Grant agreement No 101082624

CLUG DEMONSTRATION OF READINESS FOR RAIL

D2.2 START OF MISSION AND TRACK SELECTIVITY

Due date of deliverable: 30/09/2023

Actual submission date: 26/02/2024

Leader of this Deliverable: DBN
Reviewed: Y

Document status		
Revision	Date	Description
0.1	26/06/2023	First draft
0.2	03/11/2023	Review comments on final version implemented - replaces all earlier Versions – Baseline for final version
0.3	27/11/2023	Implemented review comments of the TMT review.
1.0	29/11/2023	Final approved version after quality check
1.1	05/02/2024	Update after external review
2.0	26/02/2024	Final version submitted to EUSPA

Project funded from the European Union's Horizon 2020 research and innovation programme		
Dissemination Level		
PU	Public	x
SEN	Sensitive, limited under the conditions of the Grant Agreement	
Classified R-UE/EU-R	EU RESTRICTED under the Commission Decision No2015/444	
Classified C-UE/EU-C	EU CONFIDENTIAL under the Commission Decision No2015/444	
Classified S-UE/EU-S	EU SECRET under the Commission Decision No2015/444	

Start date of project: 01/02/2023 Duration: 24 months

CLUG 2.0 has received funding from the European Union's Horizon research and innovation programme under grant agreement **No 101082624**

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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 main goal of the project is to demonstrate the readiness of using EGNSS and multisensory fusion systems for safe rail localisation.

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 objective of deliverable D2.2 is to describe and analyse the operational scenarios in order to derive constraints and recommendations for the localisation on-board unit specifically for Start of Mission and Track Selectivity. Therefore, operational scenarios are described from todays' perspective with focus on localisation challenges during Start of Mission and with regards to Track Selectivity. For this purpose, a set of operational scenarios that are potentially challenging for the future localisation on-board system is defined. The environmental conditions (e.g., tunnel) and operations (e.g., standstill, acceleration) defined in CLUG (1) are referenced in the operational scenarios. Recommendations, operational constraints, and acceptance criteria are derived from the operational scenarios and considered by deliverable D2.4.

For the definition of operational scenarios and the assessment of environmental impacts, a black box approach is applied. This means that the system architecture of the future on-board localisation system is not in focus of this document, but the system is analysed in context of railway operations and environmental conditions.

The track selective position of the train is essential information to start a mission. Today this is achieved by technical infrastructure and operational measures like trusted areas, cold movement detectors or driving the train in Staff Responsible (SR) mode until a balise is passed. However, these measures require costly infrastructure or can be time consuming. The future localisation on-board system will face similar challenges, despite the shift in localisation technology relying on GNSS. The challenges of localisation and especially to achieve track selectivity were identified in bad GNSS reception conditions, specific topological layouts and during certain operational scenarios. This showed in which scenarios localisation could be enhanced by GNSS based technology or where additional operational or technical measures might be required to overcome localisation challenges.

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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

The objective of deliverable D2.2 is to describe and analyse the operational scenarios in order to derive constraints and recommendations for the localisation on-board unit specifically during Start of Mission and for Track Selectivity.

- Topic #1: SoM

Today, for the European Train Control System (ETCS) On-Board (OB) Unit determining the position after the start-up of an ETCS OBU in L2 can be a major challenge. This leads to initial distances run in Staff Responsible (SR) mode until a valid position can be determined with a balise. The request for and operation in SR mode is time consuming and results in operational constraints increasing the required administrative effort in terms of protocols. It also impacts safety as there is no protection against driver error in SR mode.

- Topic #2 Track Selectivity

Today, the ETCS localisation is based on a reference location (balises installed along the track), providing track selectivity, and the travelled distance of the train front end in relation to this reference location. For track vacancy detection, trackside devices (track circuits or axle counters) are used today. Major aim of the standalone fail-safe localisation system defined in the predecessor CLUG (1) project is to use train positions reported by the on-board localisation system (based on a digital map and GNSS/IMU sensor data) for track vacancy proving (e.g., release of track sections).

With the aim of ensuring that a future localisation system (e.g., as designed in CLUG (1) and CLUG 2.0) improves the operational situation, Operational Scenarios and challenges in today's signalling systems shall be assessed to derive mission and system requirements. Then potential operational constraints derived from GNSS+IMU technology implementation shall be identified. The main goal of this deliverable is the analysis of challenging Operational Scenarios using GNSS+IMU localisation technology in context of Track Selectivity and SoM.

The objective of CLUG 2.0 WP2 "LOC-OB System Definition and Requirements Specification" is consolidating and completing the Localisation On-Board (LOC-OB [1]) system definition and requirements specification. Start of Mission (SoM) and Track Selectivity topics were not exhaustively addressed in Ref [26] Chapter 6, and therefore are picked up again in the follow-up project CLUG 2.0.

[1] The CLUG (1) Train Localisation On-Board Unit (TLOBU) is defined in Ref [26] of the predecessor of CLUG 2.0 project. In OCORA it is named LOC-OB (cf. Ref [26], Section 3.1.1.1). In scope of CLUG 2.0, it was agreed to use the term "LOC-OB" instead of "TLOBU".

1.1 Approach

The main goal of this deliverable is the identification of challenging Operational Scenarios related to Track Selectivity and SoM.

To achieve this, a methodology for the description and categorisation of Operational Scenarios is used as shown in Section 1.2. This methodology is then applied to analyse challenges for today's localisation i.e., ETCS (cf. Chapter 3) and future localisation using LOC-OB in the target system[2] (cf. Chapter 4) regarding SoM and Track Selectivity.

Finally, recommendations for the target system using LOC-OB (i.e., recommendations according to positioning accuracy) and/or the operation with the LOC-OB (e.g., Repositioning during SoM in case of bad GNSS reception) are collected based on the Operational Scenario descriptions. The recommendations for LOC-OB and operations made in Section 4.6 are then picked up by deliverable 2.4 Ref [4].

While D2.1 (cf. Ref [1]) derives the high-level requirements/constraints on a system level, within a wider system of interest; D2.3 (cf. Ref [3]) defines the system architecture and technical details; this D2.2 assesses scenarios to derive recommendations, operational constraints and acceptance criteria specifically from localisation challenges. This D2.2 does not focus on the technical implementation of specific type sensors and fusion algorithms. Instead, for the analysis of Operational Scenarios regarding localisation challenges, it is important to understand the characteristics of different groups of sensors, that they complement each other and how they are influenced by different environmental conditions.

1.2 Methodology

The Operational Scenarios are initially described. Topological Settings (single, parallel, parting tracks) are described afterwards. Challenging environmental conditions for the LOC-OB system are described in detail in Section 4.1. The interrelation of these three elements is indicated in Figure 1.

The Operational Scenarios in combination with Topological Settings were found to be the most appropriate elements to describe the aspect of Track Selectivity in detail (cf. Sections 4.2, 3.4, 4.3, 3.5, 4.3.1) and by observing the environmental conditions, an assessment of the operational impact on the LOC-OB can be made.

[2] The term target system in this document describes the future localisation by LOC-OB which in CLUG 2.0 is assumed to apply GNSS and IMU input data for localisation of the train front end. Further architectural details according to additional sensors used for train front end localisation are not to be defined in this document but elsewhere (D4.1 of CLUG 2.0). Details about the functional components of the target system can be found in deliverable 2.3 Ref [3].

2 Operational Scenarios

2.1 Definition of Operational Scenarios

An Operational Scenario is a specific sequence of events that lead from a precondition to a post condition, including all interactions between a system and different actors (environment, users) (cf. Ref [58]).

2.1.1 Operational Scenarios in this deliverable

In this deliverable the LOC-OB is the system in focus of the Operational Scenarios. The scenarios are defined in this section.

The Operational Scenarios defined are in general based on and/or considering the Procedures in Ref [28]. For the analysis of the challenges for future localisation using LOC-OB (GNSS and Inertial Measurement Unit (IMU) sensors for localisation) in a potential ETCS environment in Chapter 4, the Procedures have been adapted and generalized where required, to define Operational Scenarios (For example, the Scenario 8 “Joining” defined in Section 2.3 is derived from the “Operational Procedure” in Ref [28] but adapted to highlight the aspects relevant for the analysis in a challenging environments). An Operational Scenario can (but does not have to) contain such Procedures. Therefore,

- Operational Scenarios in this document utilise certain Procedures from Ref [28] or parts of them.
- The terminology of Operational Scenarios and Procedures defined in Ref [28] may therefore overlap. However, other than in Ref [28], in this document the term "procedure” is used in a generic way.
- In contrast to Procedures, the Operational Scenarios allow to put the LOC-OB into the context of environmental conditions and Topological Settings.

Operational Scenarios are analysed and discussed in context of each Topological Setting. A Topological Setting describes different settings of tracks (single track, parallel tracks, parting tracks). The three main settings used in this document are described in Section 2.4 in detail. Environmental conditions considered in context of Operational Scenarios are exemplified in Figure 1.

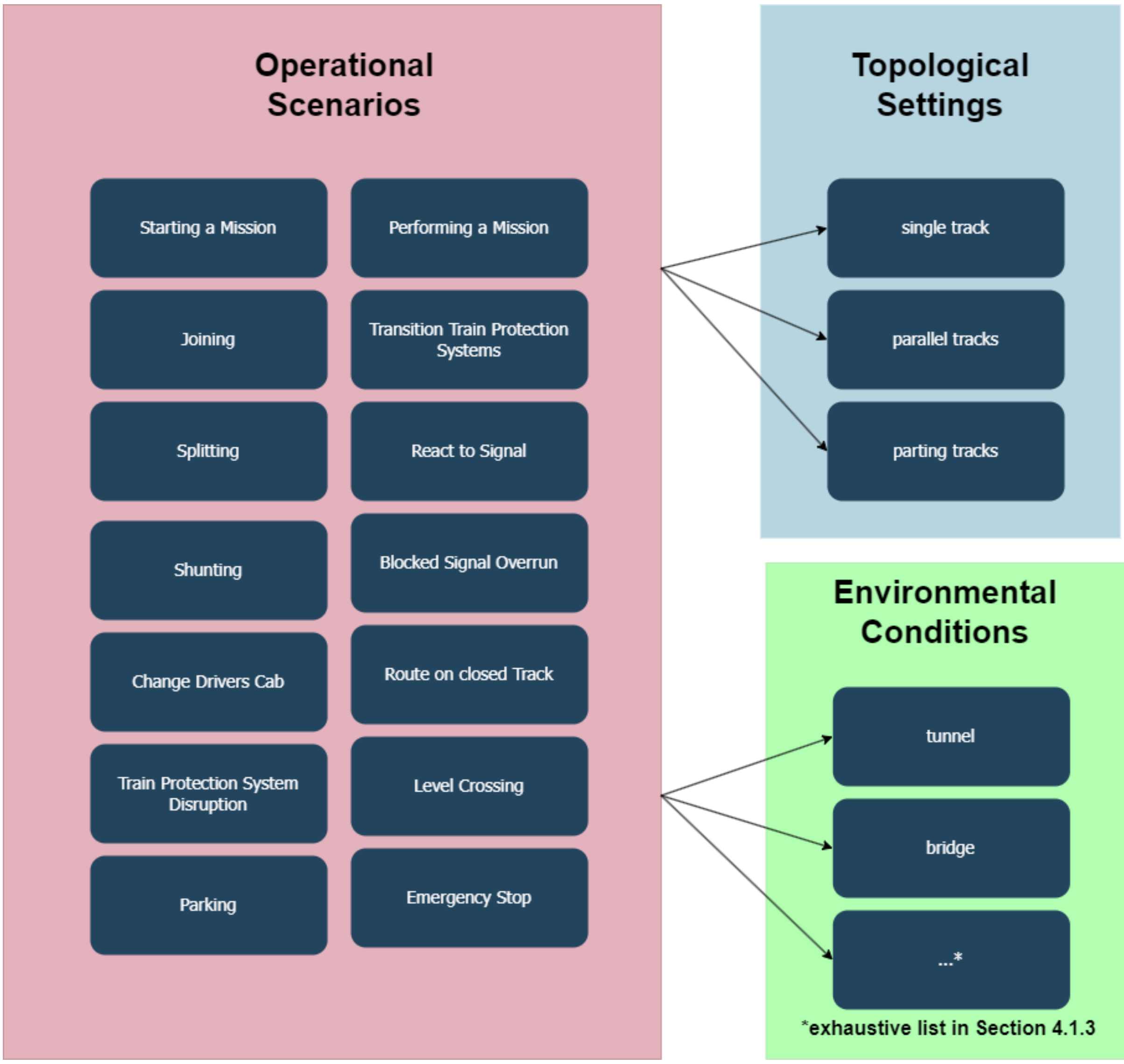


Figure 1 - Operational Scenarios-Topological Settings, Environmental Conditions.

2.1.2 Definition of Starting a Mission

Starting a Mission is performed to enable a train to transition from being parked in SB mode (with desk closed) to start operating in FS/OS mode. The corresponding ETCS SoM procedure is detailed in Ref [28], Section 3.4. According to Ref [28] the SoM procedure (ETCS SoM) starts with on-board cab activation (i.e., the ETCS On-Board Unit (OBU) being in mode Standby (SB) with a desk opened and no connection to trackside established) and it is finished as soon as the train transitions from ETCS mode SB to another mode (as defined in ETCS Ref [28] NL, SH, SR, FS, OS, LS, SN or UN). Today, the ETCS SoM procedure requires driver actions, e.g., for activation of the cab and train data entry.

In the scope of this document, the Operational Scenario Starting a Mission includes the ETCS SoM procedure, but also scenarios where FS/OS is reached through e.g., SR mode (including operational measures until transition to FS/OS occurs).

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

2.1.3 Definition of Performing a Mission

Performing a Mission is not specified as ETCS Procedure in Ref [28] and therefore defined in this document as Operational Scenario to assess it in context of the LOC-OB and described as Performing an ETCS Mission in Section 3.5. Based on the Operational Scenario Starting a Mission, Performing a Mission is the train driving in supervised mode (i.e., FS/OS). The consequences of passing different Topological Settings (e.g., a point in Parting Tracks) under specific environmental conditions shall be analysed with this Scenario.

- Precondition: Starting a Mission completed; train starts moving in FS/OS
- Postcondition: The train stops moving at specified destination in FS/OS

2.1.4 Definition of 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 2: 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 2 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 3: 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.

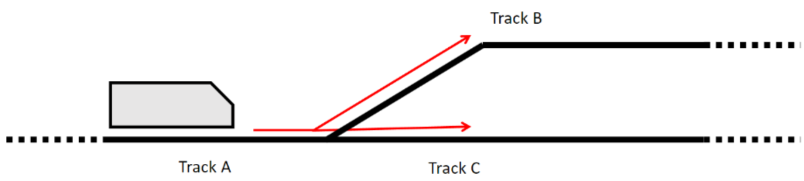


Figure 2 - Train on parting tracks.

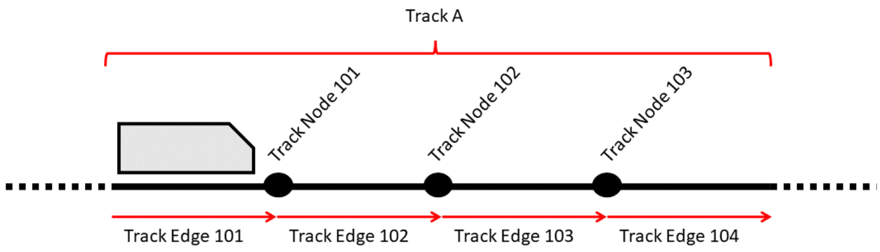


Figure 3 - Train on single track.

For the current ETCS system Track Selectivity is a combined trackside-onboard function (cf. Section 3.3). Trackside puts balises in the track and onboard reports the balise, which results in the knowledge on which track the train is. One goal of CLUG 2.0 is to assess an adaptation of the current ETCS system by migrating the Track Selectivity functionality to the LOC-OB. These changes must be assessed to determine where the LOC-OB might have difficulties to determine Track Selectivity. Just as current ETCS systems, also the LOC-OB must provide a safe location which does not imply Track Selectivity. Independent of the involved systems, determination of Track Selectivity cannot be determined immediately, in some cases it might not even be possible. These gaps occur but depending on their time/distance might not have an impact on safe localisation. Operational Scenarios discussed in this document are those that allow for analysing ETCS SoM/Starting a Mission and/or Track Selectivity aspects. Before project start of CLUG 2.0 this group of scenarios was identified to be potentially challenging for a LOC-OB using GNSS and IMU technology.

2.2 Example of an Operational Scenario “Starting a Mission”

The following example provides the basic understanding to discuss the goals of this section. A non-exhaustive list of scenarios is given in the next Section 2.3. The determination of Track Selectivity in different scenarios is analysed in Section 4.5.

2.2.1 General Scenario Description

This is a regular train operation with a start, destination and train number registered in the trackside system. As a precondition the train is in standby (ETCS mode SB), the post condition is the train Performing a Mission. In this scenario it is also assumed, that the train starts up from a regular starting position (e.g., station).

2.2.2 Detailed Scenario Description

This detailed description of the scenario is phrased independently from a specific localisation technology (current ETCS or LOC-OB).

- Pre-condition:
  1) The train is in standby (SB mode in ETCS).
- Process steps:

1) A starting procedure is carried out (in ETCS a valid position is stored in the on-board memory of the train unit and CMD confirms no movement was performed).
2) Position reported from the engine (ETCS-OB (OBU) reports valid position).
3) Trackside validates and accepts the reported position (in ETCS as trustworthy position).
4) The permission to start driving the planned route with supervision by ATP (Automated Train Protection) is granted (ETCS issues a Movement Authority (MA)).

- Post-condition:
  1) The train performs a mission (ETCS has issued a Movement Authority (MA)).

2.2.3 Track Selectivity aspects of scenario

The ETCS SoM procedure requires a valid position deemed trustworthy by Trackside to grant the train an MA. In this simple example the position was stored already in the on-board memory and the CMD confirms that no cold movements have occurred. LOC-OB can in this case use the stored track selective position as valid.

2.3 Overview of Operational Scenarios

This section aims to give an extensive, but not complete, overview of typical Operational Scenarios in a railway system. This first collection of Operational Scenarios is not assessed or filtered according to their relevance for Starting a Mission and Track Selectivity, since this is covered later in Chapter 4. Therefore, each Operational Scenario is described shortly avoiding technology specific terms, but using the format of precondition, events and postcondition. The list is the base to identify Operational Scenarios that will be picked up later for detailed description.

2.3.1 Scenario 1: Starting a Mission

Cf. Section 2.2

2.3.2 Scenario 2: Performing a Mission

Cf. Section 2.1.3

2.3.3 Scenario 3: Driver operates train within the limits issued by the signalling system

This scenario describes the regular operation of a train within the limits issued by the signalling system in the station or on the open track (e.g., stop in rear of a stop signal, slow down in case of speed restriction, etc.). Limits issued by the signalling system are in this scenario displayed on the Driver Machine Interface (DMI). Pre-condition is the train has performed Starting a Mission. Postcondition is that the train ends the mission.

2.3.4 Scenario 4: Driver operates the train exceeding the limits issued by the signalling system

This scenario describes when the train exceeds the limits issued by the signalling system and the subsequent reaction of the train protection system. Pre-condition is the train is Performing a Mission. The train exceeds the limits issued by the signalling system. The ATP reacts on the exceedance. Postcondition depends on the reaction of the ATP.

2.3.5 Scenario 5: Emergency stop

This scenario is the braking of the train to a standstill. This can be caused by functions of the ATP or actions of the driver. The pre-condition is that the train is Performing a Mission. Postcondition is the train carries on with Performing a Mission.

2.3.6 Scenario 6: Transition to/from ETCS areas

This scenario describes the transition between legacy light signalling (no ATP) or different national Class B systems such as Punktförmige Zugbeeinflussung (PZB), Linienzugbeeinflussung (LZB), etc. and ETCS. The train connects and registers with the ATP trackside. Pre-condition is that the train is Performing a Mission in ATP (or no-ATP) and post condition is that the train is in ETCS FS/OS mode (Performing a Mission). Pre- and Post-condition can be switched in order to describe the transition from an ETCS area to another area.

2.3.7 Scenario 7: Parking

This Operational Scenario describes the procedure when the engine shuts down. The shutdown procedure concerns the engine systems but also has implications on the operation. These are preventing from “cold” movement, parking in designated areas to allow flank protection etc. The Pre-condition is Performing a Mission, the post condition is that the trains is parked, and power is switched off. This can lead to a loss of position information.

2.3.8 Scenario 8: Change Train Drivers Cab

This Operational Scenario is applied when the train changes direction. It applies for train sets, single engines and regular trains of cars and engine units. The pre-condition is to end the mission at the designated area to change the train driving direction. The drivers cab in the new driving direction has to be started up (Starting a Mission). The Postcondition is that the drivers cab in the new driving direction is ready for Performing a Mission.

2.3.9 Scenario 9: Joining (of two units)

This scenario describes joining of two trains with supervision functionality of an ATP system (e.g., ETCS). It concerns engines or cab cars and units which appear as connected unit for the ATP (train data bus, train integrity monitoring), but not regular cars without train protection functionality. To accommodate joining supervised by ATP, the trackside or in-cab signals are provided to permit entering an occupied track to join the trains. There are two different common approaches of joining two trains:

9a) The first train is ready and waiting while the second train approaches from the back. The second train joins the first and changes via stand-by (e.g., ETCS mode SB) to Non-Leading (e.g., ETCS mode NL). The joint train departs towards the front, no cab change required.

9b) The first train is ready and waiting while the second train approaches from the front and performs a cab change. Another variation of this scenario is, when a cab change is carried out by the leading train after joining. The pre-condition is one train is stopped executing Performing a Mission and is in stand-by at a designated position and the other train is approaching. The postcondition is that the engine positioned in the front of the joined train is Starting a Mission.

2.3.10 Scenario 10: Splitting (of two units)

This scenario describes splitting of trains with supervision functionality of an ATP system (e.g., ETCS). Engines or cab cars and units which appear as connected unit for the ATP (train data bus, train integrity monitoring) are considered, but not regular cars without train protection functionality. The train will drive to a specific location and then is split into two units. The train section with the former leading engine, will continue with updated train data and a new mission (ETCS MA). The former non-leading (ETCS NL) engine will undergo perform the complete Start of Mission scenario. The pre-condition is that two trains are connected, and the leading train is Performing a Mission. The post condition is that the former leading train is continuing the mission, and the former non-leading train (ETCS NL) is ready for Performing a Mission.

2.3.11 Scenario 11: Shunting

Shunting Operational Scenarios describe the train changing from one track to another (e.g., to vacate a certain track) and assembly of cars and engines to trains and moving such trains without an assigned train number. In this scenario, other than regular trains no localisation information to the ATP is provided for shunting (for LOC-OB positioning cf. Section 4.5.8). The pre-conditions can be train in standby, Starting a Mission completed or Performing a Mission ongoing. The postcondition is End of Mission.

2.3.12 Scenario 12: Route on closed track (e.g., “single-line working ticket”)

This scenario refers to a train route on a closed track for purposes of construction or maintenance operations. Pre-condition is the same as for shunting, the post condition as well. Steps in the scenario can be carried out in different operational modes.

2.3.13 Scenario 13: Level crossings

This scenario describes the procedures of approaching and passing railway Level Crossings (LC). For example, information of the state of the LC is provided by the ATP system to the OBU. The steps of the scenario can require speed restrictions. The OBU needs to decelerate in the correct location if a speed restriction is active. The pre-condition is Performing a Mission and the postcondition is also Performing a Mission.

2.3.14 Scenario 14: On-Board ATP system disruption

This scenario describes any system disruption in the ATP system regarding on-board or failed communication with trackside. In this case, the on-board system falls back to a safe state and all movements must be adjusted and the positioning must be communicated to the ATP trackside system. If the communication is faulty, this might be not possible and other operational measures have to be carried out. Pre-condition is Performing a Mission, the steps of the scenario include a breakdown of any component of the ATP system and require a recovery from this state. Postcondition is the re-start into Performing a Mission.

2.4 Topological Settings

A selection of Topological Settings is described in this section. A Topological Setting describes typical track layouts within a railway network (single track, parallel track, parting track). The Topological Settings allow an organized analysis of the LOC-OB scenarios.

The selection for these Topological Settings is based on the challenges that a train front end localisation unit (LOC-OB) might face during operation. Settings with specific infrastructure elements (localisation balises, axle counters etc.) are not considered in this selection. Nevertheless, to describe how the current ETCS train localisation is working, challenges involving these infrastructure elements needed to be discussed (e.g., to describe the construction of trusted areas in Section 3.4.3.1).

To avoid misinterpretation the Figure 4 shows how in this document the terms along track and across track direction are used.

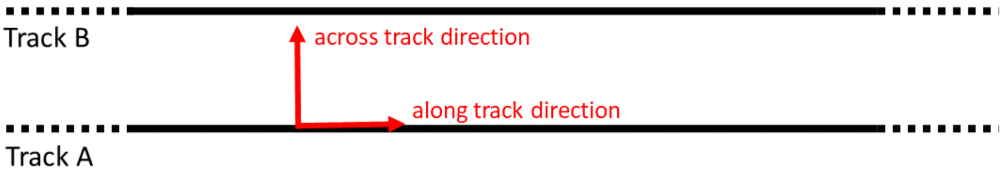


Figure 4 - Along track and across track direction.

2.4.1 Single Track

This Topological Setting defines a single-track track segment.

Figure 5 - Topological Setting for a single track.

2.4.2 Parallel Tracks

This Topological Setting defines a parallel track segment.

Figure 6 - Topological Setting for parallel tracks.

2.4.3 Parting Tracks

This Topological Setting considers the scenario of passing a point where two tracks are parting. This is the most common form of railway junctions.

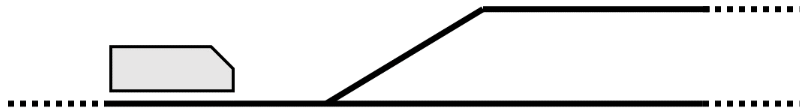


Figure 7 - Topological Setting for parting tracks.

3 Challenges for today´s localisation regarding SoM and Track Selectivity

3.1 Introduction and Scope

The following sections describe how the localisation of ETCS trains is performed in today's signalling systems. In more detail, the challenges of track selective position determination in scope of SoM and during an ETCS mission will be analysed.

RCA.Doc.68 (cf. Ref [11]) describes how track-bound railway vehicles (e.g., trains, wagons) are localised today and which limitations result from Trackside Train Detection (TTD) systems and on-board localisation based on ETCS position reports (cf. Chapter 3 of Ref [11]). Further on the document details ETCS localisation principles including the use of balises as reference locations, parameter of ETCS position reports, ETCS confidence interval (cf. Ref [27]), and safe train length.

The following analysis Is based on the previous work (cf. Ref [11]) but refers only to train front end localisation as this is the scope of CLUG 2.0.

The following sections will not explicitly refer to the Operational Scenarios introduced in Chapter 2. In today's signalling systems incl. ETCS, Track Selectivity is always relevant for localisation. SoM can be seen as a precondition of most of the Operational Scenarios. From current system point of view, the topological settings need further analysis. This will be detailed in Section 3.4.2 and 3.5.2.

Specific terms are used to describe the challenges in today's railway signalling systems within the following sections. For a better understanding, the terms are briefly explained here:

- **Valid/invalid/unknown train position**: These terms are used in scope of the ETCS SoM procedure, and they reflect the on-board view of the validity state of the reported position information (e.g., LRBG). The ETCS OBU sends a SoM Position Report message (Message 157) to trackside via radio network in case of cab activation. It contains the qualifier Q_STATUS indicating the status of the position report. OBU reports a 'valid' position if the LRBG is known, and unsupervised train movements (e.g., cold movements) prior SoM can be safely excluded. An 'invalid' position indicates that the LRBG is known but unsupervised train movements prior SoM cannot be safely excluded. If the LRBG is not known, the SoM Position Report is marked as 'unknown'. Please see Section 3.4.1 for more detailed information. Further Position Reports (Packet 0 and 1) sent after cab activation do not contain a status qualifier. One basic localisation principle in today's ETCS procedures is that a valid LRBG (thus a valid train position) does not become invalid or unknown again during an ETCS mission.
- **Trustworthy/not trustworthy train position**: These terms are used trackside in scope of the ETCS SoM procedure. They reflect the trackside view regarding the trustworthiness of a reported LRBG contained in a SoM Position Report message marked as 'valid' (cf. Section 3.4.2.1 for details).
- **Ambiguous/unambiguous train position:** These terms are used to reflect the ambiguity of a train (front end) position. In ETCS, train front end positions (Minimum Safe Front End (minSFE), Estimated Front End (estFE), Maximum Safe Front End (maxSFE)) are given based on a reference location (LRBG), the measured distance between LRBG and estimated train front

end position and a location inaccuracy. If the track is parting between reference location and train front end (e.g., due to a facing pair of points), then the train front end position can become ambiguous, i.e., it may be located on one or the other points leg. Without parting tracks, a known train front end position is unambiguous.

3.2 Trackside and On-Board Localisation

Historically grown, trackside localisation systems such as trackside TTDs are one of the major pillars for providing safety in rail operation. With introduction of radio-based ETCS, additional on-board localisation information such as train front end position and – if equipped with a train integrity device – also rear-end related information is made available for ETCS trains. Trackside train control systems can influence the frequency of ETCS on-board position reports by means of UNISIG Packet 'Position Report Parameters' (cf. Ref [28] Packet Number 58), i.e., trackside can advise the OBU to send position reports based on:

- time interval between position reports (see T_CYCLOC, resolution: 1s);
- travelled distance between position reports (see D_CYCLOC, resolution 10cm, 1m, 10m depending on Q_SCALE);
- special locations/moments (see M_LOC, e.g., "now", "every LRBG compliant Balise Group (BG)", etc.);
- an incremental distance (see D_LOC, e.g., when min safe rear end of max safe front end, respectively has passed this location, resolution 10cm, 1m, 10m depending on Q_SCALE).

3.3 Trackside and On-Board View on Topology

In today's railway signalling systems, the ETCS OBU reports a position based on a reference location (passed LRBG) a travelled distance and further position-relevant information (for details see UNISIG Packets ‘Position Report’ – packet number 0 - and ‘Position Report based on two BGs’ - packet number 1 - in Ref [28]). Based on this information, the trackside application determines the safe train front end positions within the topology. In case of parting of the track (e.g., due to points), trackside needs to consider additional information such as the reserved route, point positions and/or occupancy states reported by a trackside TDS to determine the correct track selective train position.

It is important to understand that both trackside and on-board system have a different view of the physical infrastructure (e.g., BGs). Figure 8 shows the difference. In today's ETCS systems, only the trackside system knows the position of BGs and therefore the train positions regarding the topology (“track selective position”, cf. left side of Figure 8). The on-board system reads the (linked or unlinked) BGs when passing them (cf. right side of Figure 8) but does not evaluate their position regarding the topology. In other words, the determination of a track selective position is today a pure trackside-related task.

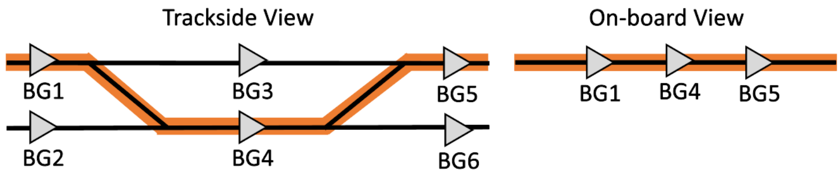


Figure 8 - Trackside and on-board view of physical infrastructure in today´s signalling systems.

3.4 ETCS Start of Mission

3.4.1 Introduction

Due to safety and operational reasons, it is preferred for the OBU to start up in an ETCS mode that supports train supervision (e.g., FS or OS, cf. Ref [53] Section 6.1.1.1). Whether or not a train is allowed to start up directly from ETCS mode SB with an ETCS MA depends also on the validity of the data reported during SoM, particularly on the validity of the LRBG. Section 3.2.4.2.6 of Ref [11] summarises under which conditions an ETCS OBU reports valid, invalid, or unknown position information. Within message 157 'SoM Position Report' (cf. Ref [28]), i.e., an OBU reports

- **valid** position information in case it knows the LRBG and can safely exclude unsupervised train movements prior SoM. Operational examples are start-up:
    - from an ETCS mode in which the train position is determined according to Active Function Table in Ref [28], e.g., SL or NL mode after train splitting or turnaround movement, Shunting, Passive Shunting,
    - from an ETCS mode in which the train position is not determined but an on-board installed Cold Movement Detection (CMD) device indicates that the position did not change compared to the stored one, i.e., SoM from NP mode,
    - after former SoM with invalid position that was confirmed by trackside.
- **invalid** position information in case the LRBG is known but unsupervised train movements prior SoM cannot be safely excluded. If trackside can confirm the invalid position, this is indicated by means of Ref [28] message 43 'SoM position report confirmed by Radio Block Centre (RBC)' sent from trackside to the OBU. A failed confirmation is reported by means of Ref [28] message 41 'Train Accepted', which results in a deletion of the stored position information on-board. Therefore, the OBU is then going to report unknown position report data until determining a new BG. An operational example is the start-up from ETCS mode NP (e.g., after being parked) without on-board CMD.
- **unknown** position information in case there is no LRBG stored on-board, e.g.:
    - initial commissioning or start-up,
    - after SoM with invalid position and failed trackside confirmation.

A fast and efficient SoM procedure implies that the train is enabled to start its movement with an ETCS MA. For technical and safety reasons, trackside can only grant a MA if it trusts the reported LRBG. The next sections take a closer look at challenges arising from start-up with unknown or not trustworthy position information.

3.4.2 Challenges

Section 3.2.4.2.6 of Ref [11] already addresses challenges arising in scope of SoM, including the Track Selectivity issue. Based on the previous analysis, further aspects will be described in more detail in the following sections.

3.4.2.1 SoM with valid but not trustworthy position

Reporting a valid position during SoM does not guarantee that a train is enabled to start moving with an ETCS MA (cf. Ref [11] Section 3.2.4.2.6). First, there may be further supplier-dependent checks that are performed and that may prevent granting of an ETCS MA. Second, a valid position reported by a train does not guarantee that trackside is able to trust it. Due to the overall system design, specific hazards may occur in different Operational Scenarios which must be prevented. For SoM, Ref [52] identifies the potential hazard ETCS-H0003 ("On-board SoM position report after movement towards LRBG").

Figure 9 illustrates the general issue that may lead to the hazardous situation. For more details refer to Ref [52]. In the depicted example, trackside cannot unambiguously locate the train even if the position report with LRBG=BG1 is marked as valid. This can be attributed to the fact that the train may have moved to a parallel points leg prior to SoM without trackside noticing it, e.g., due to cold or shunting movement in which the train has no connection to trackside and does not report its position.

Please note: The picture shows one out of several examples leading to not trustworthy position information. Further situations with different spatial BG arrangements exist that can also result into this hazard.

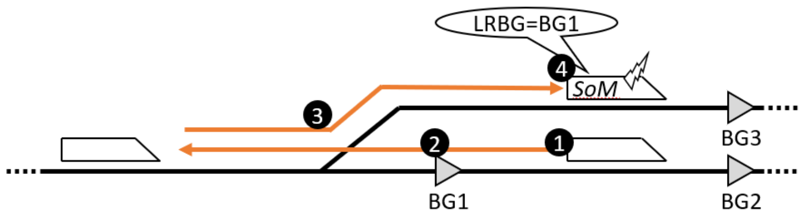


Figure 9 - ETCS-H0003 principle.

An example scenario, which can lead to the identified hazard ETCS-H0003 consists of the following steps:

1. A train running from left to right on the lower track has passed both the pair of points and BG1 (LRBG=BG1).
2. Train starts moving in opposite direction, passes BG1 and BG1 is still LRBG.
3. The point position is changed. After change of train running direction, the train passes the point on the opposite leg.

4. The train is now located on the upper points leg. It performs SoM and sends a valid SoM Position Report based on the LRBG BG1.

The hazard addresses the fact that a wrong MA (i.e., over wrong points leg) might be granted in case trackside simply trusts the LRBG given in the valid SoM position report. According to Ref [52], the mitigation of ETCS-H0003 is allocated to the trackside. Technical and/or operational measures must be implemented to avoid that a MA is granted in case of a not trustworthy train position, or they need to ensure that the train position becomes trustworthy in these situations. The latter will be detailed in Section 3.4.3.1.

3.4.2.2 Operational consequences of starting up with unknown or not trustworthy position

Trackside can only grant an ETCS MA to a train that has a valid and trustworthy position. This is not fulfilled during SoM if a train starts-up with:

- an invalid and not confirmed position (results in an unknown position),
- an unknown position,
- a valid but not trustworthy position.

In today's ETCS systems a start-up with an unknown or not trustworthy train position can occur due to the following facts:

- According to the current ETCS specifications, refer to Ref [28], the connection between trackside and OBU is terminated in case of end of mission. In this case, trackside does no longer recognise train movements.
- Most of the trains are not yet equipped with CMD devices. They are going to report an invalid position when starting up from ETCS mode NP after being parked. As trackside is often not able to verify the invalid position, this usually results into a start-up with an unknown position (cf. Ref [28] Section 3.6.2.2.2.x).
- Additional measures to ensure that a valid train position is also classified as trustworthy by trackside (cf. Section 3.4.3.1) are often limited to dedicated trackside locations (e.g., in case of placing additional BGs around points). In case of SoM out of turn (e.g., to recover from an error situation), no additional advantages are achieved from these measures.

If trackside cannot immediately grant an ETCS MA during SoM due to an unknown or ambiguous position, then a re-positioning of the train (e.g., passing a new BG) must be performed, e.g., the train needs to start moving to get a valid position (cf. Ref [54] Section 4.2.12.1.2). Today this is usually done by means of train movement in ETCS mode Staff Responsible (SR) until passing a new BG. After that trackside can upgrade the train from SR to FS/OS mode by granting an associated ETCS MA. This procedure has significant disadvantages from both operational and safety point of view, i.e:

- it is time-consuming as the driver needs an additional authorisation for SR movement (either a written order from the operator or a signal aspect) (cf. Ref [53] Section 6.1.1.12) and SR movement is usually performed with a lower speed.

- a risk of human error is introduced, this reduces the overall system safety level as safety responsibility is transferred from the technical system to both driver and operator (cf. Ref [53] Section 6.1.1.4).

3.4.3 Possible technical and operational measures to cope with today´s challenges

3.4.3.1 Achieve trustworthy train positions by setting up Trusted Areas

Trusted Areas are dedicated track areas that can be configured in the topology of the trackside application in areas for which it is quite likely that trains perform SoM. In Section 3.4.2.1 it has been described that there are situations (e.g., in case of points) in which trackside cannot trust the reported train position even if the SoM Position Report is marked as valid. Trusted Areas avoid operational and safety obstructions resulting from the fact that trackside is not going to grant a MA due to missing position trustworthiness. If a train reports a BG as LRBG that is located inside a Trusted Area, trackside classifies this BGs as trustworthy, assuming that safety is ensured by additional measures. In other words, it needs to be ensured that the train is not located on another points leg than the reported LRBG. This can be achieved by technical and/or operational measures.

3.4.3.1.1 Trusted Areas ensured by technical measures

A Trusted Area is limited by BGs. Figure 10 shows the general principle how a Trusted Area (indicated by the green bar) could look like.

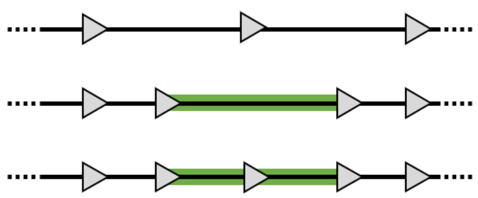


Figure 10 - Definition of Trusted Areas.

No points can be located inside a Trusted Area. Trusted Areas are usually established within stations. In general (within stations as well as between stations), ETCS Position Reports can be considered as trustworthy if there is at least one BG which consists at least of two balises located between LRBG and the next point. This approach is based on the safety assumption that multiple balise reading errors do not occur successively.

Figure 11 shows the use of Trusted Areas to mitigate hazard ETCS-H0003 mentioned above. In this example, three new BGs (4, 5 and 6) have been added and Trusted Areas are established between BG1 and BG2 as well as BG6 and BG3.

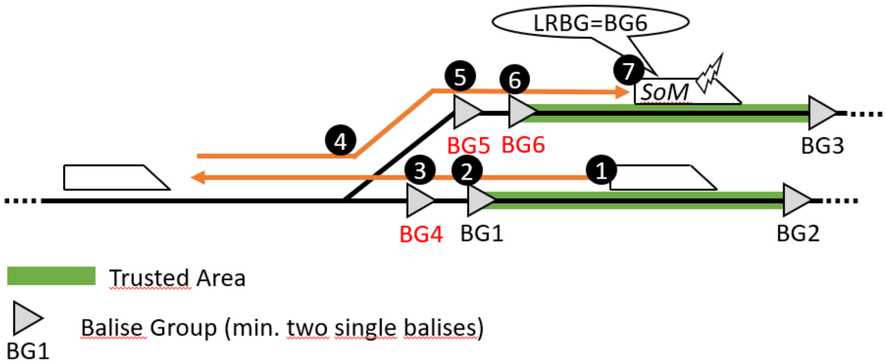


Figure 11 - Principle of mitigation of ETCS-H0003 by using Trusted Area.

Regarding the example introduced above, the following steps apply now:

1. A train running from left to right on the lower track has passed both the pair of points and BG1 (LRBG = BG1).
2. Train starts moving in opposite direction, passes BG1 and BG1 is still LRBG.
3. Train passes BG4 and pair of points. The OBU supervises the location towards the LRBG (BG4).
4. Point position is changed. After change of train running direction, the train passes the point on the upper point leg.
5. Train passes BG5. The OBU supervises the location towards the LRBG (BG5).
6. Train passes BG6. The OBU supervises the location towards the LRBG (BG6).
7. The train performs SoM on the upper leg and sends a valid SoM Position Report with BG6 as LRBG. As trackside knows that BG6 is part of a Trusted Area, the LRBG is classified as trustworthy and can be used for granting an MA.

With the use of Trusted Areas, the identified hazard ETCS-H0003 can be eliminated:

- If the train reports a valid LRBG inside a Trusted Area, the train position is trustworthy, and trackside can grant an MA.
- If the train reports a valid position outside of a Trusted Area, the train position is not trustworthy (unless trackside can ensure trustworthiness by supplier-dependent checks). Consequently, trackside is unable to grant an MA. As described in Section 3.4.2.2, the train then needs to pass at least one balise with ETCS activated before trackside can locate the train and to grant an MA. This train movement is performed in Staff Responsible (SR) mode following national operational rules including interaction between driver and operator. The overall system safety level is reduced due to a higher human error rate in comparison to supervised train movement.

3.4.3.1.2 Trusted Areas ensured by operational measures

Trusted Areas ensured by engineering rules as described in the previous section are only one possibility to avoid operational obstructions resulting from ambiguous train positions. Another possibility is to establish Trusted Areas based on operational rules (e.g., shunting prohibition or by ensuring that there are no cold movements of trains). In this situation, fewer balises are needed. For the example depicted in Figure 11 BG 4 and 5 are not required in areas where trains do not perform unsupervised movements to opposite points legs. Nevertheless, operational rules provide a lower level of safety than technical measures.

3.4.3.2 Achieve trustworthy position by memorizing train history

An alternative way to verify a valid position on trackside is to implement an associated check in the trackside train control software. Trackside could remember the reported position information as well as relevant train data such as the train length at the time the train performs End of Mission. During start-up, the newly reported position and train data can then be verified with the previously stored one. This method has two major restrictions:

- There are limitations in case of turnaround movements (e.g., in dead-end-stations) when the train starts-up with another OBU ID, another front end position and it may also report another LRBG, even if the train formation has not been changed.
- Implementing complex algorithms on trackside increases SIL4 development costs.

3.4.3.3 Reduce probability of start-up with invalid position by installing CMD devices

When entering ETCS mode NP (e.g., when being parked in a depot or stabling area) the position information stored on-board is set to “invalid” (cf. Ref [28] Section 4.10). If trackside is not able to validate this position during SoM, the stored position information becomes “unknown”.

To enable CMD in NP mode, a separate power supply must be available. According to Ref [28] Section 3.15.8, the on-board European Railway Traffic Management System (ERTMS)/ETCS equipment shall be able to detect and record after switch-off whether the train has been moved during a period (of at least 72 hours). Upon restart, the on-board ERTMS/ETCS equipment shall use the stored Cold Movement information to update the status of the on-board stored information.

Equipping trains with CMD systems increases both safety and system performance. This can be attributed to the fact that trains that are powered-off and have not performed a cold movement do not lose their valid position. Therefore, a re-positioning of the train by movement in SR mode is not required and if the valid position is in addition also trustworthy, trackside can grant an ETCS MA to the train.

3.4.3.4 Continuously supervise train movements

As mentioned in the previous sections one basic reason for not trusting a valid train position during SoM is the fact that unsupervised train movements prior SoM may have occurred without trackside noticing it. A train does not determine its position in relation to the LRBG in the following modes (cf. Active Function Table in Ref [28] Chapter 4):

- No Power (NP)
- System Failure (SF)

- Isolation (IS)

In addition, a train does not send position reports as requested by trackside (even when determining it on-board) in the following ETCS modes (cf. Active Function Table in Ref [28] Chapter 4):

- Passive Shunting (PS)
- Shunting (SH)
- Sleeping (SL)

This can be attributed to the fact that an entry to ETCS mode SB and SH is considered as End of Mission. PS and sleeping can be only entered via SH or SB mode, respectively, i.e., outside of ETCS missions (cf. Transition Table in Ref [28] Section 4.6.2). In contrast to Ref [28] Chapter 4 Active Function Table, a train does also not report its position as requested by trackside in SB mode when the desk is closed. This can be attributed to the fact, that end of mission up to B3R2 always results in a termination of the communication session between trackside and on-board system.

With TSI 2023, Change Request 1350 (always connected, always reporting) will be implemented but with restricted functionality. The CR has originally been raised to support the transition to future railway systems that (cf. Ref [55]):

- are not completely equipped with TTD systems;
- use both train position and integrity state (including safe train length) to free infrastructure;
- improve safety by keeping the communication session between trackside and on-board system and which therefore enable the trackside implementation (e.g., RBC) to influence a train moving outside of ETCS missions to mitigate potential hazards;
- allow a fast and efficient SoM.

This can be achieved if a train continuously reports its position in further ETCS modes such as SB with closed desk and SH. The current solution proposal of the CR only covers the submission of position reports in ETCS mode SB with a closed desk. It needs to be analysed and addressed in scope of the Europe´s Rail Joint Undertaking System and Innovation Pillar if this solution is sufficient to cope with the challenges arising in the future railway system.

3.4.4 Summary

The previous sections explained the challenges regarding ETCS SoM in today's signalling systems. For localisation (LOC-OB), the following aspects of ETCS SoM are important to consider:

- The major aim is to start-up with an ETCS MA to increase safety and to reduce operational obstructions.
- During ETCS SoM a train position can be valid, invalid, or unknown.
- Trackside does only immediately grant an ETCS MA if the train position is both valid and trustworthy.

Figure 12 summarizes these aspects.

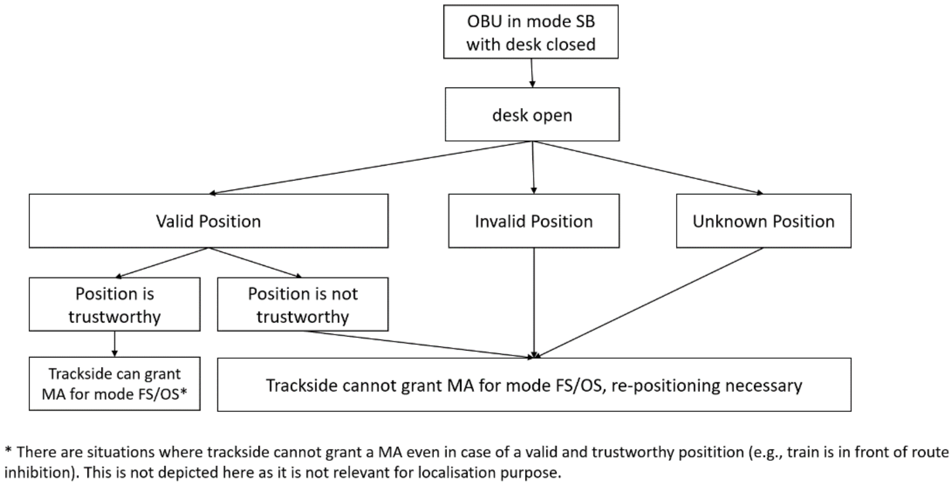


Figure 12 – Conditions for granting an MA during ETCS SoM.

To cope with the challenges described in Section 3.4.2, several countermeasures exist. They can be classified into technical and operational measures, e.g., Trusted Areas, memorizing train history, CMD and continuous supervision of train movements.

3.5 Performing an ETCS Mission

3.5.1 Introduction

Today, the determination of a track selective train position outside the scope of ETCS SoM is sole task of the trackside system. As described in Section 3.3, an OBU reports its position based on a reference location (LRBG) and a travelled distance. The trackside application determines the safe train front end positions within the topology, and if applicable also the safe train rear end position (derived from the safe train length in case of confirmed train integrity).

Today, in trackside parts of current train control systems such as RBCs, outer train positions like maxSFE and safe train rear end only play a minor role. Localisation-dependent decisions such as initially assigning trains to signals or determining whether a train is affected by an emergency or signal stop are usually performed using the minSFE position, i.e., the inner train front end position. With regard to track capacity, the relevance of the outer train positions and therefore also of the location accuracy is increasing in case there is a shift from Trackside Train Detection (TTD) towards on-board train detection (e.g., by removal/reduction of TTD systems).

To determine correct track selective train positions, additional information will be considered on trackside, e.g.,

- point positions,
- protected/assigned route.

These examples will be further described in the next sections.

3.5.2 Challenge – determination of track selective train positions in case of parting tracks

One big disadvantage of today's ETCS localisation principle is that it is based on a reference location (e.g., LRBG) and a ETCS confidence interval related to a travelled distance. In case there is a facing pair of points located between the reported reference location and a train front end position, then the problem of track selective position determination arises. Figure 13 illustrates this situation. The train has reported BG1 as LRBG and there is a pair of points located between BG1 and the outer train front end position (maxSFE as depicted in situation (a) or all train front positions (as depicted in situation (b) in Figure 13).

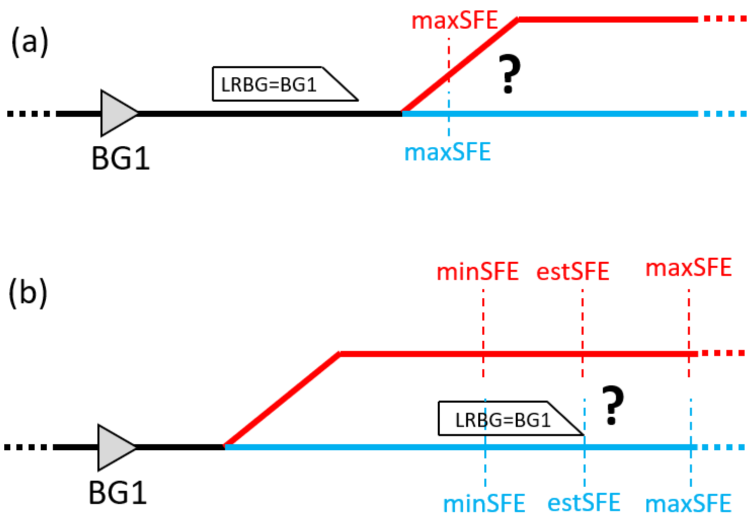


Figure 13 – Ambiguous train position due to points.

To be able to determine the track selective train front end positions in case of parting of tracks, additional information needs to be evaluated on trackside. This is going to be explained in more detail in the subsequent sections.

3.5.3 Technical solutions

3.5.3.1 Consideration of protected train running path

Trackside signalling systems ensure that switchable field elements cannot be changed anymore once locked in the running path of a train unless the corresponding route is released. In today's signalling systems route protection and submission of corresponding ETCS authorisations are performed by different subsystems. The interlocking is responsible for route control whereas the RBC submits the corresponding authorisation (e.g., MA, Staff Responsible Authorisation, Shunting Authorisation, Reversing Authorisation) to the train. In case of error situations or situations with limited trackside signalling functionality, train movement can be also authorised by the operator (e.g., by written order).

To determine a track selective train position during a mission, trackside can consider the protected train running path if the train position is located inside this path. Figure 14 (a) illustrates a corresponding situation. Trackside can derive from the protected train running path that the maxSFE position of the train is located on the upper/lower points leg as the point is locked. Figure 14 (b) outlines a common restriction of this approach. It does not work if the train position exceeds the protected train running path (e.g., due to localisation inaccuracies). Section 3.5.3.2 describes the challenges occurring if a track selective position shall be derived from point positions.

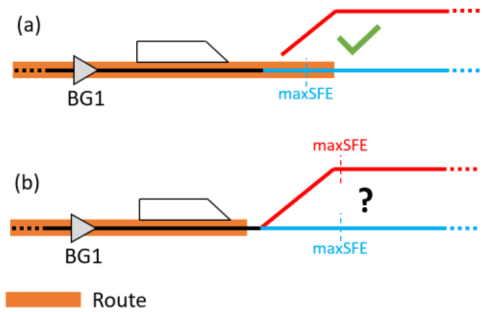


Figure 14 – Localisation of train front end position in relation to protected train running path.

Please note: In contrast to consideration of the protected train running path for track selective position determination, an evaluation of the granted ETCS authorisation is not adequate. This results from the fact that depending on the type of ETCS authorisation, it usually does not contain route related information (e.g., in case of SH/SR/RV Authorisation). Even though an ETCS MA contains linking information (i.e., a list of BGs the train is going to pass and that shall be evaluated by the OBU), it is not adequate to use that information for the following reasons:

- The linking information does not contain all BGs located in the track. BGs not contained in the linking information will not be read by a train in ETCS mode FS/OS. That way it is possible to use dedicated BGs to submit additional information to trains not being under supervision of trackside (e.g., speed restrictions for trains in SR mode).
- There is no common ETCS rule today to place BGs around points. To be able to conclude on which point leg a train is located based on the LRBG; it would be necessary to install additional BGs on every points leg. This contradicts the goals of a future railway system to reduce the amount of track assets.

3.5.3.2 Consideration of point positions

Another possibility for trackside to determine a track selective train position is the evaluation of the point position as depicted in Figure 15.

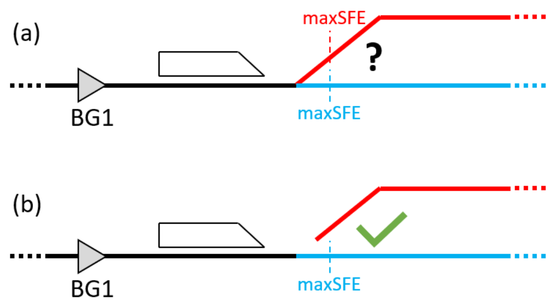


Figure 15 – Localisation of train front end position in relation to point position.

Two important aspects must be kept in mind in scope of this trackside solution approach:

1. The trackside application knows whether an evaluated point end position can be changed after train position determination or not. If this is possible, trackside needs to react on the end position change and adapt the corresponding train position (i.e., map it to the other points leg). In current ETCS systems, the fact that a track occupancy derived from a railway vehicle spans over a pair of points usually does not prevent to operate the point if the corresponding physical object does not occupy it. This is different in moving block systems defined in scope of RCA and Shift2Rail. Both, the existence of a Movable Object (RCA) and a Track Status Area (Shift2Rail) prevent the operation of points located inside these objects or areas, respectively.
2. There are situations in which no point end position is reported, e.g., in case of a disturbed point. A track selective position cannot be derived in these situations as the point does not report an end position.

3.5.4 Summary

The previous sections explained the challenges regarding track selective position determination while performing an ETCS mission in today's signalling systems. It has been elaborated that the determination of a track selective position is performed by trackside and not by on-board. In case of parting of tracks, trackside can determine the track selective train position by consideration of additional information such as the allocated train running path and/or by consideration of point positions.

3.6 Excursus: additional operational optimisations of train positions

In the Section 3.5.2, the determination of a track selective position while performing an ETCS mission in today's signalling systems was described. In the described cases, the determination of a track selective position is necessary to ensure a safe train operation.

In addition to that, further corrections of the train position can be performed by trackside. These corrections can improve the position accuracy and therefore increase the capacity of a line but are not required from a safety point of view.

An important variable influencing these optional corrections is the ETCS confidence interval: the bigger the ETCS confidence interval is, the more corrections are necessary on trackside to avoid operational obstructions. If the ETCS confidence interval is small, trackside correction may not be necessary.

There are different solutions how trackside can correct a reported train position. The following two examples show the principle behind:

(1) Aggregation of different input sources: e.g., shorting train position by using Track Vacancy Proving Section (TVPS) states (cf. Figure 16).

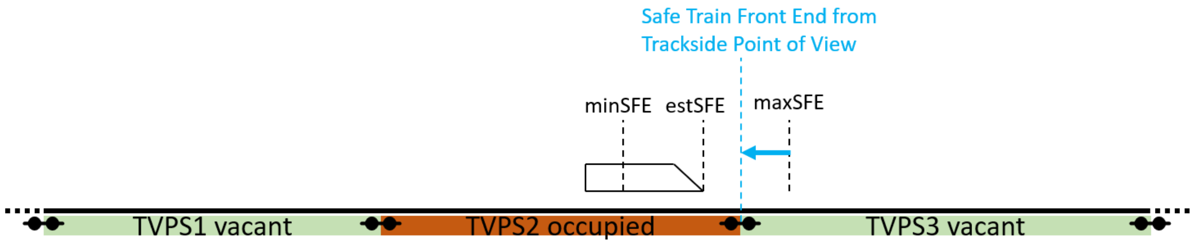


Figure 16 – Principle of aggregation of additional information by trackside to adapt (e.g., in this case shorten) the train position.

In the depicted situation, trackside can conclude that the train is not located inside TVPS3. Therefore, the determined safe train front end can be moved to the TVPS border.

(2) Consideration of further Railway Vehicles: e.g., overlapping of ETCS confidence interval of different trains (cf. Figure 17).

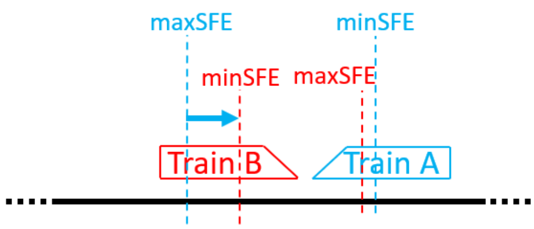


Figure 17 – Overlapping of confidence intervals (e.g., in case of splitting or joining of trains).

In this situation, trackside knows that the maxSFE of train A is not located beyond the minSFE of train B as the physical front end of train B is located between its reported minSFE and maxSFE position. The safe train front end of train A can therefore be moved to the minSFE position of train B.

Since trackside can aggregate additional information like TVPS states and positions of other trains it is able to determine a more accurate train position than the on-board system. Consequently, there may be different views on both on-board and trackside regarding the safe train positions and the corresponding safe train extent. Today, this is not seen to be a problem since only trackside localisation information (not on-board localisation information) is used by other systems.

Please note: Only train front end localisation is relevant in scope of the CLUG 2.0 project. The position corrections described in this section are not required from safety point of view. This is different for determination of the safe train rear end if no train integrity device is available or if it is not working. In these situations, trackside needs to consider additional information for determining a safe train extent.

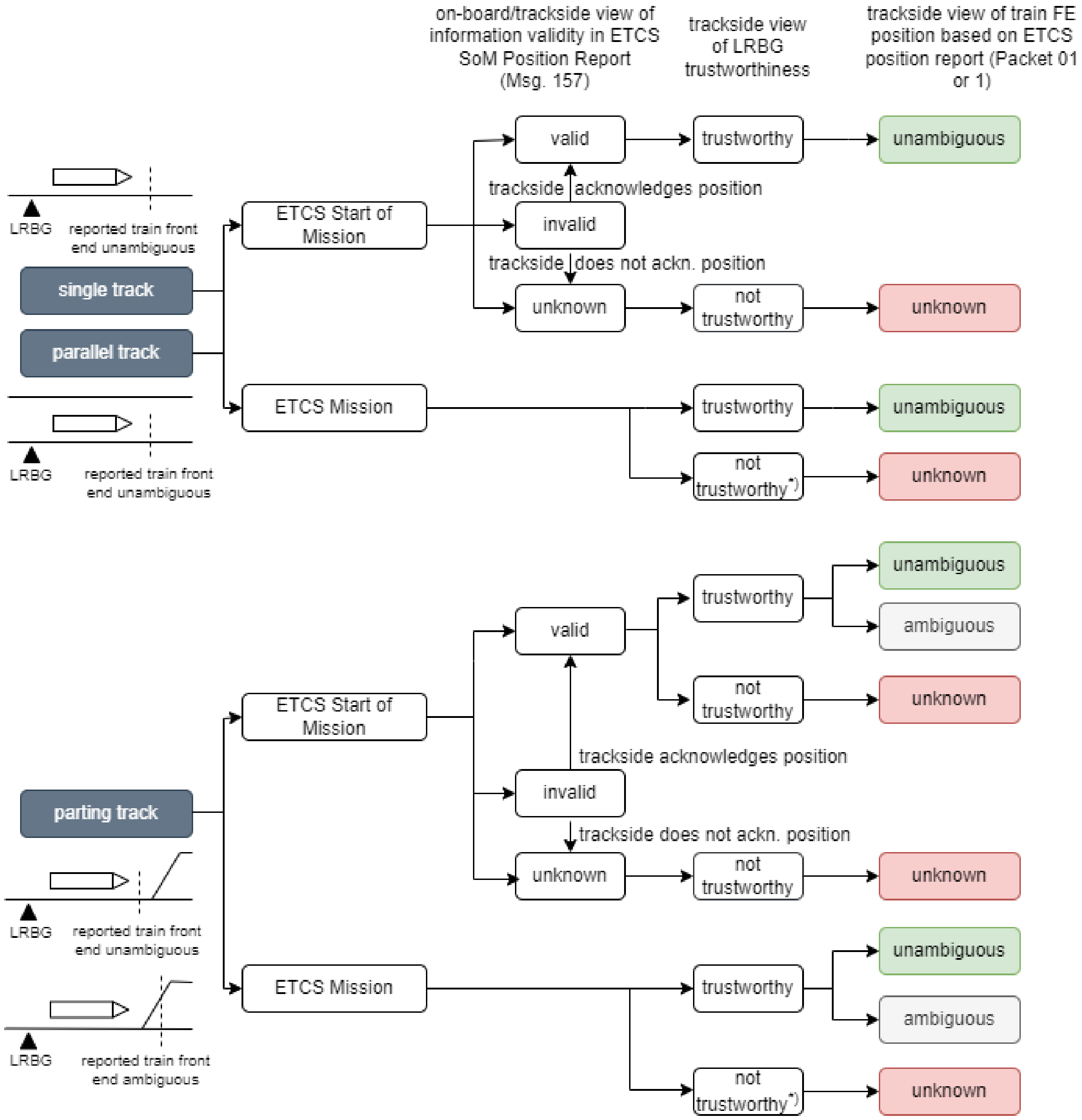
3.7 Impact of different Topological Settings

As introduced in Section 2.4 the Topological Settings are:

- single track
- parallel track
- parting track

The previous Sections 3.4 and 3.5 show that in today's ETCS systems, localisation-relevant challenges mainly result from Topological Settings with parting of tracks, e.g., due to points. This can be attributed to the fact that a valid LRBG is not trustworthy if it cannot be safely excluded that the train is located on a parallel points leg, and that train front end positions cannot always be determined unambiguously (i.e., track selective). This applies to both ETCS SoM and train movements in running ETCS missions.

Figure 18 summarises localisation-relevant consequences of performing ETCS SoM or an ETCS mission in the different Topological Settings.



Please note: not all situations and implementation possibilities are shown due to complexity and clarity reasons.

*) At the begin of an ETCS Mission an LRBG may be classified to be not trustworthy until the train passes a new BG and reports it as LRBG. Afterwards, the LRBG remains trustworthy for the rest of this mission.

Figure 18 – Localisation-relevant consequences of performing ETCS SoM or an ETCS mission in different Topological Settings.

In Topological Settings “single track” and “parallel track” without points, an LRBG reported by means of a valid SoM Position Report message can be classified as trustworthy as it can be safely excluded that the train is located on another (parallel) track than the reported LRBG (cf. Section 3.4.2.1). If a train front end position can be derived from the information contained in the ETCS Position Report packet (UNISIG packet 0 or 1), it is unambiguous. At the begin of an ETCS Mission the LRBG may be classified to be not trustworthy until the train passes a new BG and reports it as LRBG, e.g., in case of:

- starting initial train movement after ETCS SoM without trustworthy position (e.g., in ETCS mode SR for re-positioning purposes).
- establishment of a communication session outside of ETCS SoM context (e.g., due to passing a session BG or reporting a mode change to trackside).

Trackside does not derive train front end positions based on a not trustworthy LRBG (i.e., it considers the train position to be "unknown"), even if the corresponding information such as the distance from LRBG to the estimated train front end (D_LRBG) is given in the ETCS Position Report packet. This means, on-board and trackside view regarding train front end positions can differ.

As soon as an LRBG becomes trustworthy, this characteristic remains stable, i.e., every LRBG reported afterwards during the ETCS mission is trustworthy as the train has passed the corresponding track element.

In Topological Settings with parting tracks the trustworthiness of an LRBG reported with a valid SoM Position Report can be ensured by applying additional measures such as configuration of Trusted Areas (cf. Section 3.4.3.1). A trustworthy LRBG does not necessarily lead to unambiguous train front end positions. This can be attributed to the fact that if there is a facing pair of points located between LRBG and train position, this train position can be located on each of the points legs. Trackside has, in contrast to an on-board localisation system, several possibilities to resolve an ambiguous train position into an unambiguous one, e.g., by considering the track path reserved for train movement, point positions, localisation information received from other sources such as TTD systems and history of train movements.

3.8 Conclusion

Based on the previous analysis, the following conclusions concerning today's signalling system with ETCS can be derived and should be considered within the further work on LOC-OB system design:

(1) Trackside must know the track selective train position on the topology, as this is important from safety point of view.

(2) A train starting up with unknown or not trustworthy position results into operational drawbacks and decreases the safety level of the system.

(3) The major aim of SoM is to start-up directly with an ETCS MA. Therefore, valid, trustworthy, and unambiguous train positions are required.

(4) As soon as trackside classified a reference location (i.e., LRBG) as trustworthy and thus the position information as well, the LRBG does not become "not trustworthy" again during the ETCS mission.

(5) A valid train position (reported by means of ETCS SoM Position Report Message 157) does not become invalid or unknown again during an ETCS mission.

(6) The determination of a track selective train front end position is a pure trackside-related task. The on-board system does not evaluate its position regarding a topology.

(7) Localisation-relevant challenges mainly result from Topological Settings with parting of tracks.

(8) Trackside can convert an ambiguous position into an unambiguous one by considering additional information (cf. Section 3.5.3).

(9) Trackside and on-board view about train positions can differ e.g., trackside does not derive train positions from an LRBG classified as not trustworthy; and trackside is able to further precise train positions derived from on-board localisation by using additional information. This is not seen to be a problem since only trackside localisation information (not on-board localisation information) is used by other systems today.

(10) Trackside can influence the frequency of ETCS on-board position reports by means of Packet 58 (“Position Report Parameters”, cf. Ref [28]).

4 Challenges for future localisation (using LOC-OB) regarding SoM and Track Selectivity

4.1 Consideration of environmental conditions

The environmental conditions under which LOC-OB should be operable are specified in D2.1 (cf. Ref [1], UR[016] and UR[018]). These conditions might influence the availability, accuracy and safety of the sensors within LOC-OB (detailed selection of sensors to be defined in CLUG 2.0 D4.1), which could ultimately have a negative impact on the size of the ETCS confidence interval and Track Selectivity capabilities. The following sections are meant to analyse the challenges w.r.t GNSS and IMU availability and quality in different scenarios focusing on Starting a Mission (cf. Starting a Mission definition (including ETCS SoM) in Section 2.1.2) and Track Selectivity computation.

Note: Other sensors, such as speed sensors, are not explicitly considered in this section.

4.1.1 Introduction

The complete definition of functions of the LOC-OB can be found in D2.3 (cf. Ref [3]). Regarding future localisation functionality, the LOC-OB computes output data based on its sensors and data input interfaces. In this section the focus is on the environmental effects on sensors, as per their availability, accuracy and safety performances, influencing navigation computation and Track Selectivity computation.

The input data for the main functionalities of the LOC-OB are provided by a GNSS-receiver, an IMU and digital map data (for details see Section 4.1.2). The IMU measurements are important for the navigation algorithms especially in areas with poor or no GNSS signal reception. The map data processing allocates information like the topology, topography and map-related input information (e.g., reference locations).

Position calculations are performed by a fusion algorithm which is considered as black box in the LOC-OB within this document. Functionalities within the fusion algorithm are not discussed. Nevertheless, one can conclude that based on the quality of sensor inputs (e.g., degraded GNSS signals due to environmental conditions) the position output varies in terms of the achievable accuracy. Section 4.1.4 is creating this relation between environmental conditions and resulting sensor measurement accuracy.

To illustrate the difference between the position uncertainty solely based on LOC-OB originated data and map data, and the final output ETCS confidence interval (along track), the concept of the Area of Uncertainty (along and perpendicular to track) is introduced.

The Area of Uncertainty is an abstract illustration of the combined sensor and map uncertainties used in several figures in this section. Its boarders restrict the potential positions of the train front end on the map. The geometrical form of an ellipse is used to simplify the illustrations and does not relate to the fusion algorithm.

The size of the Area of Uncertainty is depending on the quality of sensor inputs, map data and the required integrity (i.e., Tolerable Hazard Rate (THR)). The computation of the final ETCS reference location, ETCS confidence interval, and Track Selectivity determination may additionally use valid and safe dynamic trackside data such as point position or safe route information, provided that such information can safely be used.

4.1.2 Functionalities of the LOC-OB

4.1.2.1 On-Board Measurement

GNSS: As mentioned in Ref [24] the GNSS-receiver tracks and processes signals from GNSS-satellites. The signals from the satellites are influenced by the local environment around the receiver (in particular, the antenna environment), with the most common effects being shadowing and multipath effects, and by atmospheric conditions (e.g., ionospheric delay). These effects can influence the accuracy of the LOC-OB output.

IMU: The IMU usually consists of 3 acceleration sensors, and 3 gyroscopes, per coordinate axis one acceleration sensor and one gyroscope. So, the IMU measures the acceleration and rotation in every coordinate axle direction and outputs the values with a high frequency (usually 50 Hz or more). Parameters for the IMU that must be taken into account when using the data are for example, specific characteristics (drift, bias, misalignment, etc.) or the vibration environment.

For the considerations in this section, the term GNSS summarizes different Global Navigation Satellite Systems (e.g., Global Positioning System (GPS), Galileo, GLONASS) and Augmentation systems and Services (SBAS like EGNOS and Ground Based Augmentation Systems like real-time kinematic positioning networks and services). The IMU functionality sub-summarizes sensors based on Dead Reckoning principles (e.g., physical odometry, visual odometry based on stereovision, etc.). The combination of Dead Reckoning of the IMU and GNSS is a typical example for a complementary redundancy. The sensors are based on different physical principles, and, to some extent, they complement each other: GNSS, e.g., is affected by outages due to shadowing effects in urban areas, which can be overcome by Dead Reckoning. However, Dead Reckoning obtains sufficient accuracy only over a short distance travelled, but GNSS is needed to assist Dead Reckoning in reducing the accumulation of measurement errors over distance.

Table 1 shows the different characteristics of the GNSS and IMU functionalities.

Characteristics	GNSS	IMU
Operation	Non-autonomous	Autonomous
Information	Absolute	Relative
Output rate	Typically 1 Hz or more	50 Hz or more
Short-term accuracy	Low	High
Long-term accuracy	High[3]	Low
Availability	Environment dependent	Mostly environment independent
Vulnerability	High	Low

Table 1 – Comparison of GNSS and IMU characteristics.

4.1.2.2 Map Data Processing and Navigation

The Digital Map is mainly used to determine an ERTMS-compliant reference location and the 1D distance measurement (for more details see D2.3 Chapter 8). It is also used to improve the output of the fusion algorithm by matching the movement parameters with the help of topology/topography data of the DM. Digital map quality properties include the safety and security of the data, accuracy of the position, the reliability/fault rate of the information (i.e., its trustworthiness or the probability of incorrect data), the age of data (frequency of survey/update), the completeness and the level of detail (density of resolution).

4.1.3 Effects on sensor measurement accuracy by environmental conditions

Figure 19 and Figure 20 sum up the accuracy delivered by the availability of GNSS and IMU and the main deteriorating factors, respectively. The trees are based on the detailed analysis of the environmental factors in Ref [23].

[3] In general, GNSS receiver output become more accurate over time, as satellite signals can be tracked more precisely in the tracking engine (e.g., in the Phase Locked Loop), and as, e.g., carrier phase ambiguities can be fixed. However, it must be noted that this does not apply in challenging environments with severe static multipath effects, where the GNSS receiver output might remain inaccurate for a longer period of time.

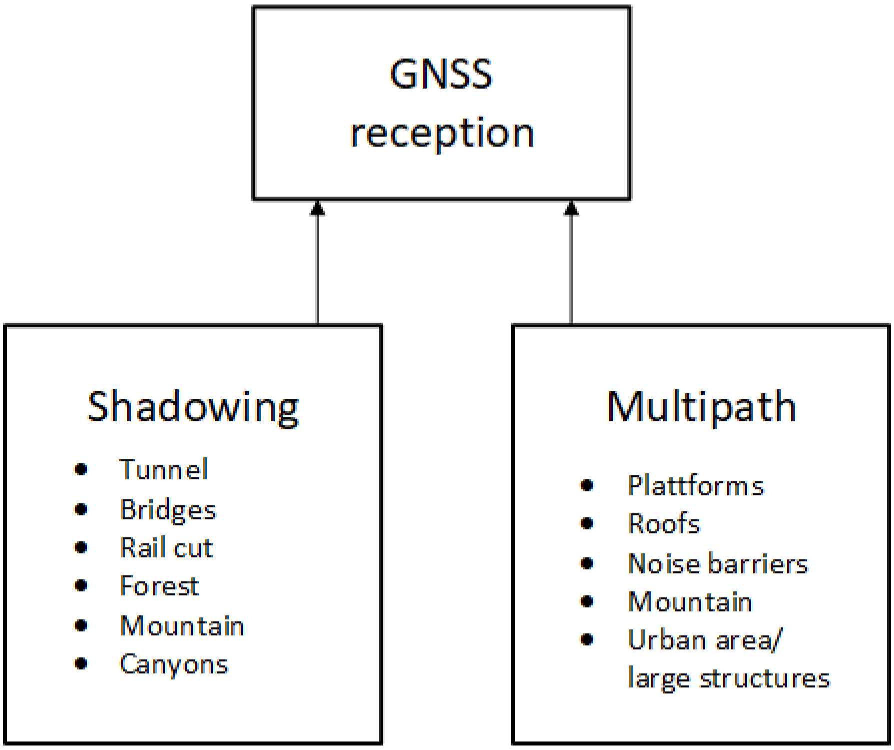


Figure 19 – Main deteriorating factors for GNSS signal reception.

Environmental conditions can have a negative effect on the GNSS signal reception. The Shadowing effect decreases GNSS signal reception up to an extent where no absolute position can be determined.

The Multipath effect disturbs GNSS signal reception and can lead to a severe reduction of usable GNSS signals.

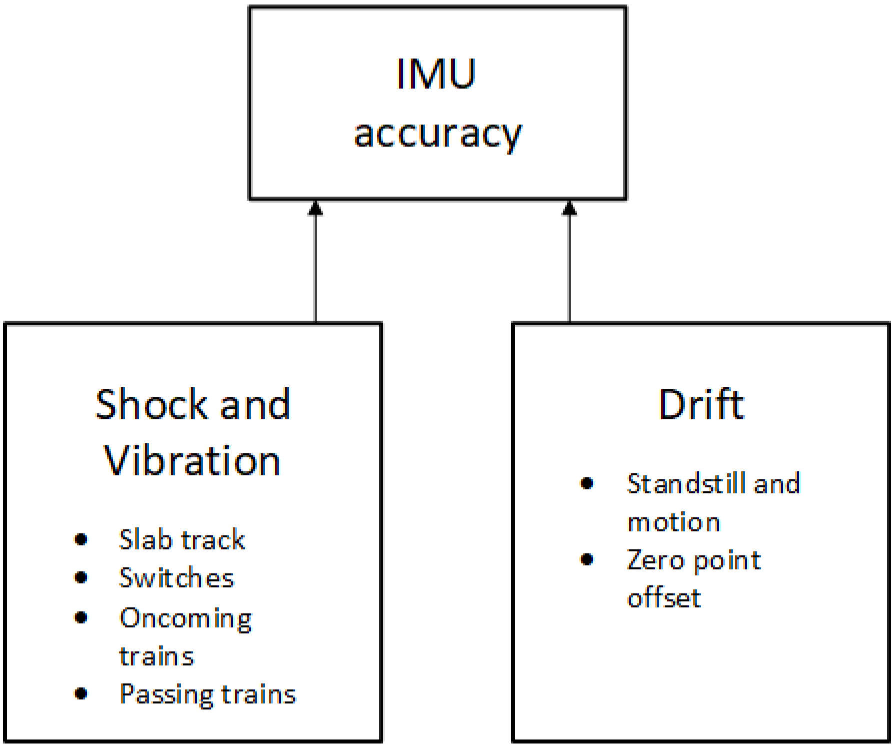


Figure 20 – Main influencing factors on IMU accuracy.

The IMU accuracy is impacted by Shock and Vibrations, as well as Drift (and sensor internal biases). The biases continuously need to be observed and estimated by the sensor fusion. Shock and vibration events are mostly temporary but must be addressed by the fusion algorithm.

4.1.4 Accuracy when combining sensor data and digital map data

The size of the Area of Uncertainty depends, among other factors on the measurement accuracy of the sensor inputs. Accuracy discussed implies that the required THR is achieved. In the matrix Table 2, different categories for the resulting size of the Area of uncertainty are defined to be later used in the descriptions of challenging scenarios.

High sensor measurement accuracy	The Area of Uncertainty is small enough to distinguish from parallel track[4]
Low sensor measurement accuracy	The Area of Uncertainty is too big to distinguish from parallel track without additional data
Limited / no sensor data available	No sensor data available, providing an infinite Area of Uncertainty

Table 2 – Sensor measurement accuracy categories.

4.1.5 Time duration for determination of LOC-OB Initial Position

The duration to render a position with the required accuracy and safety track selective with the LOC-OB is important for Operational Scenarios. The aspects in terms of GNSS accuracy are listed and discussed here.

- Environmental conditions: Bad environmental conditions such as severe shadowing conditions (tunnel, under roof, etc.) a position can NOT be calculated. In severe multipath environments (urban canyon, forests, etc.) and depending on the nature of the multipath signals (frequency, polarization of signals and constructive/destructive interferences, etc.) the calculation of a position might take very long.

The estimation of a time duration for the “best environmental case” is not very robust, because there are still numerous influences / unknown parameters.

To get a rough estimation, the GNSS Time To First Fix (TTFF) is considered here first: It refers to the time required by the receiver to perform the first position fix after power on (cf. Ref [78]).

Three different TTFF scenarios can be distinguished, depending on the status of the receiver after power on according to the availability and validity of the data required for the computation of the navigation solution:

- Cold Start: No data is stored in the receiver; however, the position solution can be calculated without the use of any almanac data. To calculate the position, clock correction, ephemeris data, and a GNSS time reference must be retrieved.
- Warm Start: Valid ephemeris and clock corrections are stored in the receiver and it just needs to retrieve the GNSS time reference.
- Hot Start: This refers to a warm start when, in addition, accurate position and clock error are known. The position solution can be computed without any information from the navigation message.

[4] This means that the distance between tracks is large enough to comply with the accuracy of the localisation. As track distance varies with class and construction requirements of railway line, no absolute threshold between high and low measurement data accuracy was stated.

Besides the availability of the navigation data, the TTFF performance depends on the amount of the visible satellites and on the power of the received signals, or more precisely on the signal to noise ratio C/N0 available at the user receiver (cf. Ref [78]).

Typical values are in the following magnitudes:

- Cold Start: 100s
- Warm Start: 50s
- Hot Start: 2s

The duration for cold start or warm start can possibly be reduced if the Navigation Message can be retrieved from other sources but the satellite signals (e.g., mobile data connection).

If RTK accuracy is needed, the calculations and data retrieval for solving phase ambiguities must also be considered. According to Ref [79], values of up to 120s must be considered for all the TTFF scenarios.

Finally, the (not yet defined) LOC-OB fusion algorithms might add additional initialization and calculation times when combining the GNSS data with other sensor measurements, before the LOC-OB Initial Position is available.

Note: No robust estimation can be made due to the high number of variables. This first, rough quantification of a GNSS-related time to first fix is used for the discussion of timely aspects in the context of the Operational Scenarios and does not directly allow for the derivation of requirements to LOC-OB. However, it can be assumed that due to regular operations of equipped engines, that Cold Start can be disregarded from the usual starting modes. Further assumptions include the implementation of common technologies such as assisted GNSS can significantly reduce Warm Start duration.

4.1.6 GNSS/IMU related approaches to improve positioning

GNSS/IMU related approaches to improve positioning can be applied during Starting a Mission and Performing a Mission. To improve GNSS visibility (gaining a line-of-sight to GNSS satellites) and/or to gain more advantageous geometric constellation between the GNSS receiver and the satellites, two main options are considered in these challenges:

- If surrounding obstacles allow for stationary waiting for improving reception conditions, the number of trackable satellite signals can improve (if line of sight to the satellites becomes available).
- Repositioning: Repositioning means moving the train (front end) for a certain distance to change GNSS signal reception and IMU measurements. The repositioning distance depends on the environmental conditions and on the required Area of Uncertainty.

4.2 Starting a Mission with LOC-OB

4.2.1 Introduction

This section discusses the approach of Starting a Mission with the LOC-OB in terms of best-case and challenging situations. The determination of the estFE position and its position status are described. The challenges to determine the estFE position are distinguished in the different Topological Settings.

4.2.2 Enhancement of Initial Position Status

As described in previous sections, the ETCS SoM procedure as part of the Starting a Mission Scenario is highly characterized by the position status provided by the train (valid/invalid/unknown according to ETCS, c.f. Table 3).

describes how the LOC-OB can potentially accelerate Starting a Mission based on GNSS/IMU usage, compared to today's localisation principles.

Column 2 shows the initial ETCS SoM position status. Initial ETCS SoM position status takes the on-board memory position and status into account and combines this information with the optional CMD input.

Column 3 refers to the different sensor measurement accuracy categories according to Table 2.

Column 4 describes if, how and under which circumstances the initial position status can be upgraded to a valid position status. Furthermore, a statement about Track Selectivity is made. The potential enhancement of the Initial position status by LOC-OB is described using the current ETCS status (Q_STATUS) to support compatibility with an ETCS environment.

Line	ET–S SoM - Initial position status	Sensor measurement accuracy (accuracy with the required THR achieved)	Potential enhancement of ET–S SoM - Initial position status by LOC-OB (valid, invalid, unknown)
1	Unknown position	No data	Unknown: A sensor position is unavailable that could enhance the current ETCS position status.
2	Unknown position	Low	Valid or Unknown: A sensor position is available that can enhance the current ETCS position status to Valid for the Single Track and Parting Track topologies. For the Parallel Tracks topology, the position status remains Unknown

			because no reference point can be determined (cf. Section 4.4.3.1). Because of the low positioning accuracy and large Area of Uncertainty, the position can be rendered track selective only on certain topologies or using additional data (cf. Section 4.2.4.1).
3	Unknown position	High	Valid: A sensor position is available that can enhance the current ETCS position status to Valid. Because of the high positioning accuracy and small Area of Uncertainty, the position can be rendered track selective on all but the parting tracks topology without additional data (cf. Sections 4.2.4.1 and 4.2.4.2).
4	Invalid position	No data	Invalid: No sensor-based position is available that could enhance the current ETCS position status.
5	Invalid position	Low	Valid or Invalid: A sensor-based position is available that can enhance the current ETCS position status to Valid for the Single Track and Parting Track topologies. For the Parallel Tracks topology, the position status remains Invalid because no reference point can be determined (cf. Section 4.4.3.1). Because of the low positioning accuracy and large Area of Uncertainty, the position can be rendered track selective only on certain topologies or using additional data (cf. Section 4.2.4.1).
6	Invalid position	High	Valid: A sensor-based position is available that can enhance the current ETCS position status to Valid. Because of the high positioning accuracy and small Area of Uncertainty, the position can be rendered track selective on all but the parting tracks topology without

			additional data (cf. Sections 4.2.4.1 and 4.2.4.2).
7	Valid position	No data	Valid: A sensor-based position is unavailable that could enhance the current ETCS position status.
8	Valid position	Low	Valid: A sensor-based position is available. Because of the low positioning accuracy and large Area of Uncertainty, the position can be rendered track selective only on certain topologies or using additional data.
9	Valid position	High	Valid: A sensor-based position is available. Because of the high positioning accuracy and small Area of Uncertainty, the position can be rendered track selective on all but the parting tracks topology without additional data.

Table 3 - Initial LOC-OB Position status.

According to the description of the Wider System of Interest defined in Ref [59], the LOC-OB shall interface a high number of current and future systems. The concept of CMD can potentially be applied to the LOC-OB, or the LOC-OB would use existing CMD data as an optional input.

The use of a stored position in combination with a dedicated CMD functionality is not fundamental for the functioning of the LOC-OB but can accelerate Starting a Mission without additional measures (cf. Section 4.2.3).

In case of high sensor measurement accuracy, the sensor-based positioning system of the LOC-OB could render the CMD functionality in some situations obsolete, provided that the appropriate integrity (i.e., THR) can be reached. However, if this is not the case, Starting a Mission might require operational or additional technical solutions if no CMD is implemented.

4.2.3 Starting a Mission

This section discusses the LOC-OB's positioning and localization procedures for the basic Topological Settings defined in Section 2.4. They are further detailed and analysed in the context of the Operational Scenarios in Section 4.5.

Starting a Mission begins with the initial position (cf. Section 4.2.2). This position can either be rendered track selective in case of a small enough Area of Uncertainty. Otherwise, additional measures or data are required.

To render the position of the estimated train front end track selective, the Area of Uncertainty must be considered. Depending on whether more than one track edge (cf. yellow lines in Table 3) is inside the Area of Uncertainty or not, LOC-OB might need additional trackside-based or on-board sensor data to render the position track selective. If the available information is not sufficient to achieve a track selective position, additional operational measures might be required.

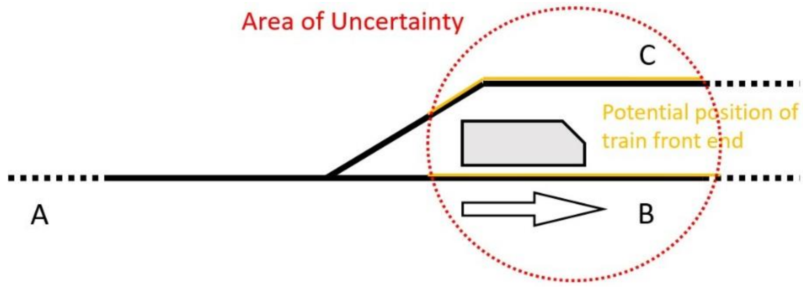


Figure 21 - Potential position of train front end.

4.2.4 Description of Starting a Mission Challenges with GNSS+IMU

In this section challenges to determine a track selective position in Starting a Mission at different Topological Settings are described. GNSS/IMU related approaches to improve positioning are discussed in Section 4.1.6.

4.2.4.1 Single track

In the single-track topology the position might be rendered track selective immediately based on the Area of Uncertainty only (sensor measurements and digital map data). A larger Area of Uncertainty than in other Topological Settings might be acceptable because of the topology of the track.

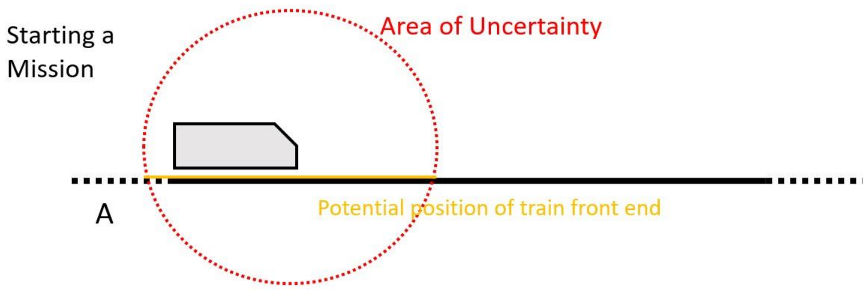


Figure 22 - Single Track Starting a Mission.

Starting a Mission with a position and the next track node inside the Area of Uncertainty means (cf. Figure 3 Section 2.1.4) that the LOC-OB cannot decide which track edge ID the train is on. Therefore, either the last safely passed track edge ID or more than one track edge ID might be reported (cf. Section 4.4.1) (assuming the position ambiguity cannot be solved by other means). In terms of Track Selectivity this is not understood as a challenge since all potential track edge IDs are on the same track in this Topological Setting (cf. definition of Track Selectivity in Section 2.1.4). However, depending on the along-track accuracy (i.e., size of the ETCS confidence interval), an incorrect track edge ID of the estimated train front end might be reported for a specific time duration (cf. Figure 3).

4.2.4.2 Parallel track

In the parallel track topology, if there is no second track in the Area of Uncertainty, the position might be rendered track selective immediately based on the Area of Uncertainty only (sensor measurements and digital map data). The acceptable Area of Uncertainty is smaller in the across track direction, but in the along-track direction it can be the same as for single track Topological Settings.

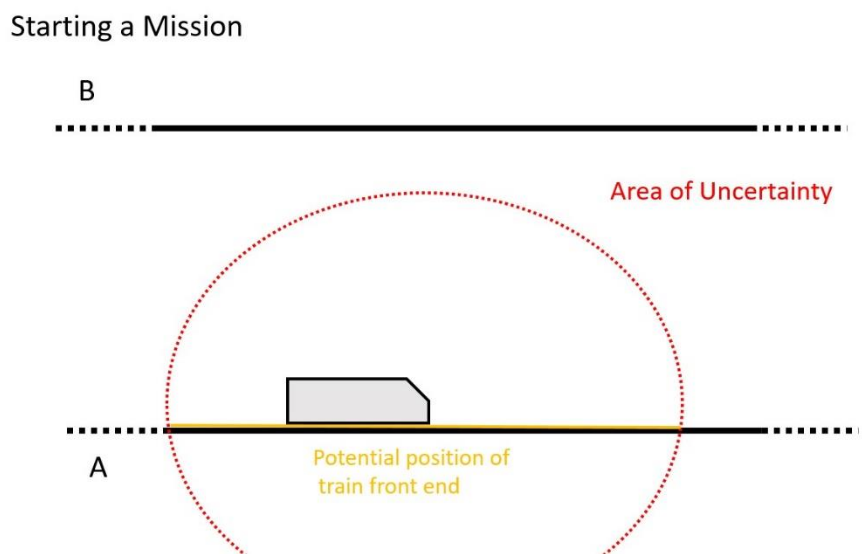


Figure 23 - Parallel Track Starting a Mission.

Starting a Mission with a position and the neighbouring track inside the Area of Uncertainty means (cf. Figure 23) that two different tracks can be considered for the estimated train front end position. If Track Selectivity cannot be achieved by the LOC-OB, this means that no valid position can be reported. To report a valid position, the reference location must be provided. At least two different reference locations would be possible in case no track selectivity is achieved. The approach to render the position track selective might require additional trackside-based, on-board sensor data or operational measures.

4.2.4.3 Parting tracks

In the parting-track topology, if point lies outside the Area of Uncertainty, the challenges reduce to those described for the single-track topology (cf. Section 4.2.4.1) and for the parallel-track topology (cf. Section 4.2.4.2).

In the parting-track topology, if there is a point inside the Area of Uncertainty (cf. Figure 24), the estFE position cannot be rendered track selective without additional trackside-based or on-board sensor data. This results in the inability of the LOC-OB to provide a track selective position for a certain amount of time until Track Selectivity can be established.

In contrast to parallel track topology, it is possible to provide a valid (but not track-selective) position, as long as the reference location lies on the joint track (cf. Figure 24 on Track A). A similar situation is described in Section 3.4.2.1.

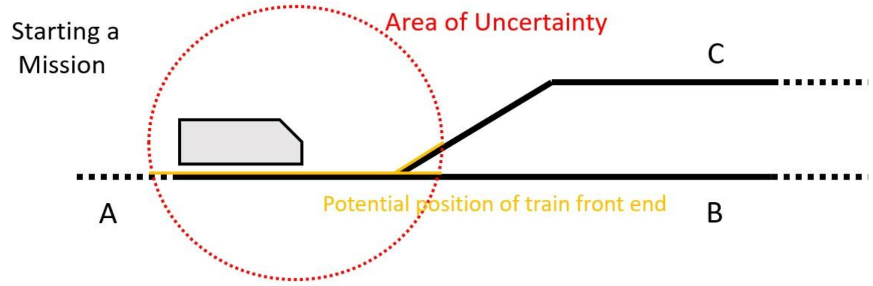


Figure 24 - Parting tracks Position Challenge.

4.3 Performing a Mission with LOC-OB

4.3.1 Description of Performing a Mission Challenges

In this section challenges to determine a track selective position while Performing a Mission at different Topological Settings are described. These challenges start after a completed start (Starting a Mission). According to the Starting a Mission definition in Section 2.1.2 this means that a MA was provided to the train.

4.3.1.1 Single Track Topology

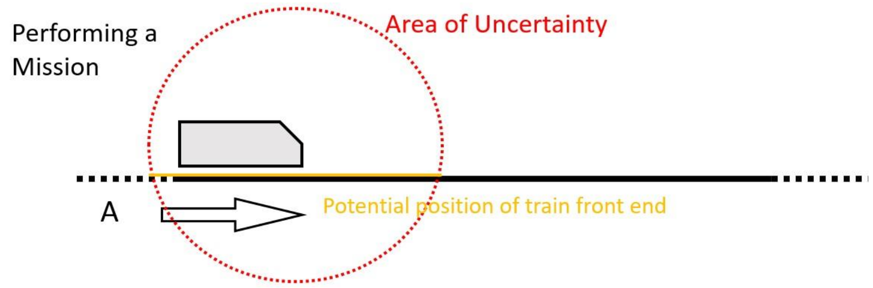


Figure 25 - Single Track Performing a Mission.

While a mission is performed, the train will drive on a track (cf. yellow line in Figure 25) while crossing track nodes. The LOC-OB will continuously determine valid estFE positions. However, as long as a track node is inside the Area of Uncertainty the LOC-OB cannot decide which track edge ID the train is on. Therefore, either the last safely passed track edge ID or more than one track edge ID might be reported (cf. Section 4.4.1) In terms of Track Selectivity this is not understood as a challenge since all potential track edge IDs are on the same track in this Topological Setting (cf. definition of Track Selectivity in Section 2.1.4).

4.3.1.2 Parallel Tracks Topology

In case of two or more tracks next to each other, it is important to differ between those tracks and to assign the estimated train front end position to the right track. In the parallel track topology during Performing a Mission, this is generally achieved when the train front end position was rendered track selective after the parting track topology (see next section). No challenge was identified for parallel track topology.

4.3.1.3 Parting Tracks Topology

While a mission is performed, the train will cross points on its way. The LOC-OB will continuously determine valid positions. For the duration of the point being inside the Area of Uncertainty and without additional data, the position cannot be rendered Track Selective in the first place (cf. Figure 26). There are three possibilities for the track edge the train front end is on:

- track edge A, before the point (cf. Figure 26);
- track edge B, on the main track after the point (cf. Figure 26);
- track edge C, on the sidetrack after the point (cf. Figure 26).

The challenge is to decide which track edge the train front end is on. When the point enters the Area of Uncertainty, all three track edges are possible candidates for the estFE position. After the point leaves the Area of Uncertainty, track edge B and track edge C are candidates (cf. Figure 27). A track selective position assigning track edge B or track edge C can only be assigned after Area of Uncertainty becomes small enough or if the LOC-OB can use additional data. A long-lasting position ambiguity can be the consequence especially in challenging environments. This may influence railway operations due to the occupation of two tracks instead of one by a train. It could also cause problems in terms of providing subsequent MA, when the train approaches the end of the previous MA.

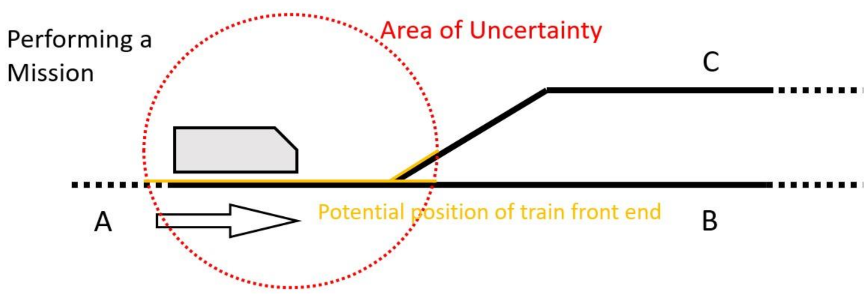


Figure 26 - Potential Position of train front end when passing a point.

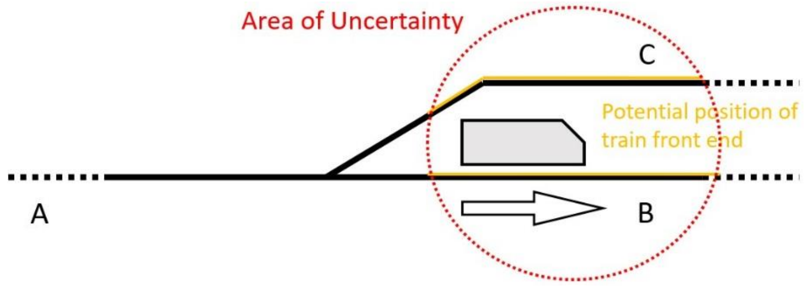


Figure 27 - Potential Position of train front end when point was passed.

Using additional data might significantly accelerate the removal of one of the track sections B or C from the possible track section candidates (if e.g., the point position is known with sufficient integrity (cf. Section 3.5.3 and Appendix A for potential constraints) or additional sensor data are available).

4.4 Outcome of Starting a Mission and Performing a Mission

The assessment of the Starting a Mission and Performing a Mission and their challenges in context of the LOC-OB shows the following differences between the current ETCS system.

4.4.1 Track edge ID management

The track edge ID is determined from the location the estFE position is on. In the Parting Track topology, without additional data, it might be difficult to determine Track Selectivity in case the estimated train front end is close to a point. This results in the need for the definition of a structured output to describe the ambiguity, with the following basic approaches that could be targeted:

1. report the most likely track edge ID with a flag indicating that there is an ambiguity,
2. report all candidate track edge IDs,
3. report the last track edge ID until the new one can safely be determined.

In the first two cases, a value of certainty could be included for the IDs reported (either a percentage, or THR, or other).

The third approach could be misleading, i.e., the fact that there is an uncertainty is not revealed.

The first approach has the advantage of a fixed size output, while the second approach holds more information (e.g., in case of three track legs, one track leg could be excluded; with the first approach, this information would not be available).

4.4.2 Position status during Starting a Mission

The Initial ETCS Position status (Valid, Invalid, Unknown) that is reported together with the position information, can now be enhanced using LOC-OB localisation. This could potentially lead to an acceleration of the operational procedures of the current ETCS in certain cases, cf. Table 3. As GNSS reception conditions might not regularly allow for such cases, operational measures as defined in cf. Section 4.1.6 are required.

4.4.3 Determination of reference location

The following sections summarize based on the Starting a Mission and Performing a Mission challenges in Sections 4.2.4 and 4.3.1, if the reference location can be determined and which assumptions are considered.

4.4.3.1 Start of Mission

In situations with no or invalid initial position status the LOC-OB can significantly accelerate the Start of Mission, provided the position is rendered track selective. The following assumptions are made:

- Assumption 1: It is not a requirement, that the reference location must have been physically passed by the train before.
- Assumption 2: It is not a requirement, that the closest reference location must be used for ETCS position report.

In case of Parting Tracks topology, a valid position according to current ETCS can be provided to Trackside by using a reference location (cf. Figure 28, using R1 instead of R2 or R3). When the estFE is not determined track selective, it is still ambiguous (similar to "not trustworthy" in current ETCS applications).

In case of Parallel Tracks topology without Track Selectivity no Valid ETCS position status can be provided.

Due to the position ambiguity Starting a Mission would not be completed in both cases without additional data or operational measures.

To determine a reference location during Starting a Mission, Track Selectivity is an important aspect. With a non-track selective positioning information from LOC-OB there was no benefit identified compared to current ETCS SoM procedure using balises. (Exception: Starting a Mission on Single Track topology.)

4.4.3.2 Performing a Mission

When Performing a Mission there is a track selective position available as precondition. The Track Selectivity normally does not get lost on single or parallel track topologies. When parting tracks topologies occur, the position information might not be track selective anymore.

The following assumptions are made:

- Assumption 3: A valid and track selective position was available during the mission, before passing a junction.
- Assumption 4: It is not a requirement, that the last passed reference point must be used for ETCS position report.

In case of Parting Tracks topology, an ETCS position according to current ETCS can be provided to Trackside by using a reference location (cf. Figure 28, using R1 instead of R2 or R3). While the position is not determined track selective, the position is reported ambiguously (track edge IDs from different tracks will be reported).

If assumption 4 is ignored, the LOC-OB might not be able to provide a distance to a reference location any more in the given example (e.g., when the reference location is located directly behind a point, while Track Selectivity is not determined yet).

In current ETCS there is no procedure defined for such a case, where during a mission no position is available.

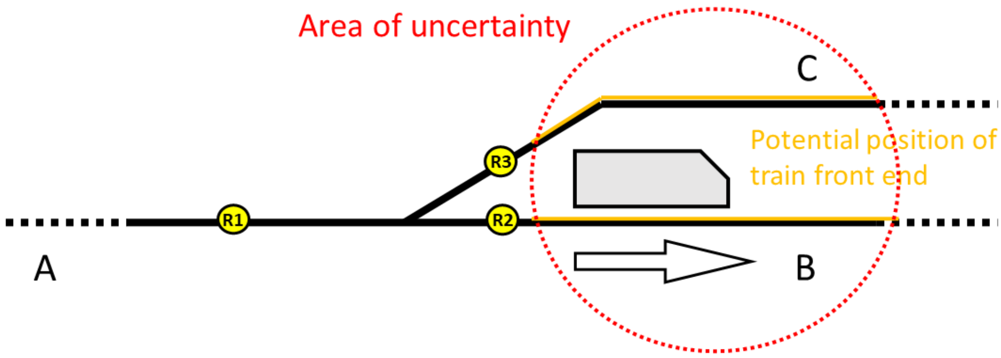


Figure 28 - Reference locations.

Note: Reference locations of the LOC-OB do not necessarily represent physical objects (e.g., balises). Nevertheless, the position and data of reference locations must be the aligned for Trackside and the LOC-OB.

4.4.4 Area of uncertainty in relation to the environmental conditions

As can be learned from the description of Starting a Mission or Performing a Mission, the duration and/or the distance to render a position track selective, the reference location to be used and the ETCS confidence interval are affected by the Area of Uncertainty. As the size of the Area of Uncertainty increases in the absence of GNSS signals, the following environments are especially challenging according to Figure 19:

- Tunnels

- Bridges
- Rail Cuts
- Mountains
- Canyons
- Forests
- Platforms
- Roofs
- Urban Areas

4.5 Challenges in context of Operational Scenarios

This section puts the Operational Scenarios defined in Section 2.3 in context of environmental conditions to identify resulting challenges. While some of the Operational Scenarios are not considered significant in the context of the environmental conditions influencing the positioning of LOC-OB, others are exploited using several different flavours of the scenario in terms of varying Topological Settings or environmental conditions. Table 4 shows which scenarios are further discussed as Challenges and which scenarios don't pose a challenge.

#	Scenario Name	Further discussion in context of LOC-OB
1	Starting a Mission	Sections 4.5.1.1, 4.5.1.2, 4.5.1.3, 4.5.2.1 and 4.5.2.2
2	Performing a Mission	Sections 4.5.2.1 and 4.5.2.2
3	Driver reacts to signal	There are no specific challenges from LOC-OB point of view for this scenario.
4	Driver runs over closed signal	There are no specific challenges from LOC-OB point of view for this scenario.
5	Emergency stop	As the train is Performing a Mission for the duration of this scenario, the challenges for the LOC-OB reduce to those described in the PaM challenges Section 4.3.1. The operational impact of the stopped train must be addressed by the ATP system and / or further applications.
6	Transition to/from ETCS areas	This scenario does not impose new challenges on the LOC-OB. From LOC-OB point of view, the interface is switched from one system to the next. How the output of LOC-OB is handled by the systems and which part of the information is obtained, is defined by the respective applications.
7	Parking	The main challenge here is the loss of position information when the engine is turned off. This scenario therefore reduces to the Starting a Mission challenges described in Section 4.2.4.
8	Change TU drivers cab	Section 4.5.3
9	Joining (of two units)	Sections 4.5.4.1 and 4.5.4.2
10	Splitting (of two units)	Section 4.5.5
11	Shunting	Section 4.5.8
12	Route on closed track	Section 4.5.6
13	Level-crossings	Section 4.5.7

14	On-board ATP system disruption	As described in the general scenario description, in case of failure of the on-board ATP system or the communication to trackside, the on-board system must fall back to a safe state and all movements must be adjusted accordingly. When recovering from this state, the challenges for the LOC-OB are those covered by Sections 4.2.4 and 4.3.1.

Table 4 - Overview of Operational Scenarios.

4.5.1 Starting a Mission Challenges

The following sections describe different versions of the Starting a Mission Challenge. The focus in these sections is on a detailed description of the Operational Scenarios which are defined in Section 2.1.1 and detailed out in Sections 4.2 and 4.3.1.

4.5.1.1 Starting a Mission with reduced duration

Description: The following scenario shows how a LOC-OB can reduce the duration of the Starting a Mission Scenario in comparison to the current ETCS. This leads to benefits for the overall scenario of moving a train in comparison to the current ETCS.

- Preconditions:
  1) The train is in standby (e.g., SB mode in ETCS).
  2) Unknown/Invalid position is stored in the on-board memory (cf. Table 3 row 2,3,5,6).
  3) Environmental conditions allow high or low sensor measurement accuracy (yellow/green cells in Table 2).
  4) The train is in a single-track area.
- Scenario Steps:
  1) The starting procedure is carried out.
  2) LOC-OB valid position of the train is determined and due to the small size of the Area of Uncertainty and the single-track topology Track Selectivity is granted by LOC-OB, without application of additional operational or technical measures.
  3) The reference location used to provide the estFE is either provided by the trackside or decided within the LOC-OB.
  4) A valid and track selective position is provided by the LOC-OB (cf. Table 3 line 2, 3, 5 and 6).
  5) The permission to start driving the planned route with supervision by ATP (Automated Train Protection) is granted (in ETCS called Movement Authority (MA) in FS).[5]
- Postconditions:
  1) The train performs a mission (In ETCS that is the FS mode if a Movement Authority (MA) was obtained).

[5] The decision to provide the permission to start driving may not only be based on valid and track selective position information but depend on further information.

For the overall scenario of Starting a Mission this reduced duration of the start is beneficial in terms of punctuality of the trains within a network. A train that is faster ready for operation can be used more flexible in service. In high density networks this flexibility may even increase capacity.

4.5.1.2 Starting a Mission with unchanged or reduced duration

Description: The following scenario shows how a LOC-OB can potentially reduce the duration of Starting a Mission in comparison to the current ETCS. In contrast to Section 4.5.1.1 in this scenario the starting procedure is not performed in a single-track area, but parallel or parting track area and low accuracy is available.

- Preconditions:
  1) The train is in standby (i.e., ETCS mode SB).
  2) Environmental conditions allow only low sensor measurement accuracy (cf. yellow cells in Table 2), this could be caused by an obstacle such as a bridge.
  3) Unknown/invalid position is stored in the on-board memory (cf. Table 3 row 2,3,5,6).
  4) The train is in a parallel or parting track area.
- Scenario Steps:
  1) The starting procedure is carried out.
  2) GNSS/IMU position of the train is determined and due to size of the Area of Uncertainty, Track Selectivity is not granted by LOC-OB.
  3) A valid and track selective position is achieved by one or more of the following options:
     a. Additional operational measures are applied to improve GNSS signal (e.g., waiting in order to improve GNSS signal quality, Repositioning in order to achieve high according to Table 2).
     b. Data from additional technical measures are considered (e.g., additional sensors installed on the train, trackside-based data).
     c. Additional operational measures yet to be defined (e.g., based on safe human input).
  4) The reference location used to provide the estFE is either provided by the trackside or decided within the LOC-OB.
  5) A valid and track selective position is provided by the LOC-OB.
  6) The permission to start driving the planned route with supervision by ATP (Automated Train Protection) is granted (in ETCS called Movement Authority (MA) in FS).[6]
- Postconditions:
  1) The train performs a mission (In ETCS that is the FS mode if a Movement Authority (MA) was obtained).

The above scenario step 3) gives an idea of the variety of options that can be applied to determine a track selective position during Starting a Mission. There can be no general statement made about the

[6] The decision to provide the permission to start driving may not only be based on valid and track selective position information but depend on further information.

duration of the Starting a Mission Operational Scenario (is it reduced or not). This highly depends on the solution of LOC-OB (additional technical measures) and the environmental conditions (additional operational measures).

In case of 3)3)a it is difficult to compare the current ETCS and the LOC-OB in terms of Starting a Mission and ETCS SoM duration. The duration for operational measures of the LOC-OB is unknown (cf. Section 4.1.5). Furthermore, the comparative duration for repositioning with the current ETCS highly depends on the distance of the train to the next Balise Group (cf. Section 3.4.2.2).

In case of 3)3)b one can assume that additional technical measures would be designed in order to reduce Starting a Mission duration.

The current ETCS using balises and odometer is not described as an optional step in 3), even though this might be a valid migration step to have LOC-OB and the current ETCS localisation system operating in parallel. In this specific scenario there is neither a benefit nor a drawback achieved by the installation of a LOC-OB using GNSS/IMU and balises in comparison to the current ETCS.

4.5.1.3 Starting a Mission with increased duration

Description: There might also be scenarios, where the time to reach a track selective position could be significantly longer compared to the ETCS SoM procedure and therefore delay the train departure.

- Preconditions:
    1) The train is in standby (similar to ETCS mode SB).
    2) No Position available in on-board memory.
    3) Environmental conditions allow no (absolute) position determination (cf. red cells in Table 2).
    4) The scenario can be applied to any of the Topological Settings described in Section 2.4 and the challenges arising from the topologies are specified in the generic Starting a Mission and Performing a Mission sections and are not specific to this Operational Scenario.
- Scenario steps:
    1) The starting procedure (Starting a Mission) begins.
    2) There is no valid position available.
    3) Valid and track selective position is achieved by one or more of the following options:
        a) Additional operational measures are applied to improve GNSS signal (e.g., Repositioning in order to achieve accurate GNSS position according to Table 2).
        a) Data from additional technical measures are considered (e.g., additional sensors installed on the train, trackside based data).
        b) Additional operational measures yet to be defined (e.g., based on safe human input).
    4) The reference location used to provide the estFE is either provided by the trackside or decided within the LOC-OB.

5) Determining the position of the train valid and track selective.
6) The permission to start driving the planned route with supervision by ATP (Automated Train Protection) is granted (in ETCS called Movement Authority (MA) in FS).[7]

- Postcondition:
  1) The train performs a mission (In ETCS that is the FS mode if a Movement Authority (MA) was obtained).

The described Operational Scenario is a good example to show disadvantages of a pure GNSS/IMU based LOC-OB solution in case of bad GNSS coverage. When there is no additional technical solution (e.g., fall back solution of balises) available, operations like starting a Starting a Mission can delay movement of trains significantly. Unplanned operational measures must be applied (e.g., repositioning) which leads to rescheduling of the succession of trains and reduced capacity of the network especially in high density lines.

4.5.2 Performing a Mission Challenges

4.5.2.1 Performing a Mission: passing a point

Description: When passing a point, the track on which the train estFE is located may not be known for a certain time duration.

- Preconditions:
  1) Starting a Mission was performed (train position is valid and track selective).
  2) The environmental conditions allow high sensor measurement accuracy (green cells according to Table 2).
- Scenario Steps:
  1) Train departs from starting point.
  2) The ETCS Confidence Interval of the train front end position passes a point (No track selective position can be provided by the LOC-OB because the Area of Uncertainty contains more than one track).
  3) One or more of the following steps must be performed to achieve Track Selectivity again:
     a) The distance between the parting tracks grows large enough, so that the parallel track moves out of the Area of Uncertainty.
     b) Data from additional technical measures are considered (e.g., additional sensors installed on the train, trackside-based data).
  4) Track selective position is provided by the LOC-OB again.
- Postconditions:
  1) The train continues to perform the mission without further disturbances.

[7] The decision to provide the permission to start driving may not only be based on valid and track selective position information but depend on further information.

This scenario describes the best case when passing a point while Performing a Mission. The technical installations and available information on-board are able to provide a track selective position after short time duration. Similar to today's current ETCS a short time of non-Track Selectivity must be acceptable by the systems using the positioning information from LOC-OB.

4.5.2.2 Performing a Mission: passing a point – low sensor measurement accuracy

Description: When passing a point, the track on which the train front end is located may not be known for a longer time duration.

- Preconditions:
    1) A mission was started (Train position is valid and track selective).
    2) The environmental conditions allow low sensor measurement accuracy according to Table 2 – Sensor measurement accuracy categories.
    3) (orange cells).
- Scenario Steps:
    1) Train departs from starting point.
       Note: The Area of Uncertainty of the estFE position is larger compared to scenario in Section 4.5.2.1 due to low accuracy.
    2) The border of the Area of Uncertainty of the train front end position passes a point (No track selective position can be provided by the LOC-OB).
       The Track Selectivity of the estFE is lost.
    3) Track selectivity cannot be achieved by technical measures.
- Postconditions:
    1) The LOC-OB cannot provide a Track Selective position anymore. Operational measures must be applied.

This scenario describes the case when passing a point during Performing a Mission. The technical installations and available information on-board are not able to provide a track selective position after reasonable time duration or distance.

4.5.3 Change train drivers Cab

Description: This Operational Scenario is applied when the train changes direction. It applies for train sets, single engines and regular trains of cars and engine units. The drivers cab in the new driving direction must be started up (Starting a Mission).

- Preconditions:
    1) The train is Performing a Mission.
    2) The scenario can be applied to any of the Topological Settings described in Section 2.4 and the challenges arising from the topologies are specified in the generic Starting a Mission and Performing a Mission sections and are not specific to this Operational Scenario. However, the designated area for cab change cannot be on a point.
- Scenario steps:

1) The train LOC-OB continuously calculates the estFE position.
2) The train ends the mission at the designated area with the LOC-OB providing a track selective position.
3) The cab of the train is deactivated, i.e., the train is switched to stand-by (i.e., SB mode in ETCS).
4) The engine positioned on the front of the train is starting a mission. The duration can vary according to the environmental conditions:
    - Reduced Starting a Mission duration as per scenario in Section 4.5.1.1.
    - Increased Starting a Mission duration as per scenario in Section 4.5.1.3.
    - Unchanged Starting a Mission duration as per scenario in Section 4.5.1.2.

- Postcondition:
    1) The drivers cab in the new driving direction is ready for Performing a Mission.

The environmental conditions in which this scenario is carried out in, have implications for the train Starting a Mission. For this scenario the impact of environmental conditions on positioning could be limited by providing the LOC-OB with additional information like train length that may be used among other information to derive the new estFE position.

4.5.4 Joining (of two units)

4.5.4.1 Joining (of two units) with approaching cab active and standstill cab inactive

Description: This scenario describes joining of two trains, with supervision functionality of an ATP system (e.g., ETCS) for the approaching train only. The train at standstill is deactivated (i.e., the cab is not active, the train is in stand-by).

- Preconditions:
    1) Train A is in standby (i.e., ETCS mode SB), stopped on a designated track edge.
    2) Train B is approaching from either side.
    3) Both trains are in an area with no major effects that disturb GNSS signal (cf. yellow cells in Table 2).
    4) A distinction by Topological Settings does not apply specific to this Operational Scenario challenge. However, partitioning of the track into smaller track edges might be relevant for this scenario.
- Scenario steps:
    1) The approaching train B LOC-OB continuously calculates its estFE position.
    2) Train B approaches the track edge border of the track edge where train A is located on, based on its position and Area of Uncertainty. Train B can approach the occupied track or track edge border according to the principles described in the Starting a Mission and Performing a Mission challenges sections.
    3) Before the train front end of train B crosses the track node train B must stop or slow down, procedures specific to the ATP system must be used.

4) The procedure for further approaching and physically coupling the two trains is carried out (this refers to current ETCS procedures being manual, automatic or a combination of both).
5) The cab of train A is deactivated, e.g., the train could be switched to stand-by (SB mode in ETCS).
6) The engine positioned in the front of the joined train is starting a Mission as described in unchanged duration (Starting a Mission) in Section 4.5.1.2. However, with additional data this scenario could be accelerated as described in Section 4.5.3.

- Postcondition:
  1) The engine positioned in the front of the joined train is ready to perform a mission.

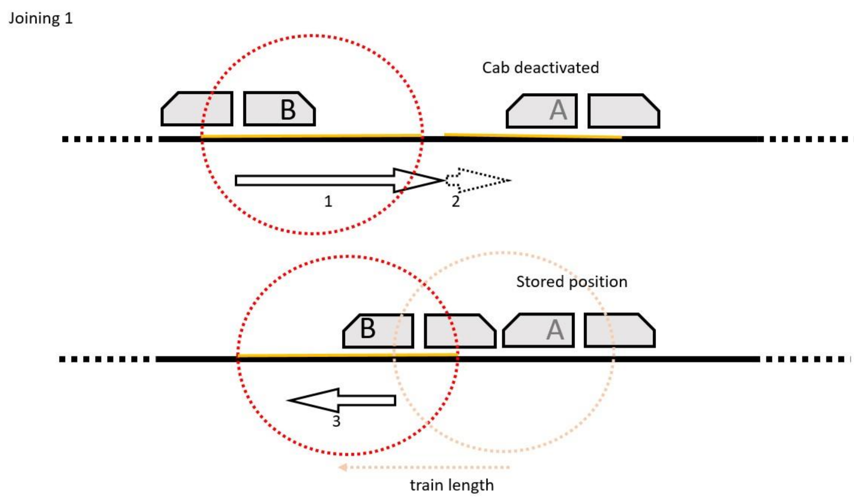


Figure 29 - Joining with standstill cab inactive.

The Operational Scenario described in the LOC-OB context does not imply big improvements compared to current ETCS solutions. The impact of environmental conditions on positioning could be limited by providing the LOC-OB with additional information like train length that may be used among other information to derive the new estimated train front end position. A possible enhancement for the LOC-OB context is discussed in the next scenario with trains maintaining an active state during the joining process.

4.5.4.2 Joining (of two units) with both cabs active

Description: This scenario describes joining of two trains, with supervision functionality of an ATP system (e.g., ETCS) for both trains. Joining fully supervised by ATP (both cabs are supervised) could be beneficial in an automatic driving context.

- Preconditions:
  1) Train A is in standby (i.e., ETCS mode SB), stopped on a designated track edge.
  2) Train B is approaching from either side.

3) For both the environmental conditions allow high or low sensor measurement accuracy (cf. yellow/green cells in Table 2).
4) A distinction by Topological Settings does not apply specific to this Operational Scenario challenge.

- Scenario steps:
    1) The standstill train A continuously calculates its position and ETCS confidence interval.
    2) The approaching train B continuously calculates its position and ETCS confidence interval.
    3) Train B approaches the track edge border of the track edge where train A is located on, based on its position and Area of Uncertainty.
    4) Before the train front end of train B crosses the track edge border, train B might stop or slow down, depending on both train positions, areas of uncertainty, train A length and integrity information, and possibly further information like additional safety margins.
    5) The procedure for further approaching is carried out based on both train positions, Areas of Uncertainty, train A length and integrity information, and possibly further information like additional safety margins.
    6) The actual coupling procedure is carried out (this refers to legacy procedures being manual, automatic or a combination of both).
    7) The cab of train A is deactivated, i.e., the train is switched to stand-by (SB mode in ETCS).
    8) The cab of train B is deactivated, i.e., the train is switched to stand-by (SB mode in ETCS).
- Postcondition:
    1) The engine positioned in the front of the joined train is starting a mission.

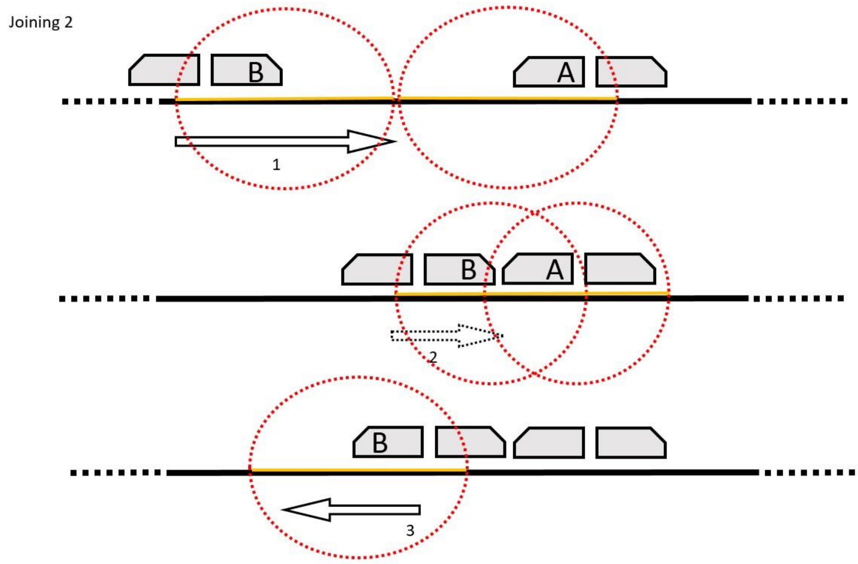


Figure 30 - Joining with both cabs active.

The described Operational Scenario could have several advantages compared to the previous one, but also faces specific challenges that need further analysis:

- In case LOC-OB of train A can provide its positioning information to train B, train B can approach much closer in an automatic driving context and thereby improve operational efficiency.
- In case a cab change is require after joining, information of the deactivated cabs could accelerate the Starting a Mission Scenario of the joint train (c.f. Section 4.5.3).

4.5.5 Splitting (of two units)

Description: This scenario describes splitting of a train with supervision functionality of an ATP system (e.g., ETCS). The train will drive to a specific location and then is split into two sections. The train section with the former leading engine, will continue with updated train data and a new MA. The former NL engine will undergo the complete Starting a Mission scenario.

- Preconditions:
  1) The train is Performing a Mission and is stopped on a designated track edge.
  2) The train has an active cab on the front end (A) and a deactivated cab on the back end (B).
  3) A distinction by Topological Settings does not apply specific to this Operational Scenario challenge.
- Scenario steps:
  1) The train continuously calculates its estFE position.
  2) The actual splitting procedure is carried out (this refers to current ETCS procedures being manual, automatic or a combination of both).
  3) The train (cab A) continues performing it's a mission with updated train data.
- Postcondition:
  1) The train is continuing its mission with active cab A.
  2) Cab B starts Starting a Mission.

The environmental conditions this scenario is carried out in, have implications for cab B starting a mission (postcondition):

- Reduced duration of Starting a Mission for cab B as per scenario in Section 4.5.1.1.
- Increased duration as per scenario in Section 4.5.1.3 or unchanged Starting a Mission duration as per scenario in Section 4.5.1.2. In these cases, the challenge could be addressed (among others) by information provided by the LOC-OB of cab A: Using the estFE position, reference location and ETCS confidence interval of LOC-OB A, and information about the train length, the position and ETCS confidence interval of LOC-OB B can potentially be calculated. Additional information like train integrity status might be required here. The Topological Setting can play a role here as well (e.g., does the train stand on a point) and require further information to determine the estFE position of the cab B.

4.5.6 Route on closed track

Description: This scenario refers to a train route on a closed track for purposes of construction or maintenance operations.

- Preconditions:
  1) The train is Performing a Mission, approaching a track or track edge with restricted usage due to construction or maintenance work.
  2) Environmental conditions allow high or low accuracy (yellow/green cells in Table 2).
  3) A distinction by Topological Settings does not apply specific to this Operational Scenario challenge.
- Scenario steps:
  1) The train continuously calculates its estFE position.
  2) The train approaches the track edge border of the track that is restricted in usage.
  3) Before the train front end crosses the track edge border, the train might stop or slow down, depending on its position, ETCS confidence interval, and possibly further information like additional safety margins.
  4) The train crosses the restricted usage area, applying the constraints specific to the working or maintenance area (e.g., speed limit).
  5) The train leaves the restricted usage area, crossing the border of the respective track edge.
- Postcondition:
  1) The train is continuing its mission under nominal conditions.

Possible advantages of using the LOC-OB in this scenario are the following:

- Typical settings of warning systems for workers in the construction or maintenance area could be optimized with the LOC-OB providing continuous position data:
  - No temporal trackside equipment might be necessary for LOC-OB based automatic track warning systems unless the environmental conditions lead to challenges.
  - Signal controlled warning systems could possibly be optimized using LOC-OB output. Based on the more precise and continuous positioning of the train, more precise warning signals for the working and maintenance personnel can be provided. This results in less and shorter interruptions of the (maintenance) work, and ultimately in shorter duration of the tracks usage restriction. The potential is high especially for moving working areas (e.g., vegetation works).
  - Since environmental conditions allow high or low sensor measurement accuracy (cf. yellow/green cells in Table 2), the Area of Uncertainty will be sufficiently small to possibly locate the train more precisely than with the current ETCS. This would mean that the train (maxSFE) enters the usage restriction area later, and the train must slow down for a shorter duration.

4.5.7 Level Crossings

Description: This scenario describes the procedures of approaching and passing of railway LCs.

- Preconditions:
    1) The train is Performing a Mission, approaching a LC.
    2) The environmental conditions allow high or low accuracy according to Table 2 (green and orange cells).
    3) A distinction by Topological Settings does not apply specific to this Operational Scenario.
- Scenario steps:
    1) The train continuously calculates its position, ETCS confidence interval, and speed.
    2) The train approaches a LC.
    3) The ATP system might enforce speed restrictions around the area of the LC.
- Postcondition:
    1) The train is continuing its mission under nominal conditions.

The environmental conditions this scenario is carried out in, determine if the LOC-OB can bring advantages for this scenario:

- If environmental conditions allow high or low sensor measurement accuracy according to Table 2 (green and orange cells), the Area of Uncertainty will be sufficiently small and the calculated speed while approaching the LC will be highly accurate and continuously available. In this case, the control of a LC could possibly be optimized (i.e., less time in closed state) or trackside infrastructure could possibly be reduced.

If environmental conditions allow no position determination according to Table 2Table 2 – Sensor measurement accuracy categories.

- (red cells), the Area of Uncertainty will be very big and the calculated speed while approaching the LC might be inaccurate. So, for protected LCs, big necessary safety margins might lead to a degraded performance of the LC control compared to a system using other mechanisms for determining the trains position.

4.5.8 Shunting

Description: This scenario describes the procedures of Shunting operations in a dedicated shunting yard or station, with shunting borders. This scenario assumes that the train is in a Shunting mode i.e., SH mode in ETCS.

- Preconditions:
    1) The train is in shunting mode.
    2) The train has completed Starting a Mission or is in stand-by.
    3) The environmental conditions allow low sensor measurement accuracy according to Table 2 (orange cells).
    4) A distinction by Topological Settings focuses on parting track topology specific to this scenario challenge. However, shunting borders also apply on parallel tracks or single-track topologies.
- Scenario steps:

1) The train continuously calculates its position, ETCS confidence interval, and speed. Note: When in Shunting operations this is particularly relevant when approaching borders of the shunting area.
2) The border of the Area of Uncertainty of the train front end position passes a point.
3) Track selectivity cannot be granted due to the low positioning accuracy of LOC-OB, i.e., the LOC-OB cannot determine if the train is on track B or track C.
4) On one of the point-legs the shunting boarder is directly reached (track B), on the other leg (track C) the shunting boarder is located more distant (cf. Figure 31).
5) Before the border of the Area of Uncertainty of the train front end crosses the shunting border (track Node 101 on track B), the train might stop or slow down, depending on its position, Area of Uncertainty, and possibly further information like additional safety margins.

- Postcondition:
  1) The train remains in the shunting area but has limited space for shunting movements due to the uncertainty on which leg of the point it is located.

The challenge in this scenario is that the Parting Tracks topology challenge must be solved before the shunting border (track node 101) on track edge B is reached (the track node closer to the point), which might not be possible in low accuracy environmental conditions without additional data provided to the LOC-OB. This could lead to difficulties to stop the train front end before the shunting border. It should be noted that shunting areas typically are characterized by more complex topologies, emphasizing the described challenges especially in environments challenging for GNSS signal reception. These environmental conditions therefore determine if the LOC-OB might require additional data. In areas of challenging environmental conditions causing larger Areas of Uncertainty, this needs to be considered in planning of shunting borders or operational procedures.

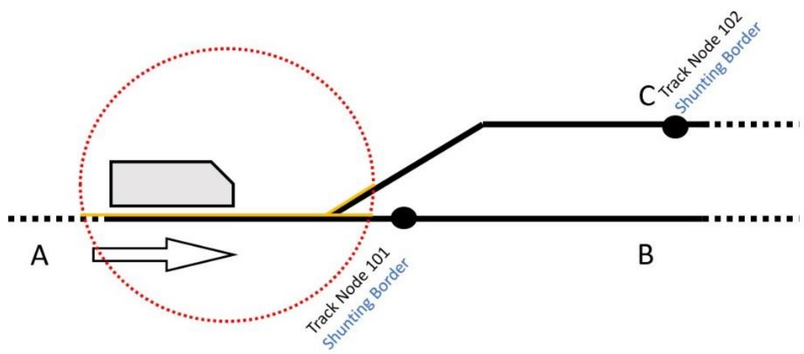


Figure 31 - Shunting borders close to a point.

4.6 Conclusions and Recommendations

This section is structured in the conclusions and respective recommendations derived from the challenging scenarios for the LOC-OB regarding Starting a Mission and Track Selectivity.

4.6.1 Conclusions

- For GNSS-centric solutions, especially in challenging environments, where no GNSS signal can be tracked, the LOC-OB’s Area of Uncertainty can grow very large. This is a significant difference of LOC-OB based localisation compared to current ETCS relying solely on balises for localisation (cf. Section 4.1.3).

Starting a Mission

- In environments with good GNSS signal reception conditions, and considering that the GNSS-based technology provides enough performance to be track selective, Starting a Mission using the LOC-OB can be accelerated compared to the current ETCS with localisation using balises (cf. Section 4.5.1.1 and Section 4.5.1.2).
- When the sensor accuracy of GNSS and IMU performance don’t allow determination of Track Selectivity, operational measures of waiting and repositioning can improve sensor accuracy LOC-OB positioning performance (cf. Section 4.5.1). The repositioning could be carried out following the ETCS “staff responsible” operational procedures (cf. Section 3.4.2.2). However, repositioning with the absence of balises will not provide a guaranteed result and possible challenges arising, should be further analysed. The ability of the LOC-OB to provide a Track Selective position is fundamental to Start a Mission without additional technical or operational measures.
- The determination of the reference location by the LOC-OB without data from the previous train operation might not be safely possible (cf. Section 4.4.3).
- For the determination of a reference location, the estFE is not necessarily required to pass that reference location, as it can be derived from input data or if it is selected as the most probable nearby option from the digital map (cf. Section 4.4.3).

Performing a Mission

- In certain topologies i.e., when passing a point in a Parting Tracks topology Track Selectivity determination might not be possible instantly, and especially in challenging environments establishing of Track Selectivity can take longer (cf. Section 4.5.2.2).

Other scenarios

- In specific operational scenarios such as Change train drivers cab (cf. Section 4.5.3), Joining (cf. Section 4.5.4) and Splitting (cf. Section 4.5.5) under difficult environmental conditions additional data like the length and integrity status of the train could be used by the LOC-OB to estimate the train front end positions. This information could accelerate the starting of a mission (might only be applicable in an automatic driving context).
- In the operational scenarios Route on closed track (cf. Section 4.5.6) and Level crossings (cf. Section 4.5.7) operations could be improved by more accurate and continuous positioning which might help to reduce timely obstructions of traffic.
- In the Operational Scenario Shunting, when challenging environments affecting the determination of Track Selectivity without additional data, a stop of the train front end before the shunting borders might be difficult to achieve.

4.6.2 Recommendations

4.6.2.1 General

1) The LOC-OB functional architecture should take several different sensor principles into account. In particular, the solution should not be too GNSS-centric to avoid the related disadvantages (cf. Conclusions). The LOC-OB solution should rather consider GNSS-independent threads/channels in addition to channels using GNSS. It should be noted that other sensor principles like curvature map have their limitations e.g., on straight lines.
2) If environmental conditions are challenging, valid and safe dynamic trackside data such as point position or safe route information could be helpful as input to determine Track Selectivity (cf. Section 4.3.1.3). Please, note that usage of trackside information such as route information by LOC-OB input needs to be analysed for applicability and confirmed particularly from safety perspective (cf. Appendix A).

4.6.2.2 Starting a Mission

1) As described in Section 4.1.6 waiting and repositioning are operational measures that could be applied to improve GNSS positioning. These operational measures should be taken into account for the LOC-OB and be further detailed as operational solutions particularly when starting a mission.
2) CMD input data should be used if available. It can be complemented by LOC-OB positions, or CMD functionality could even become obsolete in certain cases e.g., when the LOC-OB remains in "always-on" state and the reported position is track selective.
3) In case a valid position can be determined by both, memory/CMD and the LOC-OB, a strategy for managing them and determining the actual position to be used should be defined. This could be to use either one of the positions, or to combine them in a weighting algorithm based on quality parameters (cf. Section 4.2.2 Table 3).
4) Relevant functionality of the LOC-OB should be kept "always on" whenever possible, to:
   - Enable faster positioning in case of Starting a Mission (the GNSS Receiver tracking engine does not need to re-synchronize to the GNSS signals and downloads of the satellite almanac are avoided, reducing the time to first fix of the GNSS/IMU position, (cf. Section 4.1.5).
   - Reduce the need for CMD functionality if positions are immediately available or are available in memory more often when Starting a Mission is performed.
5) A time limit for determination of Track Selectivity during Starting a Mission (cf. Section 4.5.1) should be defined. If the Starting a Mission scenario requires repositioning this step should be limited in distance to avoid influence on traffic (cf. Section 3.8). The limit could be application-specific and/or configurable for specific parts of the track network. This limit should be oriented towards current ETCS performance, especially to target current safety requirements.

4.6.2.3 Performing a Mission

1) A wide range of sensors based on different physical principles (this could be vision-based sensors like stereo cameras, etc.) should be considered to determine the correct track leg e.g., after passing a point, and render a position track selective.
2) While Track Selectivity cannot be determined, the LOC-OB could hold either the last, the most probable track edge ID with a Track Selectivity flag or all potential track edge IDs (cf. Section 4.4.1). The provision of all candidate track edge IDs is recommended, as it also includes additional track edge IDs which can be used for assessment of the decision (cf. Section 4.4.1).
3) The time or the distance when the Track Selectivity is determined after passing a point should be limited. The limit could be application-specific and/or configurable for specific parts of the track network. This limit should be oriented towards current ETCS performance, especially to target current safety requirements.
4) The last safely determined reference location should be stored until a new safely determined reference location is available, even when intermediate reference locations are discarded (cf. Section 4.4.3).
5) In case of positioning ambiguities while Performing a Mission it is possible that the train passes another reference location before Track Selectivity is achieved. In such cases the use of the previous reference location for the estFE should be considered (cf. Section 4.4.3.2 Assumption 4).
6) The position of the estFE should be reported as frequent as possible, but particularly at triggers. Triggers when positions should be reported can either be locations or events of the LOC-OB (cf. Section 3.2).
   - A position should be reported when track nodes or any defined locations on the track are passed, following current ETCS procedures (cf. Section 3.2).
   - A position report should also be triggered at certain events such as when Track Selectivity is established or lost, etc.
7) If challenging environments lead to delayed determination of Track Selectivity in Shunting, the definition of shunting borders or operational procedures should reflect this.

5 Operational Constraints and Acceptance Criteria

The operational constraints identified during the analysis of the challenging scenarios lead to potential exported requirements towards some of the LOC-OB boundary systems/sub-systems:

1) The use of safe route information to support Track Selectivity is to be assessed in detail for operational constraints (cf. Appendix A).
2) The position data from an "always-on" LOC-OB has to be assessed in terms of safety constraints and regarding operational feasibility (battery-wise).
3) To render the functionality of a CMD obsolete, availability of “high accuracy” sensor data is required as discussed in Section 4.2.2. This case depending on the environment needs to be assessed for viability.
4) The reference locations stored in the digital map need to be aligned between LOC-OB and trackside (I.e., reference locations must be identical). If they were not aligned, the Trackside system using the data reported by LOC-OB could not determine the correct position using reference location and distance. Operational measures to ensure that reference location data used by LOC-OB and Trackside is identical are required.
5) Systems using the LOC-OB data such as list of track edge IDs or reference location should be provided with the constraints of the information e.g., if the reference location was determined safely or if the previous reference location had to be discarded.
6) Operational Procedures need to consider the time required to determine Track Selectivity especially in the vicinity of a point.

6 APPENDIX A: Whitepaper - Use of Route Information by LOC-OB

6.1 Background

In today's railway signalling system ETCS Level 2, the ETCS on-board unit calculates and reports a safe "along track" position based on a track selective location reference (passed balise group) and a travelled distance measured by on-board sensors.

If that distance extends beyond a facing point, track selectivity is lost, as the position report does not contain information which path the train has taken.

The trackside application however determines the safe train front end position within the topology, by considering additional information, such as the route (train running path) assigned to the train and/or occupancy states reported by a trackside train detection system.

The ETCS on-board unit does however not know its track selective position with regard to the topology.

6.2 Challenges resulting from removal of trackside assets

Within the CLUG 2.0 project, the functionality to determine the track selective safe train front end position is allocated to the on-board localisation system (LOC-OB) to the reduce number of trackside assets such as Train Detection Systems and balises. LOC-OB is intended to determine the position using GNSS and IMU data, odometry sensors and a track map.

Requesting LOC-OB to report a track selective position but limiting the use to on-board sensors and excluding the use of balises results in two challenges:

1. determining an initial track selective position at start up
2. maintaining track selectivity when running past facing points

6.3 Possible Solutions

It might be possible to solve the first challenge with GNSS in areas with good GNSS availability, and the second one with IMU, odometry and map data even in areas where GNSS is not available, once an initial, track selective position has been determined. Challenge one can however not be solved in areas with no, or poor GNSS availability, and challenge two cannot be solved if no initial, track selective position can be determined.

To fully solve the two issues, further information can be provided to the onboard localisation system. These are:

1. Additional on-board-based information generated, e.g., by further sensors (possibly providing absolute position data), cameras or enhanced algorithms.
2. The trackside shall provide additional information, such as route information, point positions or track occupancy information.

Some European projects already propose the use of route information to determine a track selective position, e.g.:

- EUG LWG describes that route information is seen useful and can be provided through the interface SCI-RC (cf. /1/, Section 5.2.11 and 6.3.2).

Further projects foresee an interface to provide route information without detailing its use, e.g.,

- Shift2Rail states in /2/ paragraph 8.3.6.1 that the Virtual Balise Transmission System shall provide dynamic route information to the on-board part of the system.
- The OCORA project introduces the interface SCI-RC providing train routing information from Route Control to CCS On-Board (cf. /3/, Section 6.26).
- RCA sketches a possible exchange of movement permission information between trackside and LOC-OB /4/.

Currently however, no analyses are publicly available and/or known that examine whether route information is (a) useful for LOC-OB to determine the safe train front end position, (b) practical, and (c) safe to use. This whitepaper sets out to explore the concerns existing towards this solution.

6.4 Open questions/concerns

The concerns described below only address the use of route information by LOC-OB. They do not apply to other on-board subsystems.

Please note: The ETCS Movement Authority (MA) is not considered as route information because a deduction of the train running path out of it via linking information is not always possible (no generic design rules for placing balises, balises are not necessarily included in MA, etc.).

The assumption that LOC-OB can use trackside-based information such as route information for track selective position determination leads to the following major concerns:

1. From safety point of view there are concerns, as the use of route information creates a circular reference, i.e., trackside uses information provided by LOC-OB to localise the train in the digital map and to determine and protect the corresponding train running path and then this information is used by LOC-OB system itself to determine the track selective train positions to report it to trackside.
2. Route information may not always be available, e.g., in case of degraded situations such as disturbed points.
3. Availability of route information depends on the implemented trackside system e.g., if the trackside system can provide route information to the train. This also includes the practical implementation of the corresponding interface due to today's undefined functional split between interlocking and RBC.
4. On-board position determination becomes dependent on availability and performance of the transmission system as reserved routes can be revoked on trackside and train positions must not be determined based on outdated information.

5. It is not clear based on which arguments it has been decided on system level that LOC-OB determines the track selective train position and if this solution is suitable.

6.5 Conclusion

In scope of the CLUG 2.0 WP2 it is currently not possible to provide a clear statement, nor a clear recommendation, to the use of route information as input for LOC-OB to determine the track selective train front end position. No clear evidence about the applicability of this approach exists. Further investigation into this topic is necessary and highly recommended (e.g., see also safety analysis performed in CLUG 2.0 WP3).

6.6 References

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8 APPENDIX C: CLUG2.0 WP2 Acronyms

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

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

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

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

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

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

9 APPENDIX D: CLUG2.0 WP2 Glossary

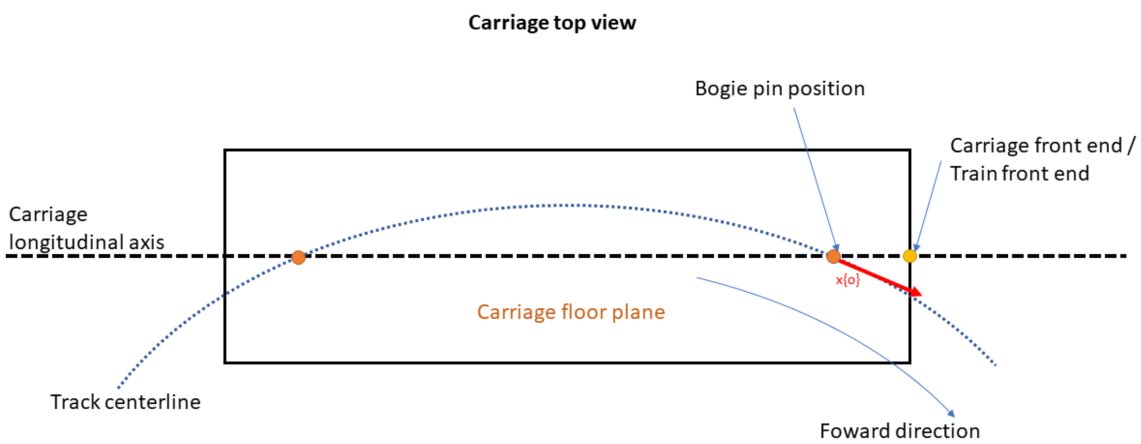
This appendix is aimed at ensuring terminology alignment and common understanding throughout CLUG 2.0 WP2 documentation. Terms definitions are already captured and hence referenced to:

- 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).



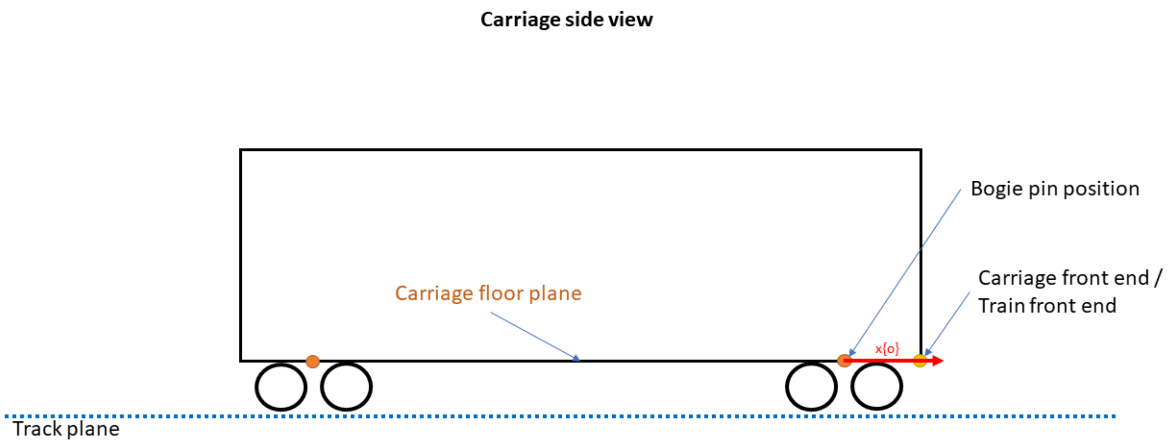


Figure 32 - 1D reference frame represented by the x-axis of the bogie frame $\{o\}$.

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]).

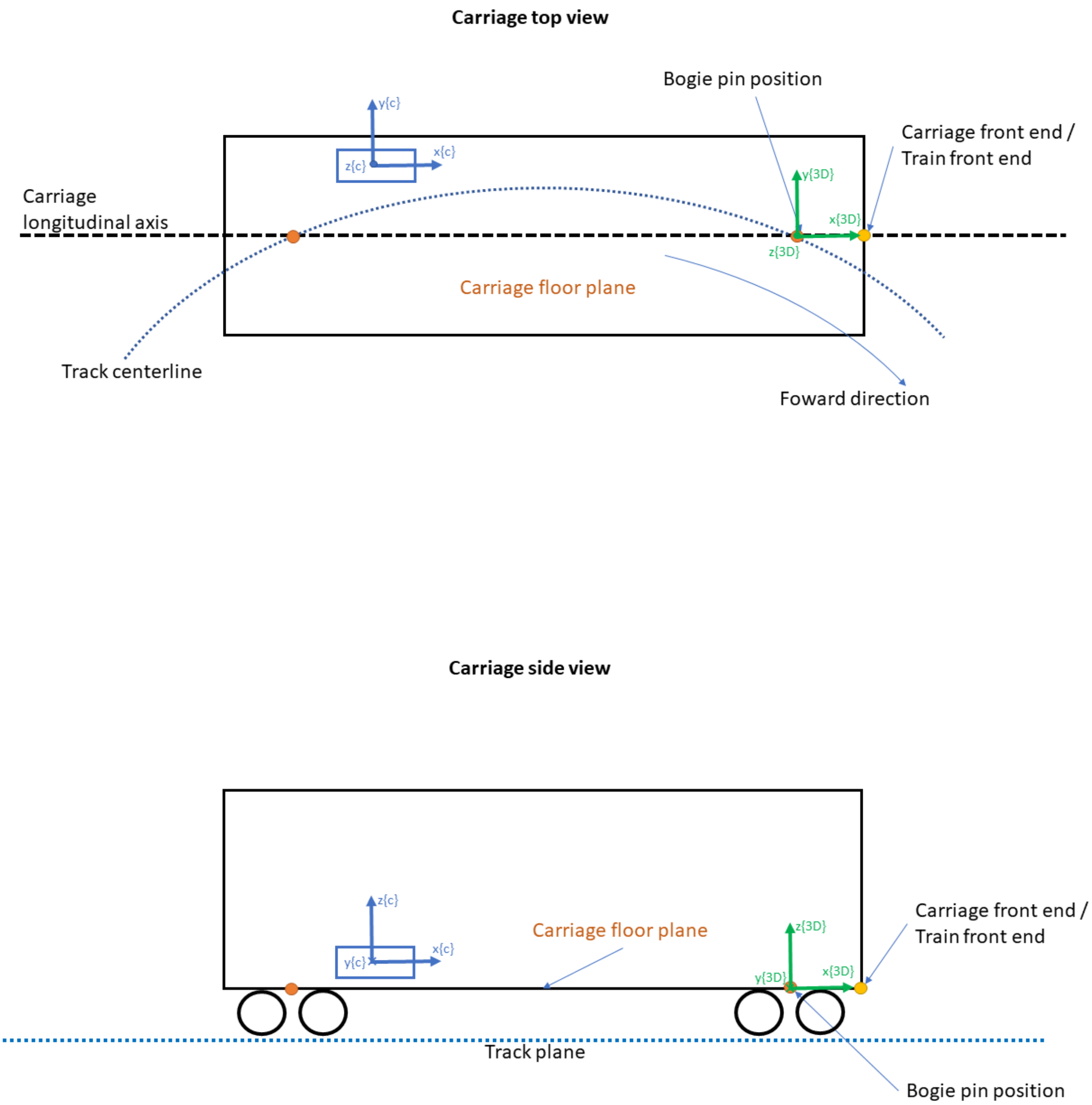


Figure 33 - 3D reference frame and carriage frame $\{c\}$.

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 33).

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

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.

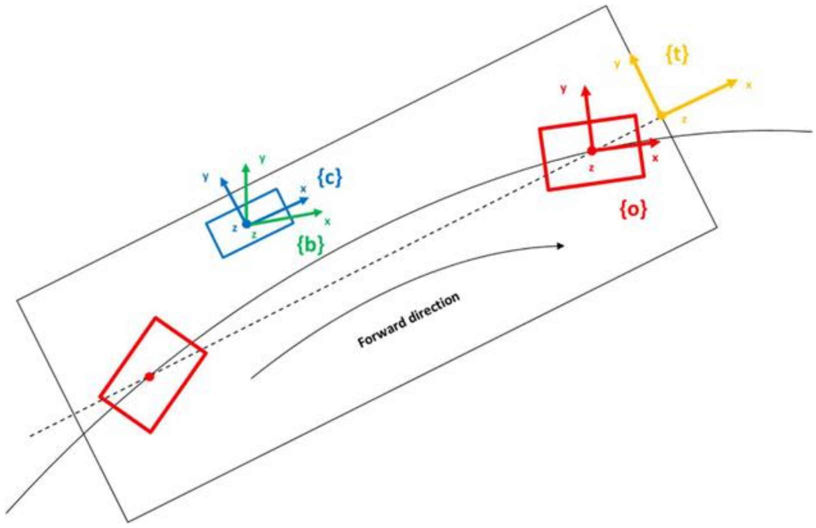


Figure 34 - On-board reference frames: front train $\{t\}$, bogie $\{o\}$ and carriage $\{c\}$ reference frames (Ref [17]).

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 33). 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 user 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 user 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 32).

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.

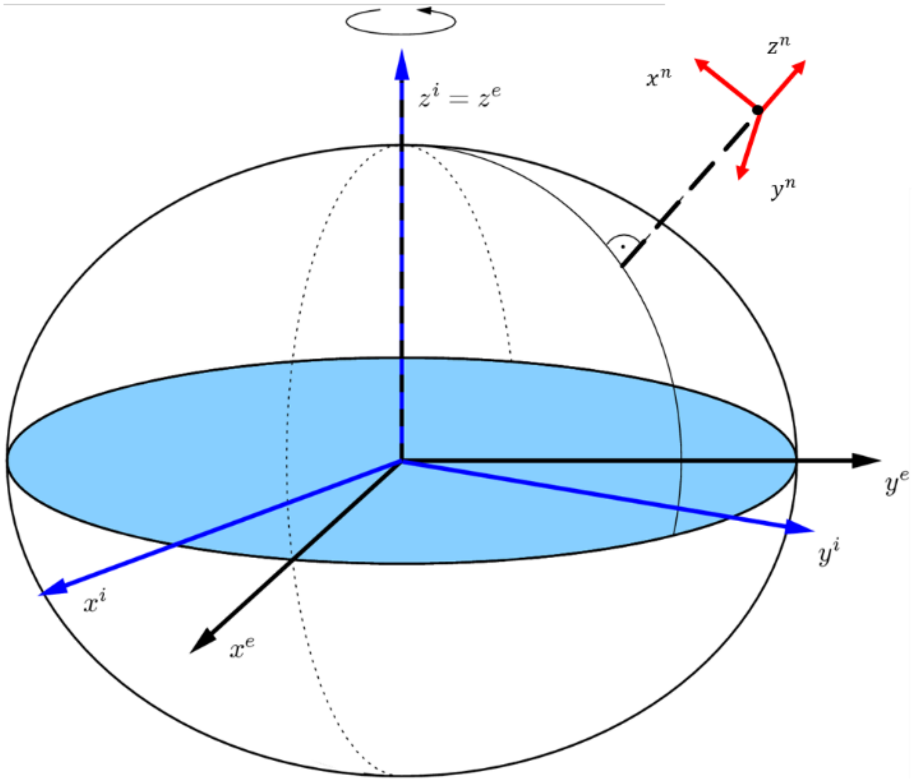


Figure 35 - Reference frames with respect to the earth centre.

Source: N/A. Definition to be applied within CLUG2.0 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 36 and Figure 37 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.

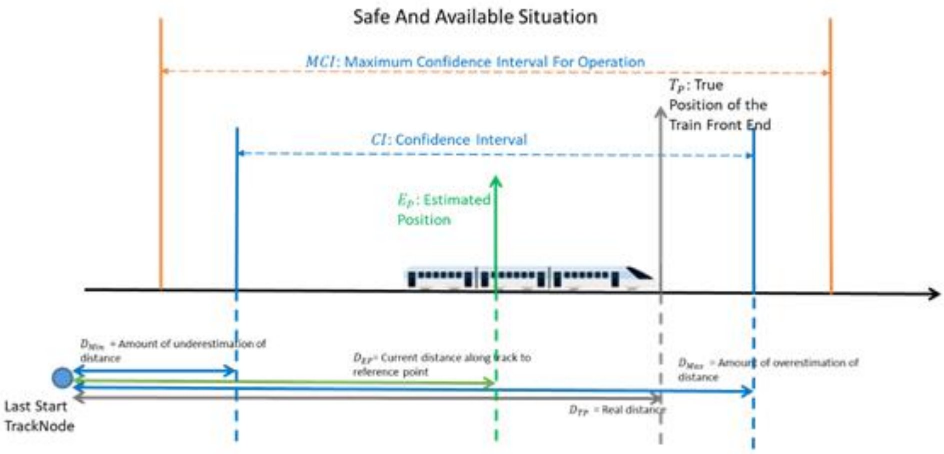


Figure 36 - Safe and available situation. Estimated position, computed Confidence Interval versus specified Maximum Confidence Interval.

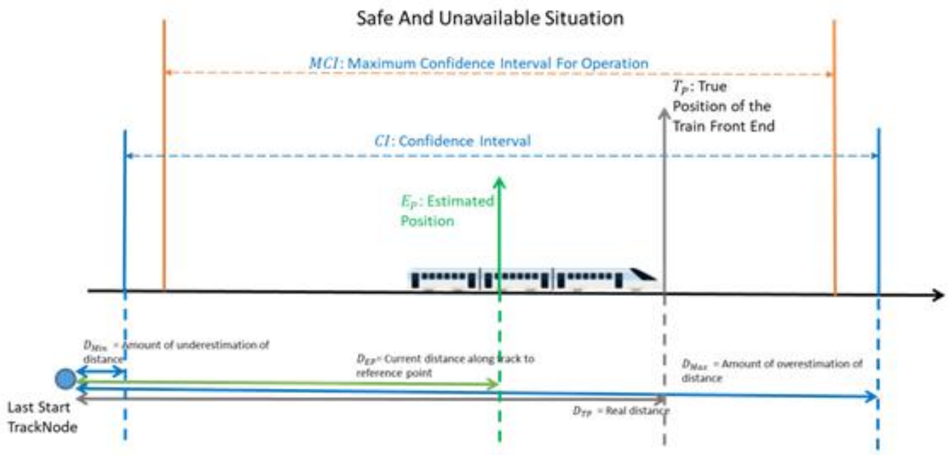


Figure 37 - Safe and unavailable situation. Estimated position, computed Confidence Interval versus specified Maximum Confidence Interval.

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 38: 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 38 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 39: 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.

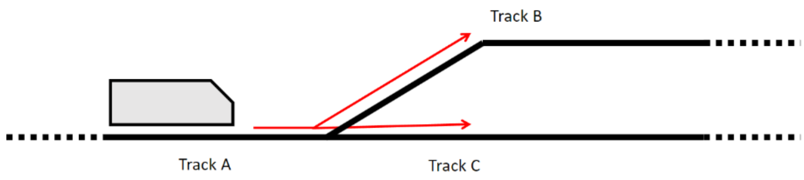


Figure 38 - Train on parting tracks.

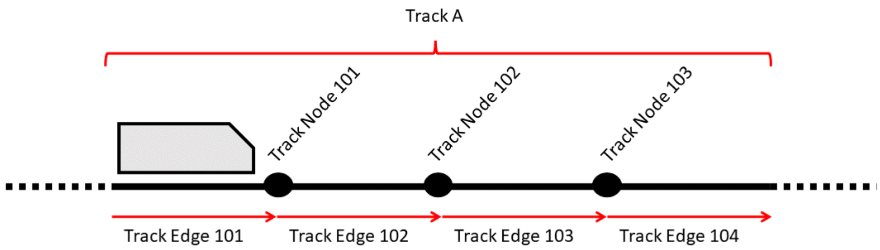


Figure 39 - Train on single track.

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 32 and Figure 33).

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 32 and Figure 34).

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

True train position

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

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

True train speed

Is the real speed of the train along the track centreline. It is expressed using the 1D reference frame (cf. Figure 32).

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 33)

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

CLUG 2.0 has received funding from the European Union’s Horizon research and innovation programme under grant agreement **No 101082624**