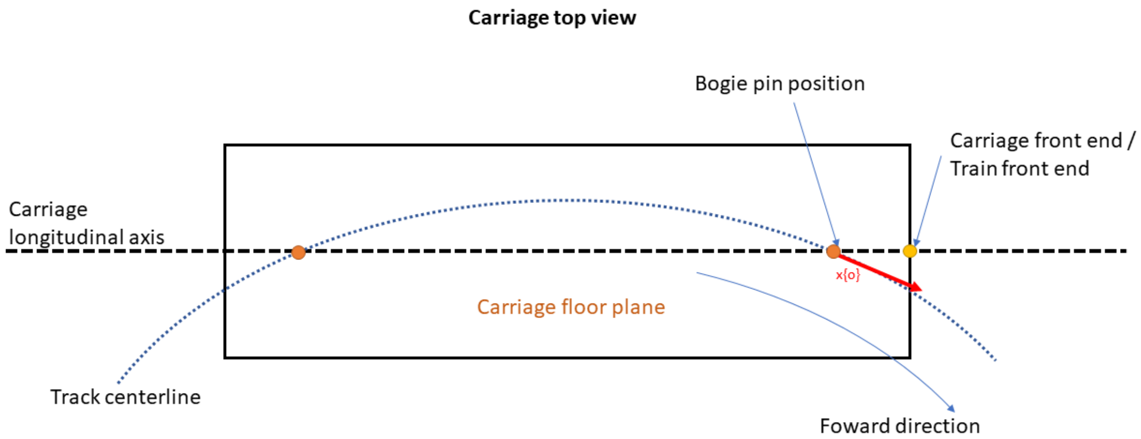
This appendix is aimed at ensuring terminology alignment and common understanding throughout CLUG 2.0 WP2 documentation. Terms definitions are already captured and hence referenced to:

- 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).



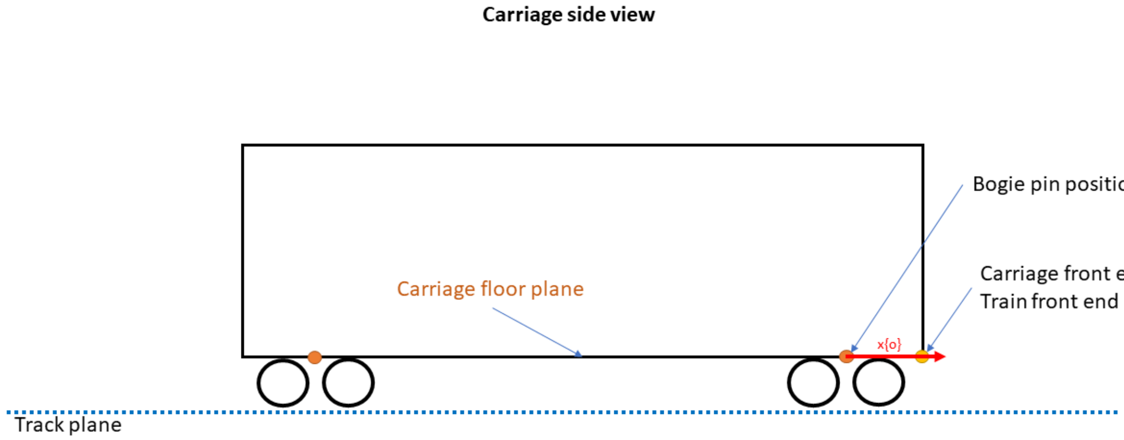


Figure 19 - 1D reference frame represented by the x-axis of the bogie frame $\{o\}$.

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]).

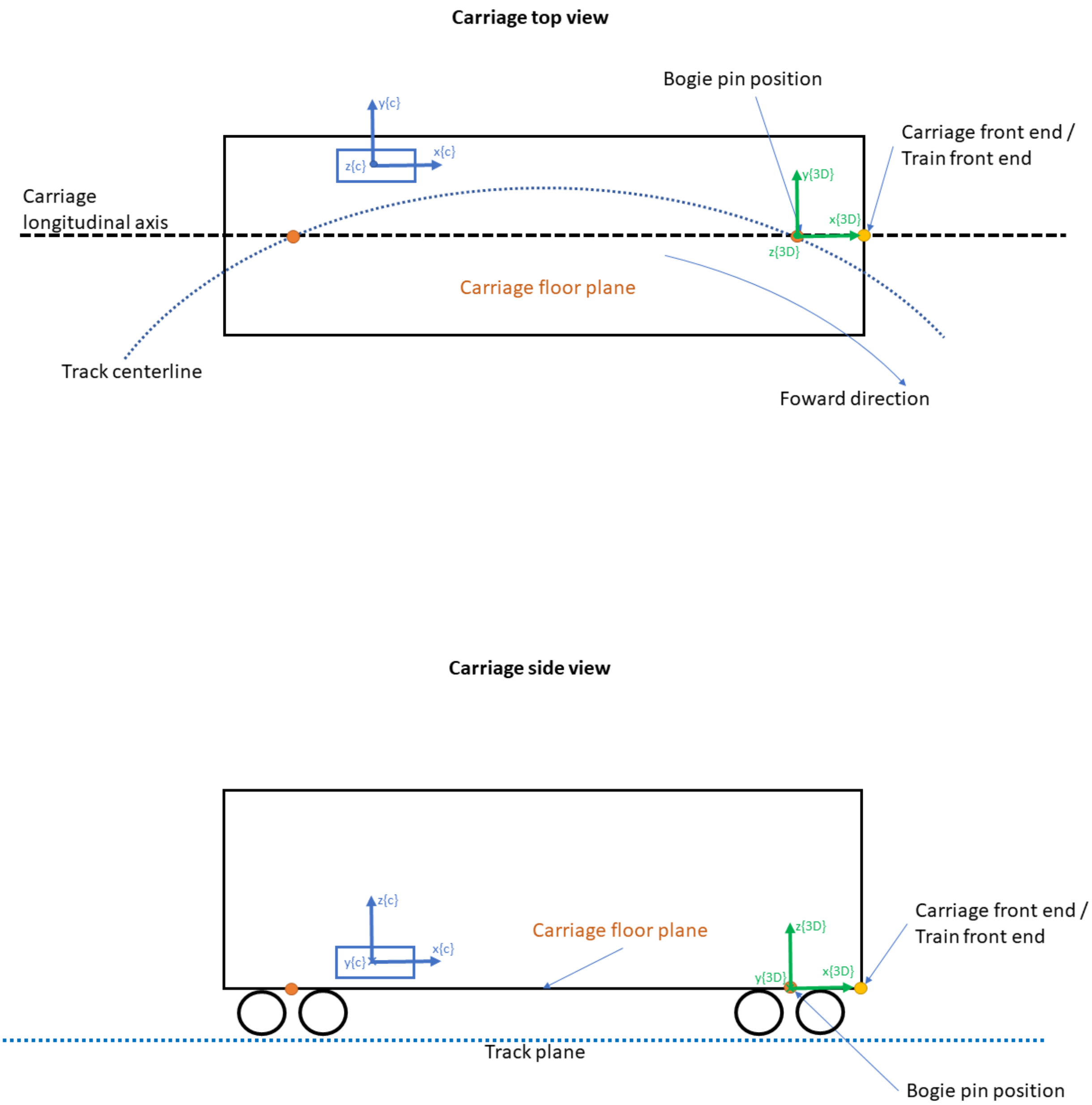


Figure 20 - 3D reference frame and carriage frame $\{c\}$.

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 20).

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

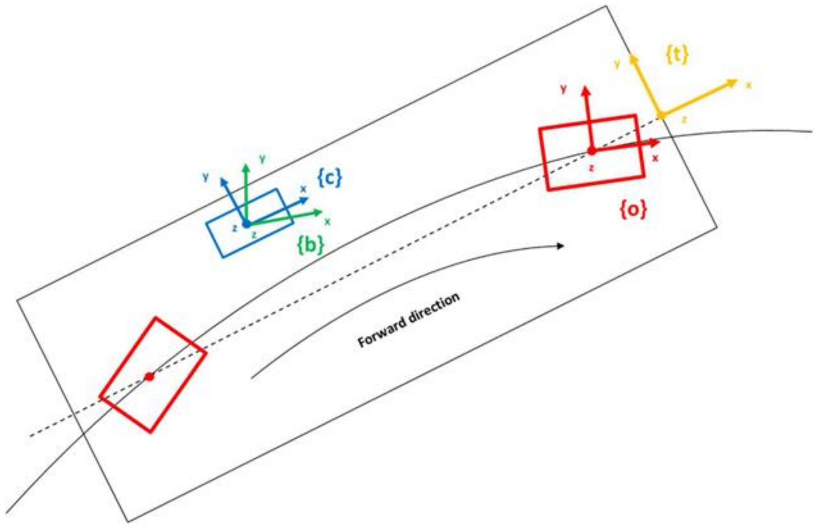


Figure 21 - On-board reference frames: front train $\{t\}$, bogie $\{o\}$ and carriage $\{c\}$ reference frames (Ref [17]).

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 20). This point is the most forward element belonging to the carriage.

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

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

Carriage reference frame {c}

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

Source: Ref [59]

Clothoid / Euler spiral

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

Source: Ref [12]

Confidence interval

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

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

User functions

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

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

Source: Ref [17]

(operational) Continuity

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

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

Source: adapted from Ref [25]

Digital Map

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

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

Source: adapted from Ref [77]

Digital Register

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

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

Earth fixed reference frame {e}

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

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

End of Authority (EoA) (Limit of Authority)

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

Source: Ref [28]

Estimated Speed

The speed the ETCS or LOC-OB equipment estimates the train is running at, with the highest probability according to the physical characteristics of the train and to the LOC-OB equipment working conditions. The speed is provided using the 1D reference frame $\{o\}$ (cf. Figure 19).

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.

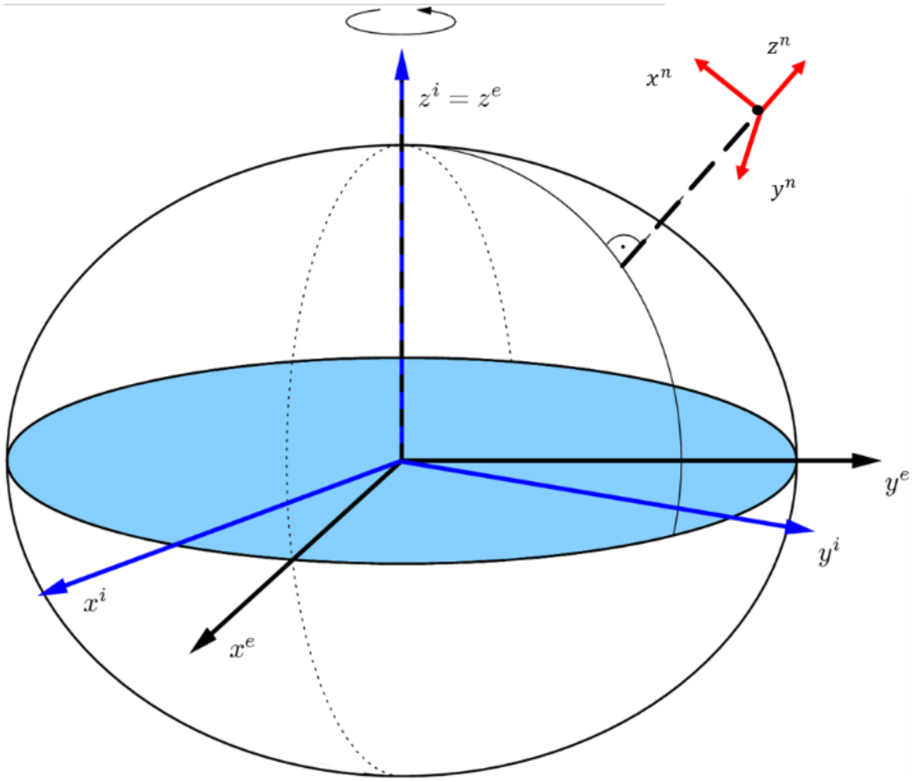


Figure 22 - Reference frames with respect to the earth centre.

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 23 and Figure 24 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.

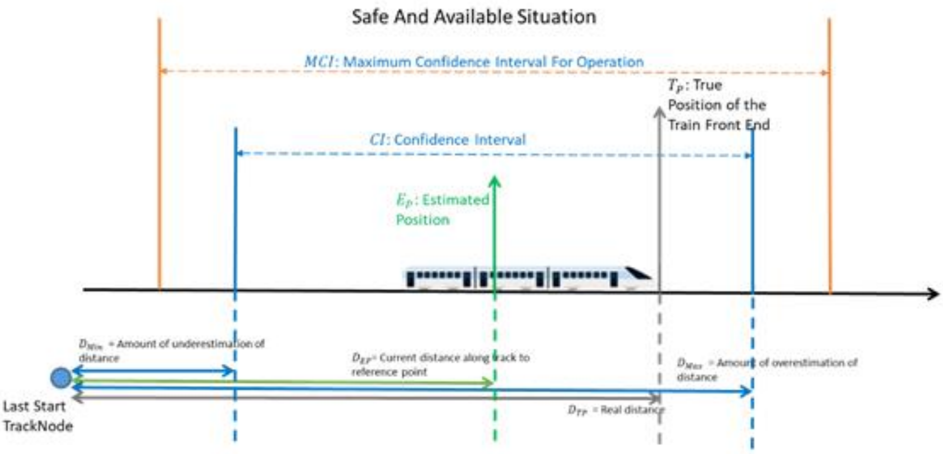


Figure 23 - Safe and available situation. Estimated position, computed Confidence Interval versus specified Maximum Confidence Interval.

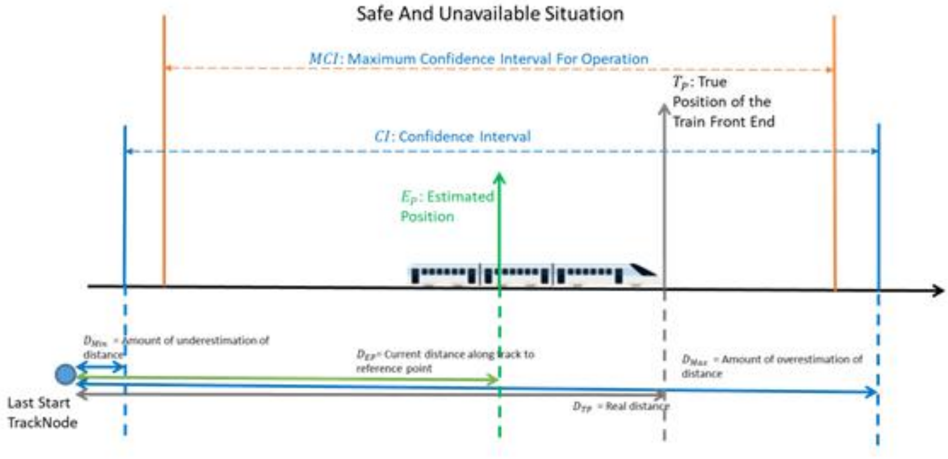


Figure 24 - Safe and unavailable situation. Estimated position, computed Confidence Interval versus specified Maximum Confidence Interval.

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 25: 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 25 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 26: 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.

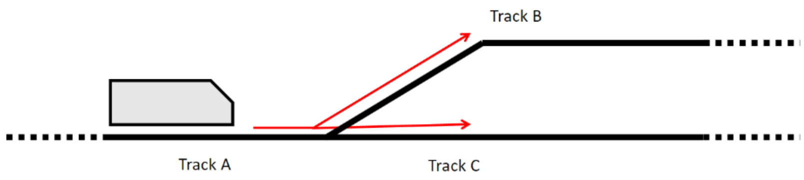


Figure 25 - Train on parting tracks.

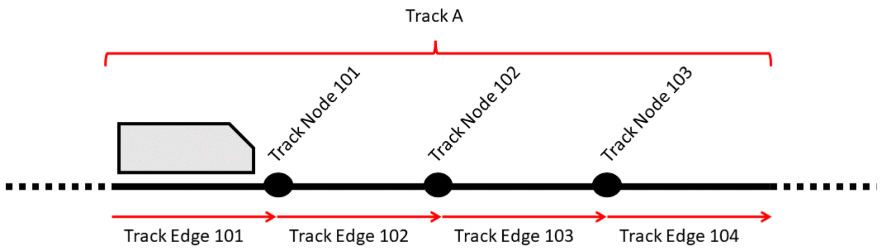


Figure 26 - Train on single track.

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 19 and Figure 20).

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 19 and Figure 21).

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

True train position

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 19).

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 20).).

Source: Ref [59]

WGS84 (World Geodetic System 1984)

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

Source: Ref [24]

Wider System-of-Interest

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

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

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