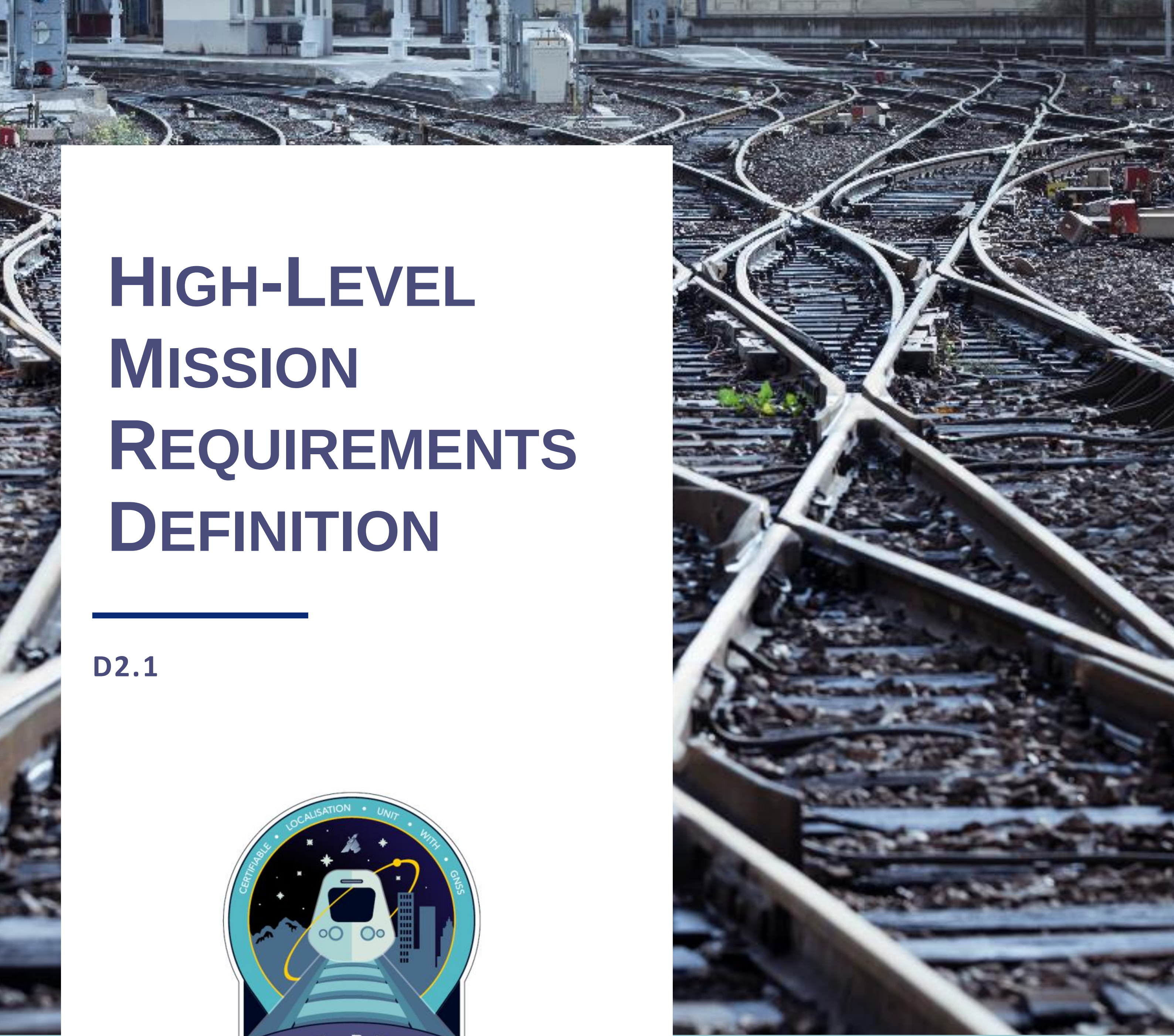

HIGH-LEVEL MISSION REQUIREMENTS DEFINITION

D2.1

JANUARY 28, 2021

VERSION 2.14

European Global Navigation Satellite Systems Agency

This project has received funding from the European Union's Horizon 2020

D2.1 - HIGH LEVEL MISSION REQUIREMENTS DEFINITION

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2.1	30th October 2020	Corrections and updates to document based on review of stable version.
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2.5	8th November 2020	Final release for review by CLUG consortium
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EXECUTIVE SUMMARY

The purpose of CLUG is to define a novel certifiable localisation architecture and concept using GNSS (Global Navigation Satellite System) in the railway environment. The project aims to demonstrate the feasibility of a multi-sensor approach for the train localisation on-board unit and to develop processes and tools for its certification.

This document is the deliverable "D2.1 – High Level Mission Requirements" of the European project "CERTIFIABLE LOCALISATION UNIT WITH GNSS IN THE RAILWAY ENVIRONMENT" (hereinafter also referred to as "CLUG). This document aims to describe the mission and in that way the scope of the project.

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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°870276 (which includes DOW, 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: 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.

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[12] DIN EN 50126-2 (VDE 0115-103-2): 2018-10 - – Railway applications – The specification and demonstration of reliability, availability, maintainability and safety (RAMS) - Part 2: Systems Approach to Safety

[13] DIN EN 50128:2012 (VDE 0831-128), Railway application – Communication, signalling and processing systems – Software for railway control and protection systems, Released 03/2012.

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1 INTRODUCTION

1.1 OBJECTIVES OF THE CLUG PROJECT

1.1.1 The H2020-project CLUG stands for Certifiable Localization Unit using GNSS in the railway environment.

1.1.2 The CLUG project will perform a mission analysis, needs identification and a preliminary feasibility study of an on-board localisation unit with the following characteristics:

- failsafe on-board multi-sensor localisation system consisting of a navigation core brought in reference using GNSS, track map and a minimal number of reference points,
- on-board continuous localisation system that provides location, speed and other dynamics of the train,
- localization system that is operational and interoperable across the entire European rail network,
- localization system that is compatible with the current ERTMS TSI or with its future evolutions.

To achieve its objectives, the CLUG's management and the design and development of the localization unit will follow agile processes taking into account former projects results – especially STARS – as well as observations resulting from new test campaigns.

CLUG has been structured to maximise the knowledge earned from STARS. Most importantly, the process to setup a recording train, its ground truth and the tools to automatise the analysis of the recordings has been greatly reused and in cases improved by CLUG. In addition, the knowledge gained from STARS has been used to mitigate many of the encountered issues and to anticipate as much as possible the difficulties when commissioning trains. An example of such an optimisation is the reuse of the data recording platform and methodology specified in STARS by the CLUG project.

1.1.3 The actual development of the Localisation System as a certified device is not in the scope of CLUG. The CLUG localization solution will be a software demonstrator. Data evaluation and testing is performed by the acquisition of real sensor data and reference position on test trains and the offline data processing.

1.1.4 The CLUG project is subdivided into five workpackages:

- WP1 “Project Management and Coordination”
- WP2 “Mission Definition and System Requirements”
- WP3 “Localisation System Design”
- WP4 “Testing and Evaluation”
- WP5 “Application to the Train Localisation System”

1.1.5 The objective of WP2 “Mission Definition and System Requirements” is the definition of the system needs, the operational scenarios and the high-level system requirements. WP2 is subdivided into three major logical blocks. The first block aims at defining the mission and its operational context. This definition of high-level mission requirements defines the scope of the project and forms basis for the development of the Localisation System design and evaluation. The second block aims at elaborating a high-level definition of the localisation system, designed to fulfil the mission needs of the railway operators. Besides, within this block the first safety considerations are addressed. The third block aims at proposing a high-level decomposition of the system architecture and its interfaces, suitable for the introduction a continuous and multi-sensor navigation system for safety related applications. Parallelly, the methods and concepts for the validation and certification are identified in preparation to the prototypical certification.

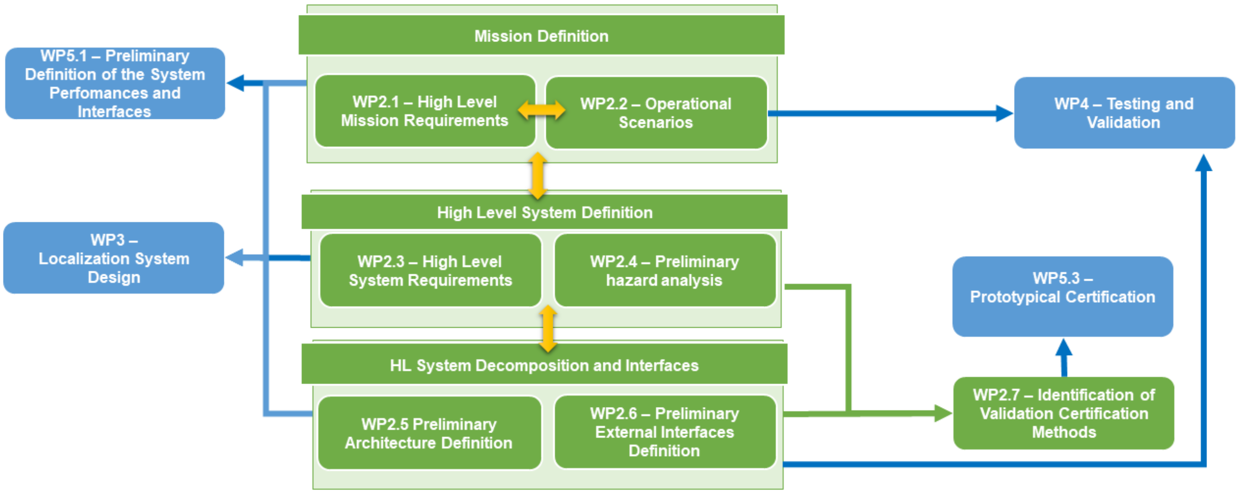

Figure 1.1 : Logical decomposition of WP2

1.1.6 CLUG capitalises on the achievements of European Commission and GSA funded projects such as NGTC and STARS.

NGTC provided some preliminary safety analysis throwing some light to the use of GNSS under many assumptions that needed to be corroborated by field testing. The results of NGTC led to a massive field testing campaign run throughout Europe under the STARS project. STARS used three train sets on three completely different environments. On one side the best-case scenario for GNSS was recorded in Sardinia. On the other side where the train recordings from Czech Republic and Switzerland. The former showed a challenging environment full of trees offering some interesting multipath recordings, whereas the latter full of high mountains corroborated the lack of sky visibility and availability of the GNSS signal in the railway domain with some challenging spiral tunnels.

In CLUG, the work done in STARS especially with regard to the data collection methodology and platform has been adopted. NGTC safety analysis and the data collection scenarios in STARS have been used as a preliminary input for the mission and system specification.

1.1.7 The functional scope of the Localisation System specified by CLUG is to locate a given reference point on a railway vehicle. This will typically be the point where the GNSS antenna is installed, but can be also any other defined point. The location of the reference point includes confidence intervals and motional information.

1.1.8 In operational use, the Localisation System will be embedded in a localisation system that provides an application layer which derives from the location of the reference point, as provided by the Localisation System , the location of the front and rear ends of the Train Unit or of an individual consists within the Train Unit which are the information needed for operation. The application layer is outside the scope of CLUG.

1.1.9 Please note that many terms listed in 1.4 are not relevant for the functional scope of the project. They are relevant to define the functional need of systems that use localisation data.

1.2 Scope of the Document

1.2.1 The purpose of this document is to define high-level mission requirements that fulfil the localisation needs of railway infrastructure operators.

1.2.2 This definition of high-level mission requirements defines the scope of the project and forms basis for the development of the Localisation System design and evaluation.

The structure of this document "D2.1 High Level Mission Requirements" is as follows:

Chapter 2 describes the railway system that is relevant for the mission definition.

Chapter 3 defines the assumptions and constraints in the context of the CLUG project.

Chapter 4 contains the high-level requirements definition where the mission requirements are defined.

Appendix A presents the results of a capacity study performed by DB.

1.3 Methodology

1.3.1 The first step towards defining the high-level mission requirements consisted of identifying the Wider System of Interest (WSoI). The WSoI contains

- the systems that need train localisation information to carry out their own functions
- defines those functions of other systems

1.3.2 These systems and their functions form the "users" (in the sense of: using systems) of information provided by the train localisation system. The WSoI is presented in chapter 2.1

1.3.3 In a second step we analysed which type of information (e.g. location, speed or acceleration) the individual functions of other systems need to carry out their tasks.

1.3.4 In a third step we analysed in which quality (e.g. accuracy, latency, frequency, safety) the individual functions of other systems need the localisation information.

1.3.5 The types of information needed and the related qualities form the users' requirements or **mission requirements**. The result is presented in chapter 4.1.

1.3.6 Note: Not all systems in the WSoI are necessarily present in a scenario where the Localisation System is implemented.

1.3.7 For assemble the mission requirements, different functional teams including ATO (Automatic Train Operation), Train Control, Train protection, Systems Engineering, Perception, Incident Prevention Management, Traffic Management, Train Integrity Monitoring, TCMS (Train Control and Management System)) at DB Netz, SNCF, SBB, Siemens and CAF were consulted.

1.4 Terms and Definitions

For a better understanding and a consistent definition in the documents of the project, we define the following terms:

- The train formation, with the terms vehicle, consist and train unit
- Track topology with track node, track edge and the directions up and down,
- The relation between track topology and ETCS (European Train Control System) reference system
- Train unit front and train unit rear ends,
- Train orientation and reverse driving
- The trains cab and the active cab
- Definition of reverse driving, Intended direction and actual movement direction

1.4.1 Train Formation: Vehicle, Consist and TU

1.4.1.1 A **Vehicle** is a single unit of rolling-stock that is typically but not necessarily capable of standing and rolling independently on rails, that may be a member of a given Class and that is identified with its own vehicle ID (see Figure 2.2 and Figure 2.3), (derived from [3]).

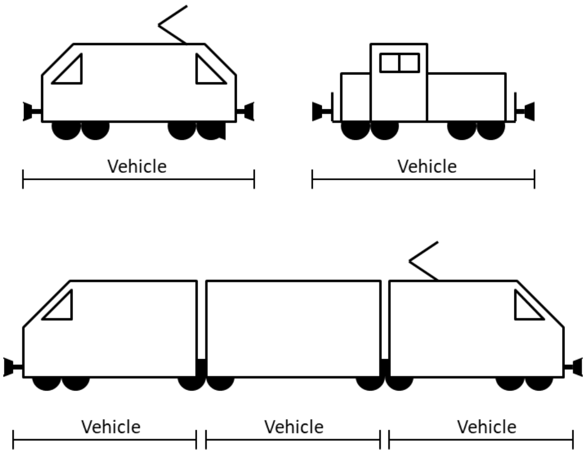

Figure 2.2: Examples for vehicles

1.4.1.2 A **Consist** is an independent item of rolling-stock, comprising one or more mechanically connected vehicles, that is used in normal operation as a whole (see Figure 2.2 and Figure 2.3), (derived from [3]).

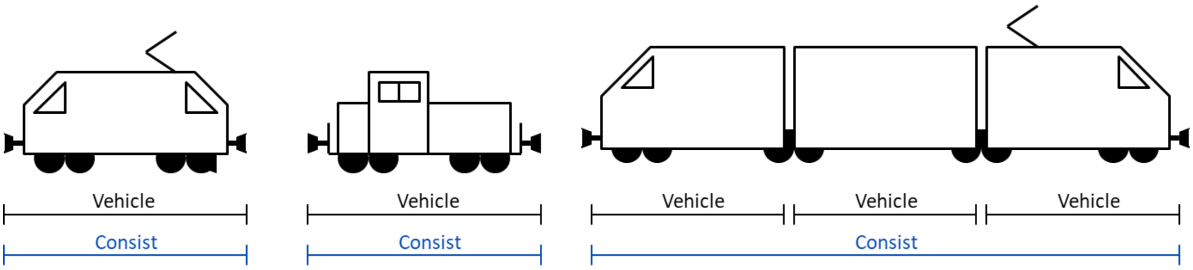

Figure 2.3: Examples for consists

1.4.1.3 Every consist has two physical (build) ends that never change during normal operation[1]. They shall be called A-end and B-end (see *Figure 2.4*).

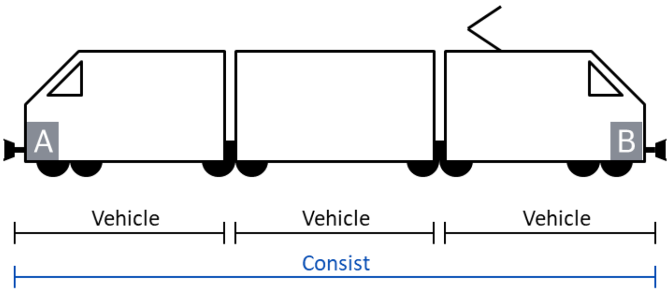

Figure 2.4: Physical ends of a consists

A **Train Unit** (TU) is a set of one or more coupled consists (see Figure 2.5). A TU is a temporary entity that is dynamically formed during normal operation by joining two or more Consists/Vehicles into a new Train Unit or by splitting a Train Unit (derived from [3]).

[1] The physical ends can only be reconfigured in a workshop.

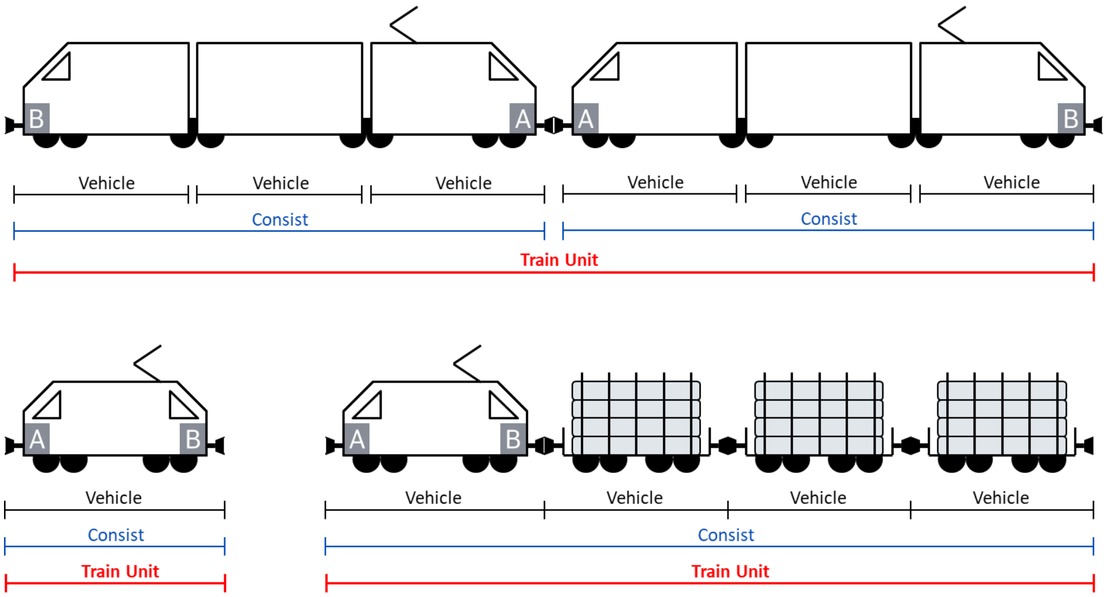

Figure 2.5: Definition of TU

1.4.1.4 The lifecycle of a **Train Unit** starts when it is formed by joining two or more Train Units or vehicles. As long as the composition of the Train Unit remains unchanged the Train Unit continues to exist. The lifecycle ends when the TU is split up or joined by other Train Units or vehicles.

1.4.1.5 In this last aspect the definition for a Train Unit differs from the common definition of a Train (e.g. in [10]) in that a train is usually bound to a train running number. A train in that sense ceases to exist when the train service is terminated. The Train Unit continues to exist, even when it is stabled or is for some reason momentarily not allocated to a train service. The Train Unit is the entity to be located.

1.4.2 Track Topology

1.4.2.1 The **Track Topology** used as reference systems to determine and express TU positions in this document is a node-edge model of the railway tracks and conforms to the topology model of RCA [8].

1.4.2.2 **Note**: The Track Topology defined in this document will be defined in detail as part of the CLUG deliverable D5.4 *"Definition of the Required Maps for Localisation"*.

1.4.2.3 **Note**: The train unit position is referred to as "location" in some other initiatives, e.g., in RCA.

1.4.2.4 A **TrackNode** is a point on a track where the track physically ends (called "TrackEnd TrackNode" in D5.06, e.g. at a buffer stop), where it logically ends (called "Pseudo TrackNode" in D5.06, e.g. at the border of an area of control of an infrastructure manager) or at a junction of tracks (called "Point TrackNode" in D5.06, at a point).

1.4.2.5 A **TrackEdge** is a directed entity that has a **Start TrackNode** and an **End TrackNode** and represents a continuous stretch of track between the Start and End TrackNodes. The TrackEdge has a true length (mileage) that starts at 0 at the Start TrackNode and counts up towards the End TrackNode (see *Figure 2.6*) A TrackEdge represents a single track.

1.4.2.6 In this document, we use **<up>** and **<down>** to define the orientation of any object relative to the track edge: **<up>** is the orientation pointing in the direction of **up**—counting mileage (towards the End TrackNode) while **<down>** is the orientation pointing in the direction of **down**—counting mileage (towards the Start TrackNode).

1.4.2.7 **Note:** Any other pair of terms that makes the orientation unambiguously clear could be used instead of up and down, e.g. **<nominal>** / **<reverse>**, **<forward>** / **<backward>**.

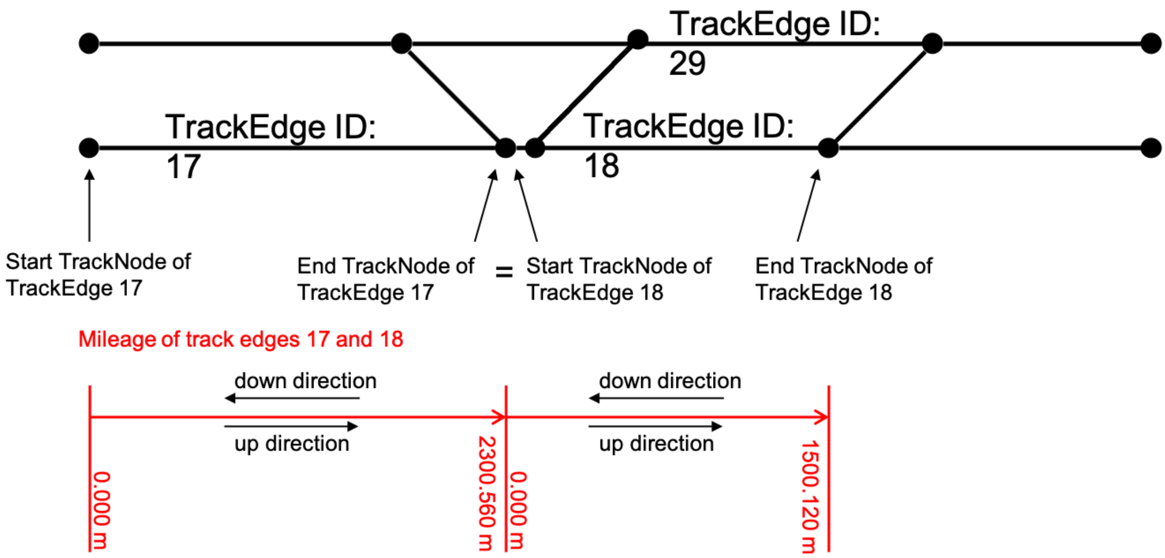

Figure 2.6: Track edge mileage

1.4.2.8 A **location** on the track as well as a train position is expressed by a **TrackEdgePoint**. The **TrackEdgePoint** is defined by the **TrackEdge ID** on which it is situated and the offset to the **Start TrackNode**, e.g., TrackEdge ID = 17 and offset to Start TrackNode = 1800 m (see *Figure 2.7*).

1.4.3 Relation between Track topology and ETCS Reference system

1.4.3.1 The track topology presented here as the reference system is similar to the ETCS reference system but differs in the two points following.

1.4.3.1.1 In the track topology every physical location on a track has exactly one expression in the reference system. In the balise-based ETCS reference system instead, there are for most locations two expressions because the location has two neighbouring balise groups and the expression used depends on the train orientation and the last relevant balise group that has been passed [12, ch.3.6].

1.4.3.1.2 In the track topology the track edge carries the orientation of the track while in ETCS it is the balise group (a point object).

1.4.3.2 Every location expressed in the track topology here (TrackEdge ID + mileage) can be mapped to the ETCS reference system.

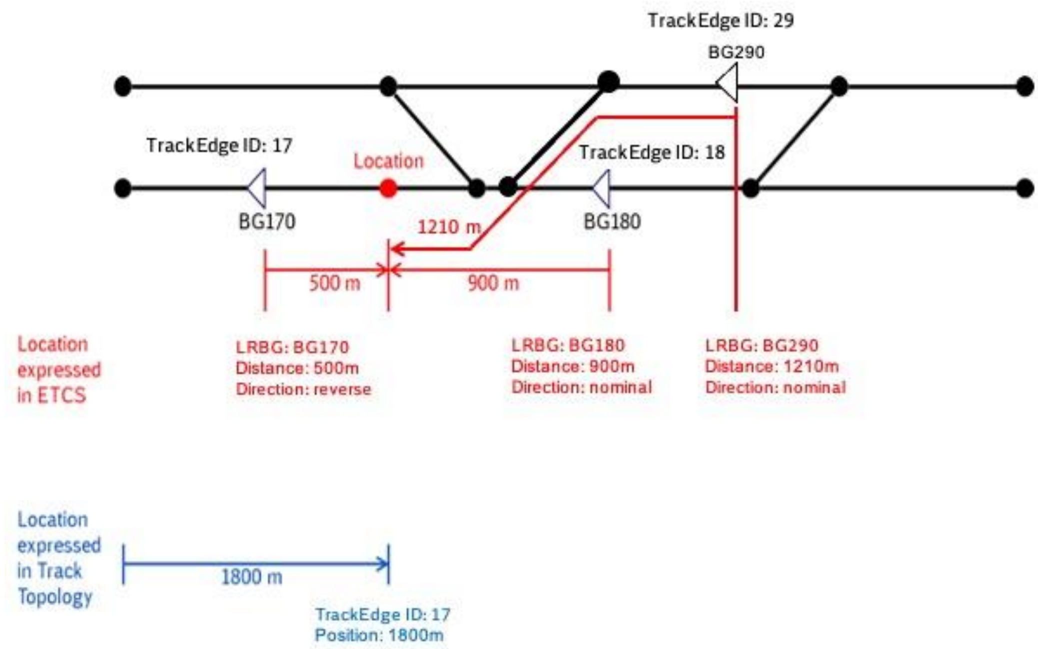

Figure 2.7: Location on a track

1.4.4 Train Unit Front and Rear Ends, Train Orientation and Reverse Driving

1.4.4.1 The **Train Unit Front End** (TUFE) means the one end of the TU that was deliberately defined to be the front end in the current configuration of the TU. In almost all operational scenarios the TUFE is pointing into the direction of the intended train movement. The exceptions are those where reverse driving is used.

1.4.4.2 The **Train Unit Rear End** (TURE) is the end of the TU that is not the Train Unit Front End.

1.4.4.3 For today's trains – except for shunting – the TUFE is that end where also the active cab is located. This may change in future either due to "Cab Anywhere supervision" or because cabs might be radically changed in ATO GoA4 trains (see cab).

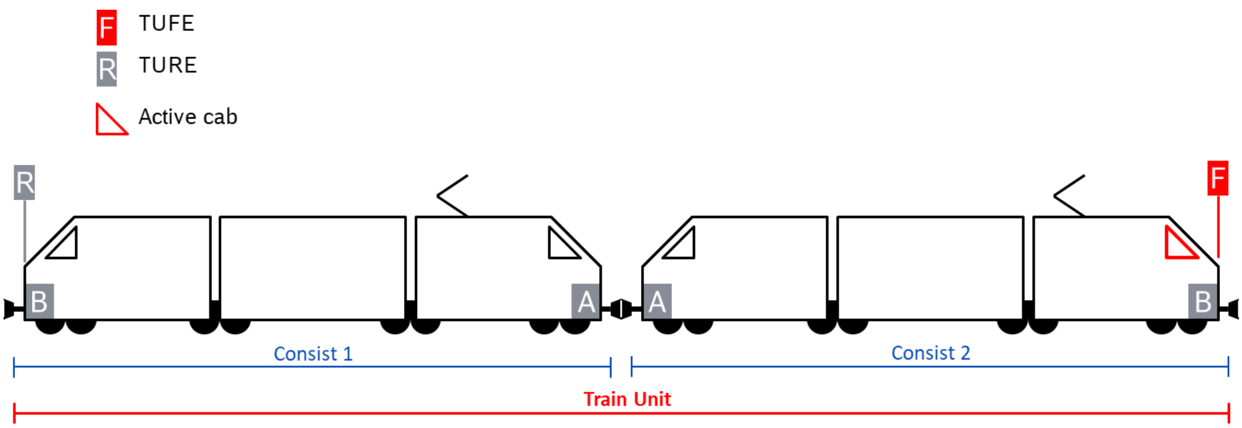

Figure 2.8: Train Unit Front End (TUFE) and Train Unit Rear End (TURE).

1.4.4.4 The **Train Unit Front End** can be expressed **relative to the track** as pointing in the up or down direction of the track edge where the TUFE is located. This is called train orientation in the ERTMS (European Rail Traffic Management System) language.

1.4.4.5 The **Train Unit Front End** can be expressed **relative to the composition** of the TU (as defined in the TCN) as being either the 1-end or the 2-end of the TU (or the related physical end of a vehicle to which the 1- or 2-end maps).

1.4.4.6 The **Train Orientation** in the sense of ETCS [10][12, ch.3.6] is the orientation of the TUFE relative to the track topology. For a given TUFE location the train orientation can be up (pointing towards the end track node of the track edge) or down (pointing towards the start track node). This value is important to control and protect the movement of the TU.

1.4.5 Cab and Active cab

1.4.5.1 The **cab** is a set of devices and a related room that is used by a driver to drive a train. With the advent of ATO trains the idea of cab might change in the future: the cab might then refer to the fact that a specific end of a consist is fit for being the TUFE because we find installed there the necessary devices for GoA3/4 driving, e.g. the sensors for obstacle detection.

1.4.5.2 The **active cab** is the cab from where a TU is momentarily controlled and, for instance, driven. This term is listed here for completeness, it should not have a practical meaning in the context of CLUG, because it is the TUFE that is relevant for CLUG.

1.4.6 Reverse driving, Intended and Actual Movement Direction

1.4.6.1 Typically, a cab has a **Reverser** (or direction controller). The **Reverser** can be set to <nominal> or <reverse>. If the **Reverser** in the active cab is set to <nominal> the TU will move into the direction of its TUFE when traction power is applied. Instead, when the **Reverser** is set to <reverse>, the TU will move into the direction of its TURE. The corresponding mode in ERTMS/ETCS is called **Reversing Mode** [10].

1.4.6.2 The **Intended Movement Direction** is the Direction into which the TU shall move when traction is applied. With the Reverser set to <nominal> - as well as for a TU that does not have a Reverser – the Intended Movement Direction is towards the TUFE.

1.4.6.3 If the Reverser of a TU is set to <reverse> then the Intended Movement Direction is towards the TURE.

1.4.6.4 The **Actual Movement Direction** is the one into which the TU is physically moving to according to the measured locations (or other information). If the Actual Movement Direction is not the same as the Intended Movement Direction for more than a very short distance this is a serious non-regular situation (e.g. the TU is rolling away).

1.4.7 Functional Safety

1.4.7.1 A **safety-related function** carries responsibility for safety acc. to EN50126-1 [11] §3.74 i.e. involved in hazard risk reduction.

1.4.7.2 A **non-safety-related function** do not carry a responsibility for safety i.e. not in involved in hazard risk reduction. Even if basic integrity requirements may be considered for the development of a such function acc. to EN50126-1 [11] §3.7 (it may be translated into SIL0 when applying EN 50128 [13]), no integrity indication to a **non-safety-related function** is given in this document for sake of clarity about the safety implication.

1.4.7.3 **A function with basic integrity** is a **safety-related function** to which a basic integrity requirement is allocated according to EN50126-2 [12] §10.2.6/7.

1.4.7.4 **A function with safety integrity level** is a **safety-related function** to which a safety integrity level (within SIL1 - SIL4 bandwidth) is allocated according to EN50126-2 [12] §10.2.6/7.

1.4.8 Other ERTMS terms

1.4.8.1 In the remainder of this document we use some terms from ERTMS, e.g. Emergency Brake Intervention (EBI) or Supervised Location (SvL) as defined in [10] and used in [4].

2 RAILWAY SYSTEM

2.1 Wider System of Interest

2.1.1 The Localisation System will be part of a localization system. The localization will be integrated into a larger system, the Wider System of Interest (WSoI) as illustrated in Figure 2.1.

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

2.1.3 The WSoI contains several other systems that have a need for the information produced by the CLUG System investigated within the CLUG project to support their own functions and that have their respective functional and non-functional requirements on the output provided by the CLUG System (see 4.1).

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

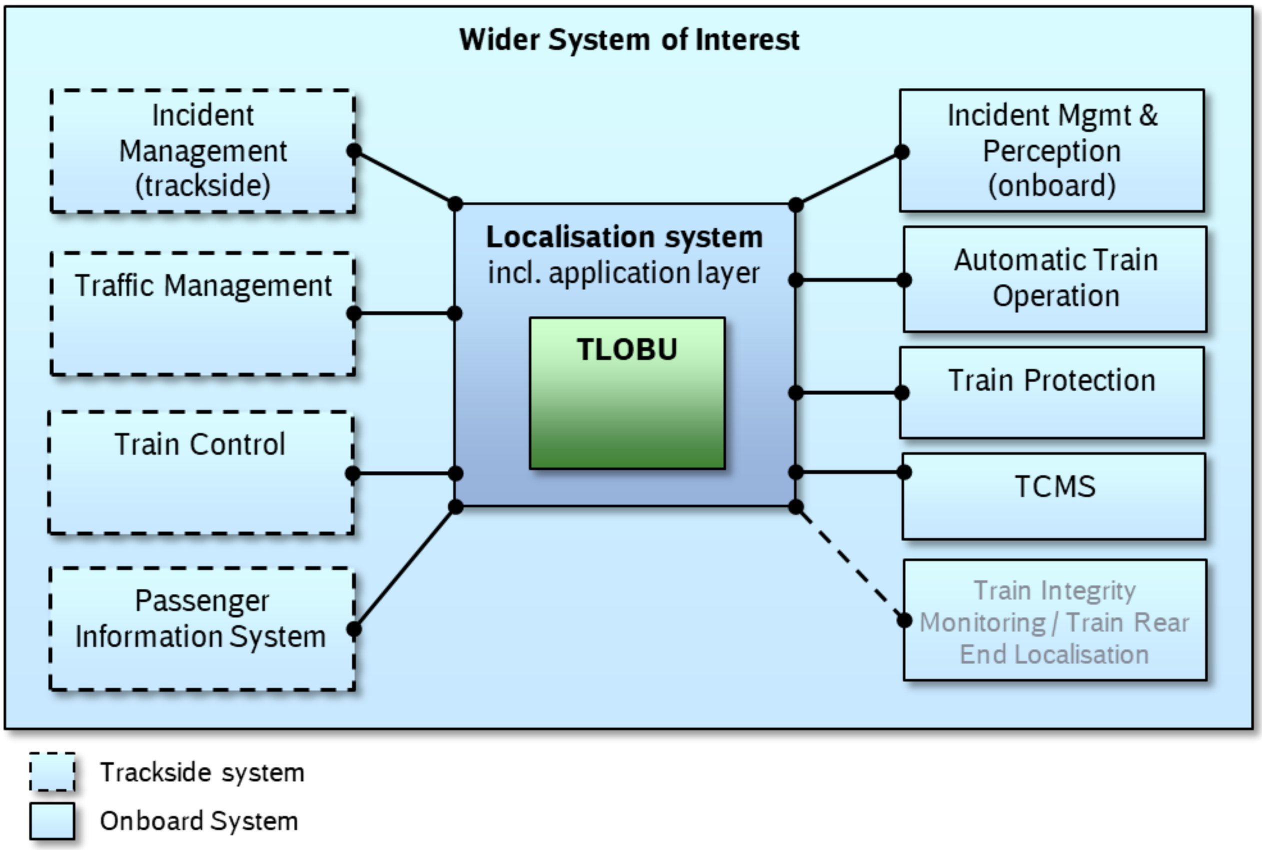

Figure 2.1: Wider System of Interest for the System Train Localisation On-Board Unit to be investigated under the CLUG project

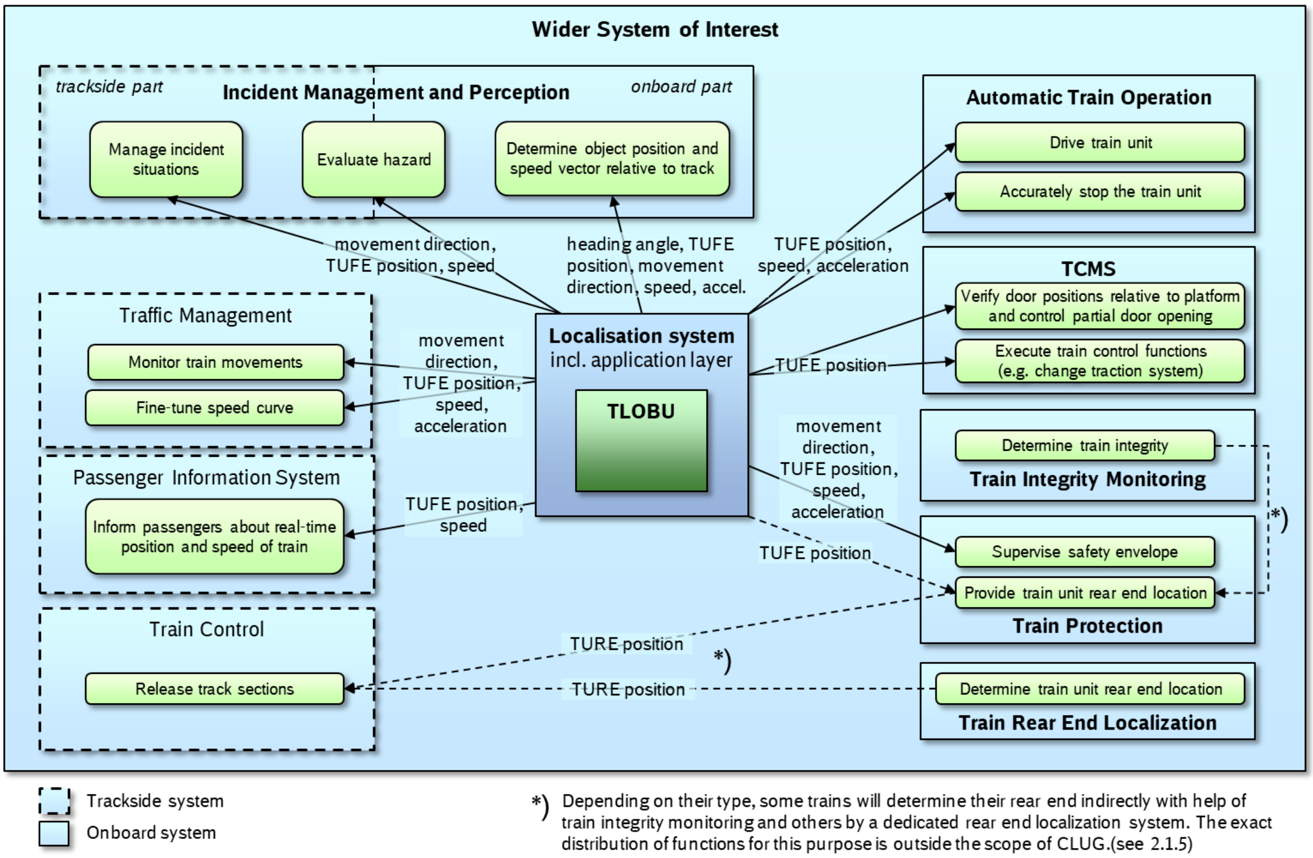

Figure 2.2: Functions in the Wider System of Interest that use information provided by CLUG

2.1.5 The CLUG project focuses on the localization of the Train Unit Front End (TUFE) but not the location of the Train Unit Rear End (TURE). The latter, however, is important for the function Release track section in Train Control with moving block. How the TURE is determined varies by type of train:

- Some trains determine TURE as a function of (TUFE, train length, train integrity status)
- Some trains, especially freight trains, might use a dedicated TURE localization device

In this document we consider the first alternative because it involves an output of CLUG – the TUFE – in the determination of the TURE, so the requirements on TURE will have an impact on the requirements on TUFE determination by CLUG. The second alternative is out of scope of CLUG.

2.1.6 In Table 2-1, the systems in the WSoI are described with their purpose, safety assumption, functions and inputs as relevant for the CLUG project have been described.

2.1.7 The safety assumptions for the systems are in line with assumptions from RCA and S2R (Shift2Rail) ATO workstreams.

System	Purpose	Safety Integrity Assumption	Functions and Inputs relevant for CLUG
Train Protection	Train Protection assures that a TU stays within the safety envelope it was given. It intervenes when it determines that the authority driving the train does not adhere to or exceeds this safety envelope.	System performing functions with safety integrity level	• To supervise that a TU that stays within the safety envelope this system must know the max safe front end, min safe front end, the speed and the movement direction on the track of the TU. • To calculate the braking curves of the train unit and the resulting intervention points in an accurate way, Train Protection needs to know the safe acceleration of the TU.
Train Control	Train Control sets and secures the route for a train, defines a safety envelope within which the train can safely move and grants an authority to move the train (where the authority includes the safety envelope).	System performing functions with safety integrity level	• To release a section of track after a TU has moved over it (so that the route can be set and the authority to move be granted to the succeeding train unit) Train Control needs to know the min safe rear end of the TU. • Note: To have a min safe rear end the length shall be known and the train integrity shall be ensured. Both will not be a topic within CLUG.
Traffic Management	Traffic Management plans the movement of trains. It also monitors the movements and reacts to deviations from the plan by eventually re-planning the movements. Traffic Management here includes also the information of customers about the real-time train movements.	System performing functions with basic integrity	• To detect deviations from the plan and decide upon necessary reactions Traffic Management needs to know track positions, speed, acceleration and movement direction of each TU. • For instance, on lines with a very high train frequency it is the task of Traffic Management to fine-tune the speed curve of each train to produce the maximum through-put of the line. For this task it needs to know position, speed, track movement direction and even acceleration very frequently and accurately.
Incident Management	Incident Management monitors potentially hazardous objects on or near the track and reacts to the situation. When an incident has occurred, it supports bringing the system back to a non-hazardous situation.	System performing some functions with safety integrity level	• For the evaluation of potential hazards and the decision on the appropriate reaction as well as for managing actions to solve an incident situation Incident Management needs to know the position, speed, acceleration and movement direction of a TU.
Perception	Perception monitors the surrounding of the train, for instance the environment in front of the train and recognizes (potentially) hazardous objects that might require a reaction by Incident Management.	System performing functions with safety integrity level	• To compute the position of distant object relative to the track where a train unit is moving Perception needs to know the accurate position, track movement direction and speed of the TU. • Especially when a train unit is moving through a curve Perception will use the accurate position of the TU to derive the heading angle of the front vehicle to, in turn, compute the distance of the object from the track.

System	Purpose	Safety Integrity Assumption	Functions and Inputs relevant for CLUG
Automatic Train Operation	Automatic Train Operation drives a train and – depending on the GoA (Grade of Automation) level – also executes other functions in the train that traditionally are carried out by a driver.	System performing functions with basic integrity	• ATO uses the position, speed, movement direction and acceleration to monitor how well a train unit is driving on the speed profile computed by ATO and to adapt the traction and brake commands if necessary • This includes the stopping of train unit at a planned stopping location with a required accuracy; the required accuracy can be relatively in some use cases like stopping at platforms with platform doors, in shunting or when stabling multiple train units in one track.

Train Control and Management System (TCMS)	TCMS (Train Control and Monitoring System) controls many of the train sub-components, mostly on the hardware side, including traction and brake systems. Modern TCMS automate some driving tasks traditionally carried out by the driver.	System performing some functions with safety integrity level	• [functions with basic integrity] To fulfil the specific driving task of keeping the train unit at a constant speed, TCMS needs to know the speed of the train unit
			• [functions with safety integrity level] TCMS controls certain functions of the train for which it has to know the position of the train relative to a location which triggers a certain behavior, examples are
			  • horn sounding
			  • control traction system changes while running
			  • verify that or which doors face the platform before executing opening command

Train Integrity Monitoring (TIM)	TIM determines if a train unit is integer or not. TIM here refers to a system that does so by physically detecting the loss of train integrity on board of the train (and not by measuring the rear end location).	System performing functions with safety integrity level	• TIM has no needs towards CLUG but may play a role in the determination of the train unit rear end position
Passenger Information System (PIS)	PIS (Passenger Information System) gives passengers real-time information about train times and deviations from the plan	System performing functions with basic integrity	• For most off its task PIS does not need to know the current location of the train but rather the estimated future arrival and departure times at stations. These are provided by TMS based on "Monitor Train Movements" and/or by ATO based behind the function "Drive train unit" • For the specific function of informing the passenger about the real-time location of the train, PIS uses indeed the current location, and eventually speed, of the train

Table 2-1: Systems Interfacing with the Localisation System, their purpose, safety considerations, functions and inputs as relevant for the CLUG project

2.2 LINK TO THE RCA (REFERENCE CCS ARCHITECTURE)

2.2.1 Table 2-2 presents the mapping of the systems in the Wider System of Interest (WSoI) to the RCA architecture. Please note: As this document is compiled the RCA architecture has not fully defined the usage of the interfaces foreseen in RCA (for the interfaces defined in RCA see [8]). That is why we only map systems in the WSoI for CLUG with the corresponding systems in the RCA system architecture.

System in WSoI for CLUG	System in RCA system architecture
CLUG	VL
Traffic Management	TMS-PAS, TMS-AE, TMS-PE
Train Control	APS-SL, -OA, -MOT, -FOT, -MT
Train Protection	APS-VS
TCMS	VD
Automatic Train Operation	ATO-AV
Train Integrity Monitoring / Train Rear End Localisation	N.A.
Incident Management / Perception	N.A.
Passenger Information	N.A.

Table 2-2: Link to the RCA

3 ASSUMPTIONS AND CONSTRAINTS

1. The Train Unit is equipped with its own devices for speed measurement outside of the scope of CLUG that the Train Unit uses for specific purposes like
   - Keep the Train Unit at a low constant speed, e.g. for coupling or washing modes
   - Detect slip/slide situations
   - Detect standstill and apply holding brakes automatically.
2. Note: Point 1 does not exclude that location information determined by the CLUG system is used in TCMS for other train control functions (see table 4-1).
3. The capacity requirements defined in chapter 4.1 assume
   - that mainline railway technology, incl. ERTMS/ETCS, is used for the operation of the railway, also for high-frequency commuter services.
   - that the train unit rear end is located by Train Protection as a function of (train unit front end, train length, train integrity status).

4 HIGH-LEVEL REQUIREMENTS DEFINITION

4.1 Mission Requirements

4.1.1 D2.3 High-level System Requirements defines the requirements for the CLUG system. The system requirements are derived from a set of mission requirements that are presented in this chapter. The starting point is the functions for which other systems use information provided by CLUG and the high-level requirements the other systems face when using information from CLUG (users' requirements).

4.1.2 The full list of mission requirements is given in Table 4-2.

4.1.3 The mission requirements fall into different categories

- Capacity: An accuracy requirement that must be fulfilled in order to reach a railway capacity target
- Functional: Information what a user's function needs in order to fulfil its own purpose
- RAM requirements
- Safety requirements
- Other: Other performance requirements, mostly inherited by existing norms

4.1.4 The reliability, availability and maintainability requirements to the CLUG subsystem (on one Train Unit) will be defined in D2.3 "High Level System Requirements Definition" by analogy with comparable localisation systems.

4.1.5 The safety requirements regarding the hazards involving the localization functionality on a CLUG equipped train will be defined in a dedicated process (as part of D2.4 "Preliminary Hazard Analysis") in line with EN 50126 (Ref. [11], [12]) and considering the application of "explicit risk estimation" risk acceptance principle (incl. harmonised risk acceptance criteria) defined in CSM-RA Regulation 402/2013 incl. amendment 1136/2015.

4.1.6 4.1.7 and 4.1.8 give additional background information on capacity and other requirements.

4.1.7 Requirements for Capacity

4.1.7.1 To increase the capacity of the railway network is one of the core targets of digital railway technologies of which CLUG is part of. As shown in an analysis conducted by DB [see APPENDIX A], the most challenging scenario related to this target are high-frequency lines: either lines with high-frequency commuter services or crossings in nodes where routes intersect at grade. There is a potential to increase capacity on high-frequency commuter lines up to 33 trains/h by successful implementation of digital rail technologies, incl. CLUG (see Appendix 5).

4.1.7.2 The same analysis shows that CLUG contributes with four effects to the capacity target. The effects are summarised in Table 4-1.

Effect	Information or quality provided by CLUG	User(s) and using function	Safety assumption
Fast release of track section	• Small overreading amount of train location • High frequency and small latency of TUFE determination	Train Protection::Compute Min safe rear end (end user: Train Control::Release track section) Note: MR_R03	Function with safety integrity level
Precise driving	Accurate location, speed and acceleration	ATO::Drive Train Note: MR_R10	Function with basic integrity
Safely know acceleration in computation of Emergency brake distance	Acceleration	Train Protection::Compute Emergency Brake Distance Note: <new>	Function with safety integrity level
Small underreading amount of location in EBI computation	Small underreading amount of train location	Train Protection::Compute Emergency Brake Intervention Note: MR_R04	Function with safety integrity level

Table 4-1 Effects of CLUG on capacity

4.1.8 Other Requirements

4.1.8.1 The functions in Traffic Management, Incident Management and Passenger Information – if not otherwise stated in table 4-1 are assumed to have lower or equal accuracy requirements for train position, speed and acceleration, than the functions of ATO, Train Control and Train Protection. The rationale for this assumption is that ATO, Train Control and Train Protection execute inner control loops in the operation of the Train Unit, while the management and information system form outer control loops that correct the operational plan in case of bigger deviations. In consequence, there is no need to define higher accuracy requirements for the management and information system than what is defined for the control systems that execute the operational plan.

4.1.8.2 For Passenger Information only one function is considered: the real-time information of customers about the train location and speed. For other functions of Passenger Information, we assume that they rather need a forecast of future train positions and times as is generated by Traffic Management.

4.1.8.3 Two requirements originate in the use case to accurately stop the train. There are two systems involved:

- ATO has the function to accurately stop the train at a given stopping point within a given tolerance. To allow for the usage of platform doors the tolerance is +/- 0.5m. Without platform doors the tolerance would be ruled by the shortest length in the implementation area by which a usable platform is longer than the longest passenger train that stops there to let passengers alight and board. This function is assumed to have a basic integrity.
- TCMS has the function to verify that the doors of the train are positioned at the platform edge – to mitigate the risk of passengers falling down onto the track bed in case that ATO failed to position the train correctly. TCMS can also have a function to allow only those doors of the train to open that are positioned at the platform. This function only verifies the position of the doors against the location of the platform, independent of the usage of platform doors. Therefore, the accuracy requirement is only ruled by the shortest length in the implementation area by which a usable platform is longer than the longest passenger train that stops there to let passengers alight and board. It is assumed that the difference in length between shortest platform and longest train using it, is >= 5m. This function is assumed to have a safety integrity level.

4.1.8.4 One requirement originates in the train control functions defined in subset-034 [5]. These functions are executed by TCMS – or will be executed by TCMS in future GoA3/4 operation – and require that TCMS executes them at the right location. For this purpose, TCMS receives a remaining distance to this location from the Train Protection System. So, the distance is calculated by Train Protection but the requirements on the accuracy originate in the function executed by TCMS.

4.1.8.5 Other requirements are inherited from existing performance requirement definitions of other systems; where this is the case a reference is defined.

4.1.9 Requirements of the users of CLUG data

The table summarises the requirements other systems face in functions where they use input data from CLUG. We call these here “External user requirements”. These values are starting point to derive the requirements for the CLUG system itself.

ID	**System of WSoI = External user**	**Function**	**Safety Assumption**	**External User Requirement**	**Requirement category**
MR_01	Traffic Management	Monitor Train Movement	Function with basic integrity	This function needs • estimated and max safe front end • estimated speed • actual movement direction	Functional
MR_02	Traffic Management	Fine-tune speed curve	Function with basic integrity	This function needs • estimated and max safe front end • estimated speed • actual movement direction • estimated acceleration *Note: accuracy requirements for this function are inherited from requirements of ATO::Drive Train Unit*	Capacity
MR_03	Train Protection	Compute Min safe rear end	Function with safety integrity level	This function needs • min safe front end.	Functional
MR_04	Train Protection	Compute Min safe rear end	Function with safety integrity level	The distance between estimated TURE and the min safe rear end, resulting from the inaccuracy in the TUFE determination, must not be bigger than the distance travelled 1s at the current estimated speed.	Capacity

ID	System of WSoI = External user	Function	Safety Assumption	External User Requirement	Requirement category
MR_05	Train Protection	Compute Min safe rear end	Function with safety integrity level	The min safe rear end position of a TU must be determined and sent at an interval of 1s and when it is sent the value must not be older than 1s. For this purpose, the TUFE provided to Train Protection must be determined at an interval of 0.2s and when it is sent the value must not be older than 0.2s. *Note: For the rationale, please refer to Table 6-4.*	Capacity
MR_06	Train Protection	Compute Emergency Brake Intervention	Function with safety integrity level	This function needs • max safe front end • estimated front end • max safe speed • max safe acceleration Note: see [4], 3.13.9.3.1 ff.; the max safe acceleration is used in the computation of V_{bec} as input to the emergency brake distance	Functional
MR_07	Train Protection	Compute Emergency Brake Intervention	Function with safety integrity level	The computation of the EBI has two capacity requirements: • [MR_07] The distance between EBI and the EBD foot must not be enlarged by the inaccuracy of the safe speed and the safe acceleration[2] by more than the distance travelled in 1s, so no more than 1s*V_{est} • [MR_09] The distance between EBI and the EBD foot must not be enlarged by the inaccuracy of the TUFE determination (under-reading amount in max safe front) by more the distance travelled in 1s, so no more than 1s*V_{est}	Capacity
MR_10	Train Protection	General		The Train Protection shall support train speed up to 600 km/h.	Other

[2] Values v_{delta0}, A_{est1} and A_{est2} in the calculation of EBI

ID	System of WSoI = External user	Function	Safety Assumption	External User Requirement	Requirement category
MR_11	Train Protection	General		The confidence interval for the safe speed must conform to subset-041, clause 5.3.1.2 [9]	Other
MR_12	Train Protection	Detect rollaway or movement against the movement authority	Function with safety integrity level	This function needs • min safe front end • actual movement direction *Note: In contrast to the intended movement direction which is determined by train orientation and Reverser position*	Functional
MR_13	TCMS	Verify door positions relative to platform and control partial door opening	Function with safety integrity level	This function needs • max safe accurate front end • min safe accurate front end Note: min/max accurate front end values are not received by TCMS directly from the localisation system but from Train Protection via the train interface [5][6]	Functional
MR_14	TCMS	Verify door positions relative to platform and control partial door opening	Function with safety integrity level	The max/min safe accurate position of the train relative to the platform must not deviate by more than ± 2m from the true train position. The output rate of the localisation for this function must be 200ms to comply with subset-119 [6], 4.3.2.	Other
MR_15	TCMS	Train Control functions	Function with safety integrity level	These functions need: • max safe accurate front end • min safe accurate front end Note: received by TCMS indirectly via the train interface [5][6]	Functional

ID	System of WSoI = External user	Function	Safety Assumption	External User Requirement	Requirement category
MR_16	TCMS	Train Control functions	Function with safety integrity level	The measurement of the remaining distance to a location, which triggers a control action from TCMS, must not deviate by more than 1s * velocity from the true distance. The output rate of the localisation for this function must be 100ms to comply with subset-119 [6], 4.3.2. Note: Decisive for the output rate is the localisation of the Train Unit relative to a change of traction system, which has the highest requirement.	Other
MR_18	ATO	Drive the TU	Function with basic integrity	This function needs: • estimated front end • estimated speed • estimated acceleration	Functional
MR_19	ATO	Drive the TU	Function with basic integrity	ATO must keep the Train Unit in a window of +/- d around the exact calculated speed curve, where d is not bigger than the distance travelled in 2s. So, the window is +/- 2s * velocity *Example: For a train travelling at 40 km/h or 11.1 m/s the ATO must drive the train so that it is not more than 22.2m in advance and not more than 22.2m in the rear of the calculated speed curve.*	Capacity
MR_20	ATO	General	Function with basic integrity	The ATO shall support train speed up to 600 km/h.	Other
MR_21	ATO	Accurately stop the TU	Function with basic integrity	This function needs: • estimated front end • estimated speed • estimated acceleration	Functional

ID	**System of WSoI = External user**	**Function**	**Safety Assumption**	**External User Requirement**	**Requirement category**
MR_22	ATO	Accurately stop the TU	Function with basic integrity	ATO must stop the Train Unit at the defined stopping point with an accuracy of +/- 0,5 m. *Note: In cases where such accuracy is required from ATO..*	Other
MR_23	Perception and Incident Management	Determine object position relative to the track	Function with safety integrity level	This function needs • heading angle • estimated front end • estimated speed • actual movement direction • estimated acceleration	Functional
MR_24	Perception and Incident Management	Determine object position relative to the track	Function with safety integrity level	*Note: To what extend the accuracy requirements of this function deviate from the requirements of other functions defined in this table is subject to further research.*	
MR_25	Passenger Information System	Show real-time information on train unit movement	*Non-safety-related function*	This function needs • estimated front end • estimated speed	Functional
MR_26	Incident Management	Manage incident situations / Evaluate Hazard	Safety assumption to be settled	This function needs • estimated front end • estimated speed • actual movement direction	Functional

Table 4-2: Systems Interfacing with the CLUG System and their requirements

5 CONCLUSION

5.1.1 This document is defining infrastructure operators (users) and their functions that require localisation information in an environment with increased technical railway network capacity.

5.1.2 Then the user requirements were derived by assessing railway infrastructure targets with the focus on capacity, function needs which are required for the user to fulfil its own purpose and other performance requirements, mostly inherited by existing norms.

5.1.3 The localisation requirements with the applicable safety assumptions for each of the infrastructure user functions are summarized. These requirements with the applicable safety assumptions form bases for the definition of the Localization System.

5.1.4 A systematic breakdown of the operators localisation requirements forms the functional and performance requirements for the Localisation System documented in D2.3 "High Level System Requirements Definition".

5.1.5 Any non-compliance of the Localisation System with the requirements defined in D2.3 "High Level System Requirements Definition" will have a direct impact on the infrastructure operator functions defined in this document.

6 APPENDIX A: RAILWAY CAPACITY WITH DIGITAL TECHNOLOGIES

6.1 DIGITAL TECHNOLOGIES FOR IMPROVED PERFORMANCE OF THE RAILWAYS

In this appendix we study the possible increase in technical railway network capacity achieved by application of digital technologies in railway operation. Technical capacity is the number of train paths that can be scheduled on a given section of the railway network, considering the mix of different train types and respecting the current scheduling rules (e.g. sectional running time allowances and buffer times).

The digital technologies assumed in the study are summarised in table 6-1

Digital Technologies	Capacity effect	CLUG caters to the effect by
CTMS (Capacity and Traffic Management System) A TMS (Traffic Management System) that is conceptually extended by functions that optimise the capacity of the network, e.g. by speed profile optimisation that can optimise the through-put of a cross-section where this is needed.	Decreases the minimal technical headway by adapting the planned speed of a train and, thus, decreasing the braking distance.	not applicable
ATO (Automatic Train Operation) **Reference: Shift2Rail IP2 ATO workpackages**	Decreases the minimal technical headway by precisely driving the train on a planned speed profile and thus reducing the lead time that the signal must be indicated to the train before an intervention by Train Protection would take place.	Precise TUFE location, speed and acceleration data.

APS (Advances Protection System, incl. moving block) **Reference: RCA - Reference CCS Architecture**	Decreases the minimal technical headway by ❖ realising shorter route setup, MA (Movement Authority) creation and route release times ❖ realising moving bock	not applicable
GNSS-based Localisation	Decreases the minimal technical headway by • providing safe acceleration value to EBD computation • providing a small confidence interval for EBI calculation • providing a small confidence interval to train rear end localisation	Safe acceleration with small confidence interval Safe TUFE location with small confidence interval
Fast trackside-train communication (e.g. with 5G)	Decreases the minimal technical headway by shortening communication track-to-train (for MA provision) and train-to-track (for route release procedure)	not applicable

Table 6-1: Digital rail technologies and effects

6.2 THE CHALLENGE OF HIGH FREQUENCY LINES

A preliminary analysis showed that it is useful to distinguish three scenarios for capacity

1. Single-track routes where the capacity is constraint by the number and location of stations where the trains can meet, and which have a limited potential for capacity increase by digital technologies
2. Double-track routes with mixed traffic and a rather high spread in train speeds. In these scenarios a substantial increase of capacity is possible but because of the speed spread the maximum number of trains is limited to 12…18 trains/h depending on the traffic and speed mix
3. Dedicated commuter lines with homogeneous stopping patterns and speeds as well as crossings in big nodes. Also, these scenarios have a substantial potential for increase in capacity and, because of the homogeneous and rather low speeds, the maximum number of trains can be increased to even beyond 30 trains/h if all technologies are successfully implemented. As we will show, a capacity of 33 trains/h might be possible.

Because of the high frequency, scenario 3 is the most challenging for the performance of any system that consumes headway time and, thus, has an impact on the capacity. The localisation system is one of these systems. When the localisation system consumes only 2s more headway time for each train than strictly necessary, e.g. through large confidence intervals, this results in a loss of 66s during an hour of operation when 33 trains/h are scheduled, and it actually reduces the capacity from 33 to 32 trains/h. In high-frequency scenarios every second counts.

In Germany the standard buffer time between two subsequent trains is 60 seconds. For high-frequency commuter lines, however, 60 seconds are not feasible, and 15 seconds is the minimum value to be respected. The operational headway (scheduled time between two trains) must be pushed down to 109 seconds to achieve 33 trains / h for a commuter trunk line. Subtracting the 15 seconds buffer time, a minimal technical headway (occupation time for train) of 94 seconds is required. Table 6-2 shows the resulting minimal technical headway for different capacity targets in a high-frequency scenario.

Trains/h	**Operational headway** (scheduled time between two trains) [s]	**Buffer time**	**Required minimal technical headway** (the occupation time of one train on the critical cross-section) [s]
This is the base capacity achieved today on typical commuter lines with mainline technology and lineside signalling			
24	150	15	135
27	133	15	118
30	120	15	105
The row above is today's bottom line with mainline technology			
31	116	15	101
32	112	15	97
33	109	15	94
The row above id the probable bottom-line when applying the said digital technologies			
The range below might be achieved by applying other game-changer technologies (e.g. brakes and braking curves)			
34	105	15	90
35	102	15	87
36	100	15	85

Table 6-2: Operational and technical minimal headway for different capacity targets

To achieve a capacity in range of 30 trains / h or above all named digital technologies are required to bring their contribution in decrease of technical minimal headway. Table 6-4 presents a hypothesis for the distribution of occupation time for 33 trains / h = 94 seconds minimal technical headway.

6.3 HEADWAY MODEL AND VALUES FOR HIGH-FREQUENCY LINES

To better understand the headway calculation following below, a snippet of the occupation times of subsequent trains is shown in Figure 3. The minimal technical headway is the result of a critical cross-section. The preceding train must have passed the critical cross-section with its min safe rear end in order to authorise the following train to proceed beyond its previous "old SvL" to the critical cross-section "new SvL". After that the preceding train is no longer decisive for the movement of the following train because the former is running at higher speed than the latter.

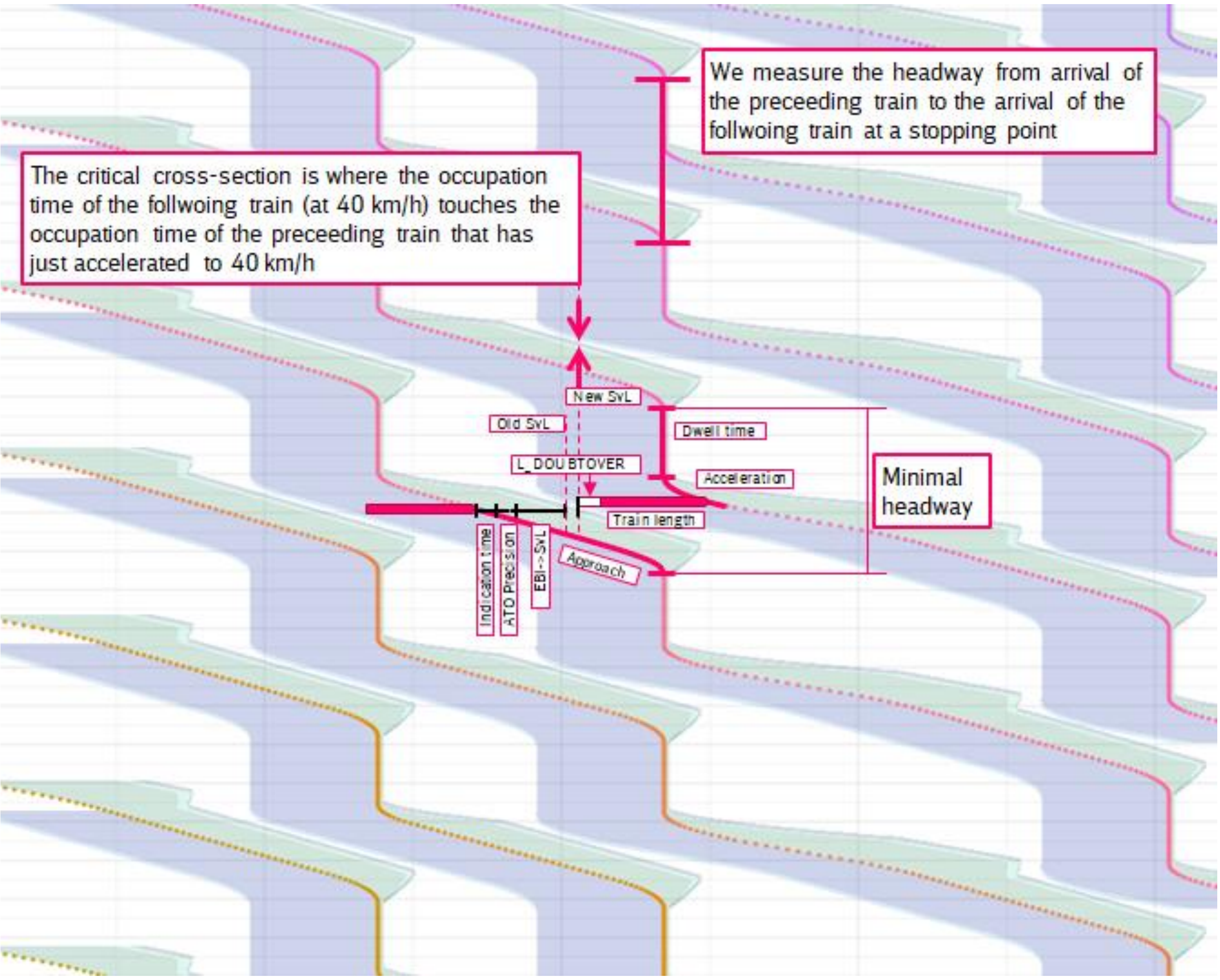

Figure 3: String line diagram with occupation time for high-frequency commuter scenario

The minimal technical headway is made up of five basic elements, some of which are further broken down in the calculation:

- Dwell time
- Acceleration time from stopping point
- Processing rear end localisation and route release
- Processing route setup and MA generation
- Indication of MA for ATO
- Approach time to stopping point

The train and scenario parameters for the calculation are summarised in table 6-3.

Parameter	Value
Train length	204m
Dwell time	36s
Approach speed	40 km/h (this rather low speed improves the through-put of the line compared to higher speeds)
Acceleration at <= 40 km/h	1,0 m/s^2
Deceleration at <= 40 km/h	0,8 m/s^2
Braking model	Lambda, Passenger train in P
Braked weight percentage (emergency)	153
T_traction_cut_off	5s
Service brake interface	No
Traction cut off interface	No
National values for braking curves	Germany (DB)
Acceleration in EBD calculation	0,1 m/s^2 (estimated speed = 0,0 m/s^2, confidence interval for safe acceleration = 0,1 m/s^2)

Table 6-3: Train and scenario parameters for high-frequency commuter train scenario

Table 6-4 shows the actual values of the elements of the occupation time and highlights where CLUG has a contribution the reduction of the occupation time and, therefore, in the increase of capacity.

Component	Description	Value	CLUG impact
The preceding train has stopped at the stopping point			
Dwell time	Time that elapses from wheel stop to wheel start	**36s**	
Acceleration time and new supervised location	Time that elapses from wheel start to the moment when the preceding train unit has reached the critical speed of 40 km/h. The position of the min safe rear end at this time will become the new supervised location.	**11,1s** The min safe rear end of the preceding train is now 153m in the rear of the stopping point	**CLUG Effect** The underreading amount goes fully into the distance that is cleared for the following train.
The min safe rear end of the preceding train has now passed the critical section and is 153m in the rear of the stopping point. After processing this location will become the new supervised location.			
	Note: the following two elements together provide a Train Position Report with Train Unit Rear End Position (or equivalent information).		

	To determine the TUFE is an intermediate step. The two steps together must not consume more than one second. Since the Train Protection System is more complex we allow it to consume 0.8 of the 1.0 second and require the localisation system to consume only 0.2s.		
Clearing time: interval of localisation establishment	The interval in which the localisation system produces a TUFE Meaning: It takes at most 0,2s to provide a localisation and at the moment it is sent the location is at 0,2s old	**0,2s**	**CLUG Effect** The frequency and latency of localisation fully add to the occupation time in this element
Clearing time: process localisation and train integrity status and assemble Train Position Report in Train Protection	The time that elapses between the moment the localisation system provides the TUFE position to the moment when the Train Position report is ready to be sent. Note:: The TPR is sent every second and when it is send the location is at most 1s old. This is the TPR interval.	**0.8s**	
Clearing time: send localisation to Train Control		**0.15s**	
Route release time	The time required by Train Control to process the min safe rear end of the preceding train unit and release track section	**1s**	
The route is now available up to 153m in the rear of the stopping point The MA the **following** train has right now is still the one of <TPR_Interval> = 1s before, the old SvL is at 163m in the rear of the stopping point The next elements calculate the creation of the MA extension for the following train up to 153m in the rear of the stopping point. The following train approaches at 40 km/h.			
Route setup time	The time needed to set and secure the movable infrastructure elements (e.g. points), if any In this scenario there are none.	**0s**	
MA generation time	The time that elapses from the moment the route is set up until the moment that the movement authority is processed by train protection onboard of the train and available to ATO. This includes the transmission from trackside to train.	**2s**	
The new SvL (at 153m **in the rear of the stopping point) is now available to ATO. This must coincide with the last point of decision on whether to brake or not. That is why the indication time and ATO driving precision must be included in the occupation time**			

MA indication time (= how far the decision point whether to brake or not is lying before the EBI)	The time that the extended MA must be available to ATO prior to reaching the old EBI (of the not-yet-extended MA)	**5,2s** *formula:* *MAX(5s;0.8*t_{BS})*	
ATO driving precision	The time that ATO must drive in the rear of the EBI in order to reliably NOT reach the EBI. This is analogous to t_{Driver} for human-driven trains.	**2s** *formula:* *MAX(2s;0.2*t_{BS})*	**CLUG Effect** ATO can realise this driving precision only with sufficiently accurate navigation data.
At this point in time the following train must not be closer than the distance EBI->SvL from its old SvL at 163m in the rear of the stopping point. The			
Approach distance	The distance from the EBI of the old SvL to the stopping point	**314 m** = 151m (EBI->old SvL) + 163m (old SvL->stopping point)	**CLUG Effects** - The overreading amount of the TUFE position fully adds to this distance (here: <= 10m) - The provision of a safe acceleration with small confidence interval significantly reduces the Emergency brake distance which is part of the approach distance (here: safe confidence interval <= 0,1 m/s²)
Approach time	The time that the following train unit needs to travel from its position when the critical MA extension arrives up to wheel stop at the stopping point at the platform	**35.2s** 314m of which - 237m at 40 km/h - 77m decelerating	
The following TU has now stopped at the stopping point, 93,65 after the preceding train had.			
Sum		**94s**	
Buffer time		15s	
Operational headway		**109s**	
Technical capacity		**33 trains/h**	

Table 6-4: Elements of the minimal headway for 33 commuter trains per hour

6.4 Appendix Conclusions for the Localisation System

The CLUG system contributes with 4 effects to the increase of capacity of high-frequency lines. Three of the effects take place in processes assumed to be related to functions with safety integrity level.

1. [function with safety integrity level] A fast release of track sections supported by two qualities of the information provided by CLUG
    a. a small overreading amount in the determination of the TUFE which is in turn used for the determination of the min safe rear end of a Train Unit and the subsequent route release
    b. the determination of the TUFE with a high-frequency and small latency to be used in 1.
2. [function with basic integrity] A high precision, frequency and small latency in the determination of accurate location, speed and acceleration to be used in ATO for precise driving of the Train Unit
3. [function with safety integrity level] a small confidence interval in the determination of the Train Unit's acceleration to be used in the EBD-calculation in the Train Protection system
4. [function with safety integrity level] a small underreading amount in the determination of the TUFE which adds fully to the distance EBI→ SvL

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