Rail to Digital automated up to autonomous train operation

D21.1 – Operational requirements and system capabilities of an ASTP system (Use Cases)

Due date of deliverable: 20/12/2024

Actual submission date: 15/05/2025

Leader: Marc SARRAT, SNCF

Reviewed: Y

Document status		
Revision	Date	Description
01	03/04/2023	Chapters 1 to 4 - First issue
02	28/04/2023	Chapter 5 - First issue
03	12/05/2023	Chapters 6 & 7 - First issue
04	15/05/2023	Chapters 1 to 4: update taking into account comments
05	23/05/2023	Chapter 5: update taking into account comments
06	26/05/2023	Chapter 8 - First issue
07	02/06/2023	Chapter 6&7: update taking into account comments
08	16/06/2023	First Stable Version of the document for WP21 review
09	26/07/2023	First issue for external review
10	13/09/2023	TMT review
11	31/10/2023	TMT review – second update
12	07/06/2024	TMT review – second update
13	15/11/2024	Integration of the comments and results from the following documents: TMT V3.0 ESA 240313_V2

		EUSPA 240314 TN1 Revision TN2 Revision 03 24/07/2024 TN4 Revision 03 19/08/2024 TN5 Revision 1.0 23/07/2024 TN6 Revision 1.0 22/06/2024 TN8 Revision 2 07/06/2024
14	11/12/2024	Integration of comments from ESA and EUSPA reviews: • 240314_EGNOS in ERJU-Comments-EUSPA_D21.1_revEUSPA_ESSP_22Nov.xlsx • 240314_EGNOS in ERJU-Comments - EUSPA D21.2_revEUSPA_ESSP_22Nov.xlsx • ESA_Comments_Updated_D21_1_and_2.xlsx
15	15/05/2025	Update after External and MCP reviews
16	21/05/2025	Typo corrections
17	11/06/2025	Reference corrections

Project funded from the European Union's Horizon Europe research and innovation programme		
Dissemination Level		
PU	Public	X
CO	Confidential, restricted under conditions set out in Model Grant Agreement	

Start date: 01/12/2022 Duration: 8 months

ACKNOWLEDGEMENTS

This project has received funding from the Europe's Rail Joint Undertaking (ERJU) under the Grant Agreement no. 101102001. The JU receives support from the European Union's Horizon Europe research and innovation programme and the Europe's Rail JU members other than the Union.

REPORT CONTRIBUTORS

Name	Company	Details of Contribution
Saïd El Fassi	SNCF (EXT)	Author
Adrien Gharios	SNCF	Co-author
Marc Sarrat	SNCF	WP21 Leader
Gregorio Velasco	ADIF	Contributor
Manuel Cáceres	ADIF	Contributor
Ramiro Valdes	ADIF	Contributor
Laurent Cuvelier	ATSA	Contributor
Andrea Lucidi	ATSA	Contributor
Angelo Bonvissuto	ATSA	Contributor
Marc Berger	ATSA	Contributor
Francesco Inzirillo	MERMEC	Contributor
Petr Kačmařík	AZD	Contributor
Iban Lopetegi	CAF	Contributor
Gorka De Miguel	CEIT	Contributor
Paul Landa Zabalegui	CEIT	Contributor
Andrea Gotovac	DB	Contributor
Zoltan Abram	DB	Contributor
Benjamin Siebler	DLR	Contributor
Andreas Lehner	DLR	Contributor
Saro Thiyagarajan	FT	Contributor
Claudio Evangelisti	FSI	Contributor
Rodrigo Caceres	INDRA	Contributor
Francesco Parilla	INDRA	Contributor
Michaela Haberler-Weber	OEBB	Contributor
Patrick Rozijn	NS	Contributor
Bernhard Stamm	SMO	Contributor

Ulrich Kaelberer	GTSD	Contributor
Thorsten Ulbricht	SBB	Contributor
Vivien Fouquet	ADS	Contributor
Francisco Javier Gonzalez	RENFE	Contributor
Miguel Fernandez Elorriaga	CEDEX	Contributor
Gabriele Ridolfi	RFI	Contributor
Jérôme Lalouette	SNCF [SP - TCS]	Contributor
Ettore Canestri	EUSPA	Reviewer
Silvia Porfili	EUSPA	Reviewer
Gerarda De Pasquale	EUSPA	Reviewer
Pauline Martin	EUSPA	Reviewer
Maria Mota	EUSPA	Reviewer
Natalia Castrillo Merlan	EUSPA	Reviewer
Jean-Christophe Denis	ESA	Reviewer
Frederic Bauer	ESA	Reviewer
Carlos Lopez	ESA	Reviewer
Arnaud Boisseau	ESA	Reviewer
Didier Flament	ESA	Reviewer
Jerome Foussette	ESA	Reviewer
Christian Wullems	ESA	Reviewer

EXECUTIVE SUMMARY

The challenge of WP21 Advanced Safe Train Positioning operational needs of the project R2DATO is to provide Advanced Safe Train Positioning solutions with more accurate position and speed, which will provide possibilities of optimising headway as well as energy train control assistance (ATO), allowing energy saving and densification of trains with less trackside equipment. ASTP "Advanced Safe Train Positioning" will reduce maintenance costs and improve availability within equivalent safety considerations.

The Technical Enabler 2 ASTP focuses on the development of modular and scalable advanced safe train positioning (ASTP) system. It serves all CCS and non-CCS functions such as ATP, ATO, TMS, TCMS, applications of RU in train (e.g., DAS or travel-information) or on trackside. Then ASTP system should be scalable for different Safety Integrity Levels to cover the wide range of applications from low cost to high end resolution applications. Addressing the targets above, this document:

- Identifies common high-level user needs and system capabilities of ASTP,
- Defines required system performance for the ASTP system.

The ASTP is considered as a component of the CCS on-board architecture. Based on users' needs among infrastructure managers and railways undertakings, operational and environment needs are identified.

The reference frame to provide the localisation information by the ASTP to users is discussed. Two concepts are presented, one is to provide ASTP localisation information independent of the train configuration using a fixed reference frame, the other one is to use the train front end as the reference frame for providing ASTP localisation information. The first concept was selected mainly to avoid solving at the ASTP level the complexity of the dynamic train configuration.

Due to the use of new technology of sensors that are based on advanced positioning, new performance criteria are defined. The document discussed the differences between the existing ETCS performance concept with a confidence interval that grows and resets while passing a new reference location and the new one introduced with the absolute positioning concept defining at any time a confidence interval for an absolute position. The performance of this new concept is based on operation needs defining two limits of the confidence interval depending on train operation; train running in an area with no constraints or an area with constrains.

Possible supporting information required to enhance the quality, the safety of the localisation information is identified. WP22 shall confirm the needs.

The document presents functional and non-functional requirements derived from users' needs.

Clarification is provided to localisation information users to convert ASTP localisation information to their own reference frame.

To be noticed that WP21 was held in two steps. The first final release D21.1 v12 raised several open issues. During year 2024, a process of clarification of the identified open issues was launched and

was formalised in the form of several Technical Notes included as appendixes in this document. Since most of the open issues where related to the overall CCS-OB architecture or specification (out of WP21 scope), WP21 could only provide the members points of view and proposals without considering the open issue closed. Only the System Pillar, with a broader scope of work, is able to take the right decisions to definitely close the identified open issues.

The current release of D21.1 includes all changes based on decisions defined in the technical notes.

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

The confrontation of this set of requirements within WP22 demonstration will provide important feedback on the feasibility of a safe localisation equipment using alternative technology from the one specified today (odo balise principle). Results from WP22 shall confirm the following items:

1. The principles of architecture and interfaces with the CCS-OB components.
2. The need of supporting information listed in the document.
3. The achievement of defined performances.

The results of WP21 will be provided under two deliverables:

- D21.1 – Operational Requirements and System Capabilities of ASTP System (Use Cases)
- D21.2 – System requirements of ASTP system

ABBREVIATIONS AND ACRONYMS

APM	Automatic Processing Module
ASTP	Advanced Safe Train Positioning
ATO	Automatic Train Operation
ATO-OB	Automatic Train Operation On-Board
ATP	Automatic Train Protection
ATP-OB	Automatic Train Protection On-Board
BTM	Balise Transmission Module
CCS	Control Command and Signalling
CCS-OB	Control Command and Signalling On-Board
CI	Confidence interval
CMD	Cold Movement Detection
DAS-OB	Driver Advisory System On-Board
EBD	Emergency Brake Deceleration Curve
EBI	Emergency Brake Intervention supervision limit
EGNOS	European Geostationary Navigation Overlay Service
EoA	End of Authority
ERTMS	European Rail Traffic Management System
ESA	European Space Agency
ETCS	European Train Control System
ETCS-OB	European Train Control System On-Board
ETRS89	European Terrestrial Reference System 1989
EUSPA	European Union Agency for the Space Programme
FRMCS	Future Railway Mobile Communication System
GNSS	Global Navigation Satellite System
IM	Infrastructure Manager
JRU	Juridical Recorder Unit
LRBG	Last Relevant Balise Group
LRRL	Last Relevant Reference Location

MA	Movement Authority
MAACI	Max Accepted Acceleration Confidence Interval
MAAU	Max Accepted Acceleration Underestimation
MAAO	Max Accepted Acceleration Overestimation
MAPCI	Max Accepted Position Confidence Interval
MAPU	Max Accepted Position Underestimation
MAPO	Max Accepted Position Overestimation
MASCI	Max Accepted Speed Confidence Interval
MASU	Max Accepted Speed Underestimation
MASO	Max Accepted Speed Overestimation
MDCM-OB	Monitoring, Diagnostics, Configuration, Maintenance On-Board
NID-C	Country identifier
NID_RL	Reference Location identifier
NTC	National Train Control
NTP	National Train Protection
OCORA	Open CCS On-board Reference Architecture
Q_LOCACC	Accuracy of the balise location
R2DATO	Rail to Digital automated up to autonomous train operation
RCA	Reference CCS Architecture
RU	Railway Undertaking
S2R	Shift to Rail
SC	Steering Committee
SCI	Standardised Common Interface
SCV	Signal Converter
SiS	Signal in Space
SoM	Start of Mission
STM	Specific Transmission module
TCMS	Train Control and Monitoring System
TDS	Train Display System
THR	Tolerable Hazard Rate

TIMS	Train Integrity Management System
TIU	Train Interface Unit
TMS	Traffic Management System
TMT	Technical Management Team
TTD	Trackside Train Detection (using conventional methods)
TTLS	Train Time and Localisation Service
WGS84	World Geodetic System 1984
WP21	Work package 21 of the project R2DATO
WP22	Work package 22 of the project R2DATO

Please refer to additional acronyms defined in SUBSET-023 [1]

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This document represents the deliverable D21.1 – Operational Requirements and System Capabilities of ASTP System (Use Cases) of the task 21.1 which is part of the work package WP21 Advanced Safe Train Positioning operational needs of the project R2DATO.

The main goals of task 21.1 is to describe operational needs and system capabilities of an ASTP system (Use Cases).

Based on initial assumptions from X2R5 [19], the task is dedicated to collect user needs in operational context (IM and RU…Passenger, freight, regional, fixed trainsets, loco with variable amount of coaches / freight wagons, Speeds between 0 and 500 km/h), define system functions and boundaries, with the target of keeping ASTP solution at an acceptable cost level.

Following release 12, a major change is introduced in the document to provide ASTP localisation information using a fixed reference frame (e.g., bogie pin) and not to provide localisation information using the train front end as a reference frame. This change results from the decision taken by WP21 partners during meeting October the 1st, 2024.Considerations of this change is discussed along the document.

The document presents the results of task 21.1 through the following chapters:

- Chapter 3 ASTP objectives presents a reminder of the existing ETCS localisation principles and then identifies the main goals of the ASTP.
- Chapter 4 Operational context and users' needs identifies all stakeholders interested by the improvement of the localisation system, builds a list of operational scenarios, operational user's application.
- Chapter 5 ASTP boundaries assumptions and constraints describes the system under consideration, the ASTP boundaries and the operation requirements, constraints.
- Chapter 6 Accuracy, performance and capacity presents the existing ERTMS position performance models, two new position models and then make a recommendation on the model to be selected.
- Chapter 7 ASTP Functional requirements describes the system functions that the ASTP shall achieve
- Chapter 8 ASTP Non functional requirements presents high-level non-functional requirements
- Chapter 9 ASTP operational scenarios defining operational scenarios, in nominal and degraded modes
- Chapter 10 Dissemination of ASTP localisation information presents based on some train configuration, the principles to convert by the user the ASTP localisation information to their own reference frame.
- Chapter 11 makes a summary of identified exported constrains to components in interface with the ASTP.

- Chapter 12 concludes about the work done by WP21, it highlights the main findings and identifies what WP21 is expecting from WP22 to consolidate these results.

This document is completed by appendixes. These appendixes take the form of technical notes required for the resolution or recommendation on open points identified during the works. They are attached to keep trace of some statements in the document.

The list of appendixes is the following:

- Appendix A: ASTP availability justification target. This paper provides justifications based on data used to assess the availability target of the ASTP.
- Appendix B: List of user subsystem. This paper provides a list of possible users and for each of them potential localisation data required.
- Appendix C: Estimated error using different reference frames. This paper provides assessment of relative errors of speed, position according to the reference frame considered, mark along the track axis or reference mark along the longitudinal axis of the vehicle.
- Appendix D: Technical note #1. ASTP reference frame and function allocation between ASTP and ETCS. The paper presents two concepts of reference frame (train front end reference frame, ASTP reference frame) and makes decision on the one to be used, ASTP reference frame.
- Appendix E: Technical note #2, ASTP functions allocation. This paper shows the consequences of specific architectural decisions regarding the functional allocation of CCS functions.
- Appendix F: Technical note #4, routing information for ASTP. This paper presents the interest of using routing information such as point information to help the track selectivity of the ASTP.
- Appendix G: Technical note #5, model of accuracy and constrained areas. This paper presents an analysis of two accuracy models, speed dependent model and fixed value model.
- Appendix H: Technical note #6, accuracy objectives. This paper discusses of the safety level, the accuracy required for positioning information required for ATO functions
- Appendix I: Technical note #8, needed data from CMD function. This paper discusses the type of information that the CMD shall provide.

2 DEFINITIONS

2.1.1.1.1 ASTP reference point

On the vehicle where the ASTP is installed, the ASTP reference point defines the origin of all reference frames used by the ASTP to express the different localisation information (refer to definition 2.1.1.1.14).

The ASTP reference point is a point located on the plan defined by the carriage floor, on the carriage longitudinal axis. The ASTP reference point is fixed, it doesn't depend on the train configuration. It is a static parameter.

Note: Preferably, the ASTP reference point should be one bogie pin of the vehicle.

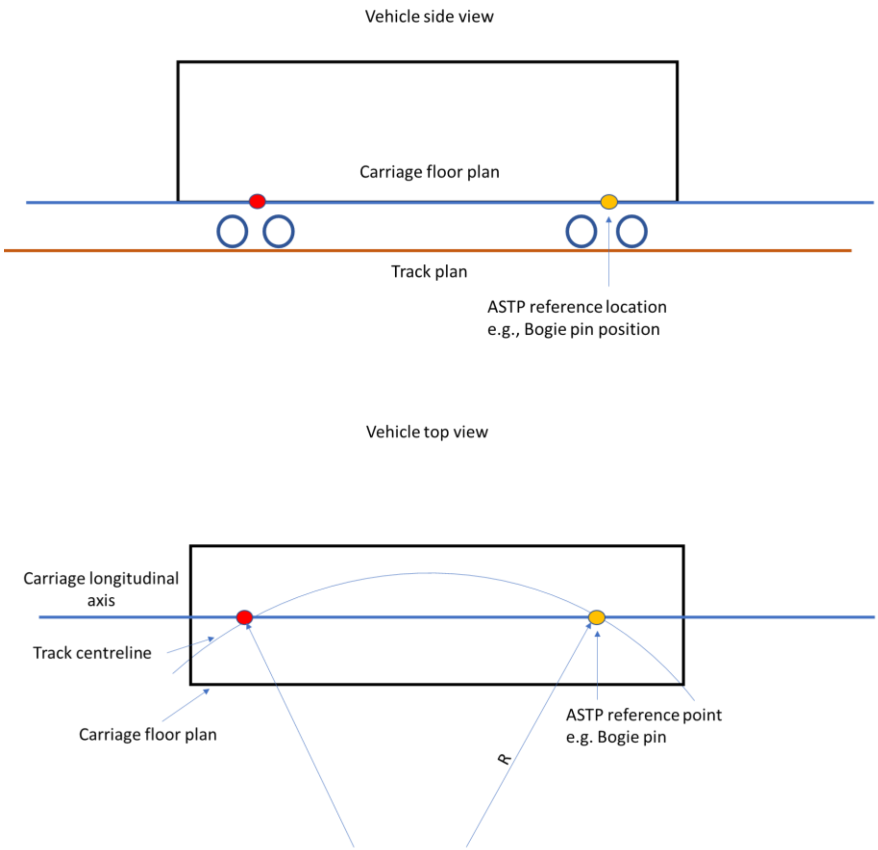


Figure 1: ASTP reference point

2.1.1.1.2 ASTP 1D reference frame

It is a one-dimensional reference frame attached to the vehicle where the ASTP is installed. On the plan of the carriage floor, it is defined by the origin represented by the ASTP reference point (refer to definition 2.1.1.1.1) and a x axis following the track centreline and oriented toward one end of the vehicle. The end of the vehicle used as the reference for the orientation of the x axis is defined by static configuration (e.g., side A or side B of the vehicle).

This reference frame is fixed, it doesn't change with either the train configuration, or the train movement.

This reference frame is defined by static parameters represented by the ASTP reference point location and the orientation of the x axis in the vehicle.

This 1D reference frame is used by the ASTP to express along the track centre line, the position, the speed, and the acceleration of the carriage where the ASTP is installed.

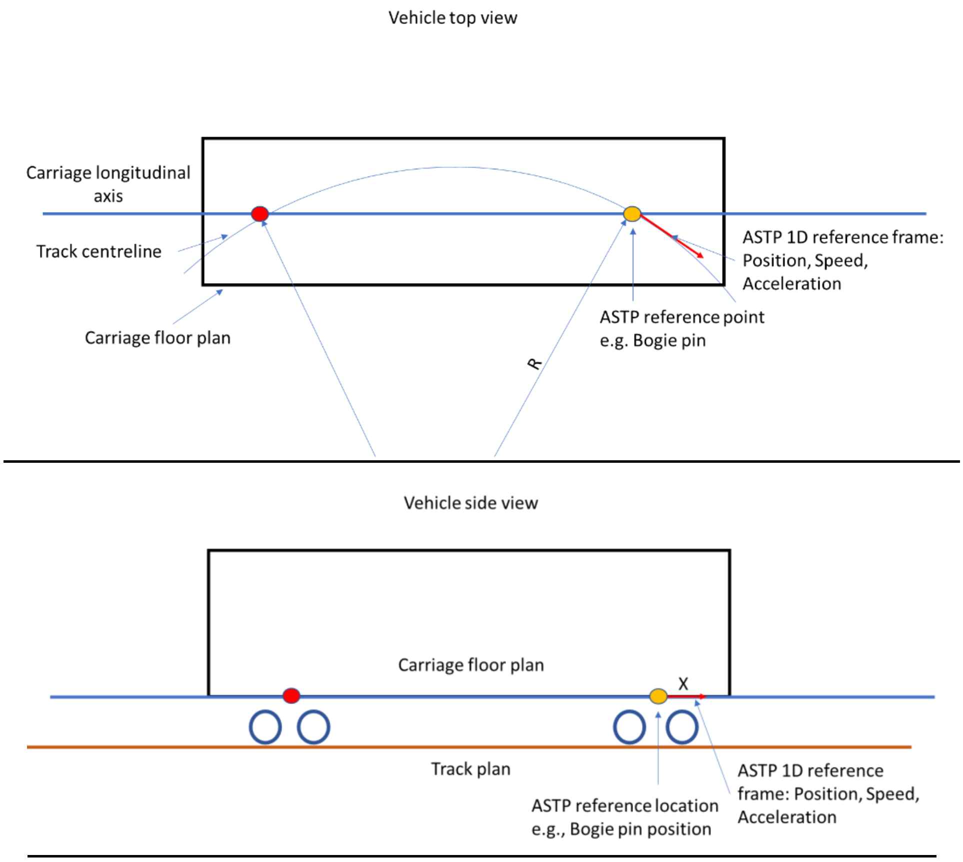


Figure 2: ASTP 1D reference frame represented by the bogie frame.

2.1.1.1.3 ASTP 3D reference frame

It is a three-dimensional reference frame attached to the vehicle where the ASTP is installed. It is defined by the carriage frame by a right trihedron. The origin is the ASTP reference point (refer to definition 2.1.1.1.1). On the plan defined by the carriage floor, the x axis is the carriage longitudinal axis oriented toward one end of the vehicle (same direction as the x axis 1D reference frame), y axis is the orthogonal to the carriage longitudinal axis oriented to the left, z axis the orthogonal to the carriage floor oriented up. This reference frame is fixed, it doesn't change with either the train configuration, or train movement.

The 3D reference frame is used by the ASTP to express the velocity and acceleration of the vehicle where the ASTP is installed.

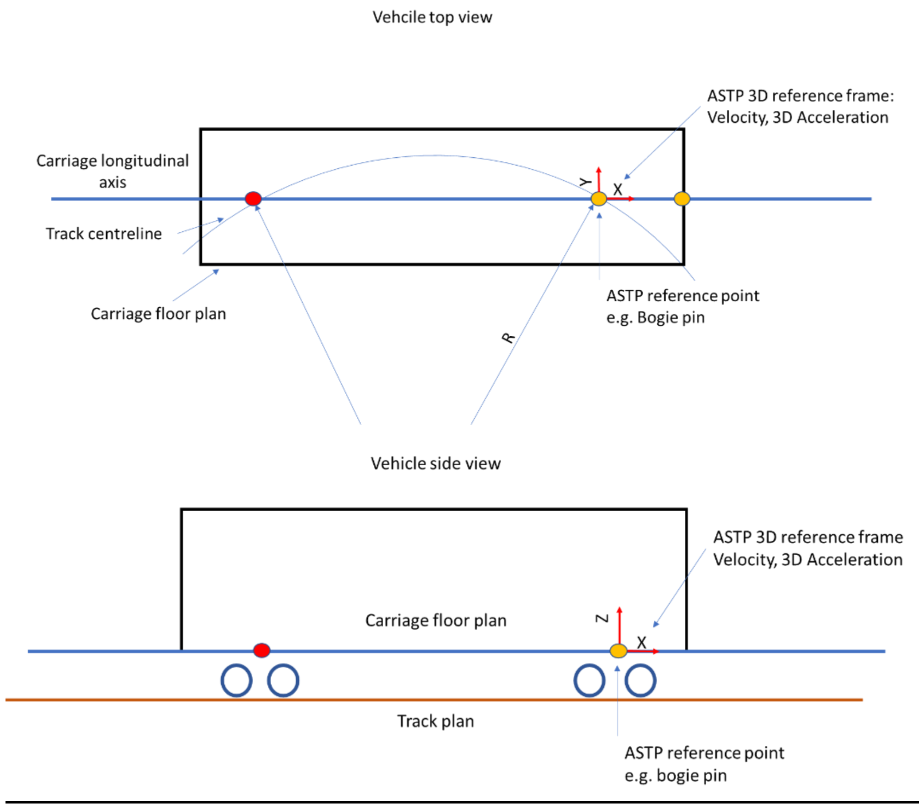


Figure 3: ASTP 3D reference frame represented by the carriage frame.

2.1.1.1.4 ASTP absolute position reference frame.

It is an absolute geocoordinate system using a 3 D reference frame (e.g., Long, Lat, Alt, using WGS84 system coordinate). It is used by the ASTP to express the absolute position of the ASTP reference point (refer to definition 2.1.1.1.1).

Note: The GNSS receiver is working with WGS84 coordinate system that is a fixed system. The use of ETRS89 at the level of the ASTP would lead to update transformation law due to the European continental drift. To avoid all ASTP yearly update, WGS84 is selected.

2.1.1.1.5 Accuracy

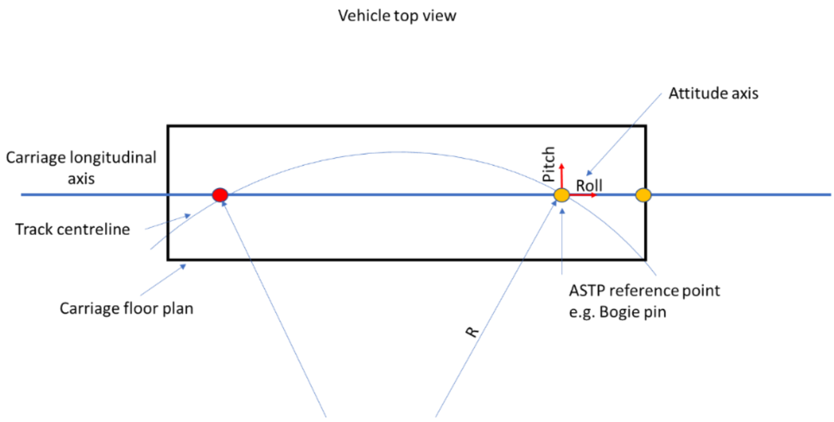
The difference between true and estimated values with a defined probability. For more information see chapter 6.2.

2.1.1.1.6 Angular rate

It is the angular speed of the rotational angles of the attitude. For more information see chapter 7.1.8.

2.1.1.1.7 ASTP Attitude reference frame

It describes the orientation of a rigid body with respect to a fixed coordinate system by determining the rotational angles, yaw-pitch-roll of the vehicle where the ASTP is installed. On the plan defined by the carriage floor, the roll axis is the carriage longitudinal axis oriented toward one end of the vehicle, pitch axis is the orthogonal to the carriage longitudinal axis oriented to the left, yaw axis is the orthogonal to the carriage floor oriented up. Angles are absolute values using as references the horizontal plan to determine the pitch and roll angles, the direction to the north to determine the yaw. For more information see chapter 7.1.8.



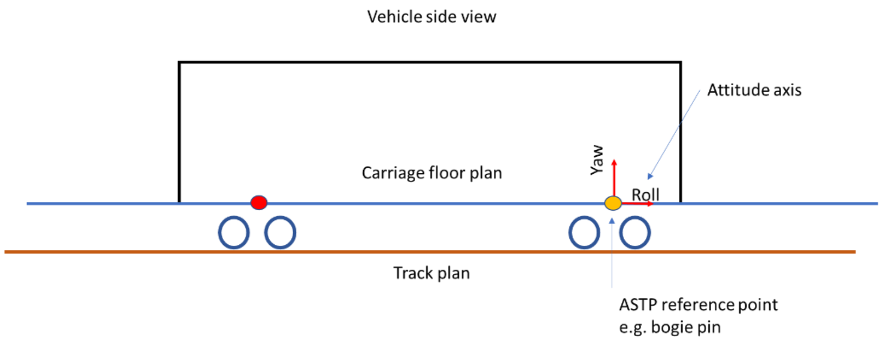


Figure 4: ASTP attitude reference frame represented by the carriage frame

2.1.1.1.8 Confidence Interval

The position, speed, acceleration interval within which the ASTP assumes the true ASTP position, speed, acceleration is, with a defined probability (THR). For more information see chapter 6.2.

2.1.1.1.9 Estimated ASTP Distance

It is expressed as the distance along the track centreline between a reference location (refer to definition 2.1.1.1.15) and the estimated ASTP reference point position (refer to definition 2.1.1.1.1).

2.1.1.1.10 Estimated ASTP Position

The position the ASTP estimates the ASTP reference point (refer to definition 2.1.1.1.1). is at, within a probability. Also referred to as "Estimated Position" SUBSET-023 [1]. Relations between estimated position and L_DOUBTOVER/ L_DOUBTUNDER position are provided in chapter 6.2.1. The estimated ASTP position, shall be considered as a relative position (refer to definition 2.1.1.1.16) to a reference location (e.g., LRBG).

2.1.1.1.11 Estimated ASTP Speed

The speed the ASTP estimates the vehicle where it is installed is running at, within a probability. The speed is measured using the ASTP 1D reference frame (refer to definition 2.1.1.1.2). Also referred to as "Estimated Position" SUBSET-023 [1]. Relations between estimated speed and over/underestimation speed are provided in chapter 6.2.2.

2.1.1.1.12 GoA level

The definition of GoA arises from apportioning responsibility for the given functions of railway operations between operational staff and involved technical railway systems. The table below from ERTMS/ATO SRS SUBSET-125 [6] defines the operation principles for each GoA level.

GoA	GoA name	Train operator	Description
GoA1	Non automated train operation	Train driver in the cab	The train is driven manually; but protected by automatic train protection (ATP). This GoA can also include providing advisory information to assist manual driving.
GoA2	Semi-automated train operation	Train driver in the cab	The train is driven automatically, stopping is automated but a driver in the cab is required to start automatic driving of the train, the driver can operate the doors (although this can also be done automatically), the driver is still in the cab to check the track ahead is clear and carry out other manual functions. The driver can take over in emergency or degraded situations.
GoA3	Driverless train operation	Train attendant on-board the train	The train is operated automatically including automatic departure, a train attendant has some operational tasks, e.g., operating the train doors (although this can also be done automatically) and can assume control in case of emergency or degraded situations.
GoA4	Unattended train operation	No staff on-board competent to operate the train	Unattended train operation: all functions of train operation are automatic with no staff on-board to assume control in case of emergencies or degraded situations.

2.1.1.1.13 Kinematic data

Set of data including speed, acceleration, attitude or angular rate of the vehicle where the ASTP is installed.

2.1.1.1.14 ASTP Localisation Information

Set of spatial values referenced to the rail network, and kinematic variables referenced to the ASTP reference frames, that provide ASTP reference point position of the vehicle where the ASTP is installed in a specific point of the network and its dynamic behaviour from its speed, acceleration, and orientation values.
The table here after provides a list of localisation information using the ASTP reference frames. The definitions of data items are provided in chapters 6.2 and 7.1.

Type of set of data	Data items
ASTP 1D position	Reference location id, Position qualifier, Estimated distance, Underestimation of the estimated distance, Overestimation of the estimated distance, Track edge id.
ASTP 1D speed, acceleration	Movement direction, Estimated ASTP speed, Underestimation ASTP speed, Overestimation ASTP speed, Estimated ASTP acceleration, Underestimation ASTP acceleration, Overestimation ASTP acceleration.
ASTP reference point 3D position	3D Position, 3D Position uncertainty.
3D ASTP reference point velocity, acceleration	3D Velocity, 3D Velocity uncertainty, 3D Acceleration, 3D Acceleration uncertainty,
Vehicle attitude	Attitude, Attitude uncertainty. Covariance matrix of the rotational angles,

	Angular rate, Angular rate uncertainty.

Table 1: List of localisation information

2.1.1.1.15 Reference location

A location on the track (e.g., balise group reference location, absolute geographical point, origin of a track edge, track node…) used as a reference by the trackside and the CCS-OB. Reference location is used to send track and signalling information from trackside or the train position from the CCS-OB see SUBSET-023 [1]. Estimated distances are given in relation to this location that is known by the on-board and the trackside.

2.1.1.1.16 ASTP Relative position

The ASTP reference point position expressed with a distance from a reference location in a 1D reference frame.

2.1.1.1.17 Supporting Information

Information not directly translatable into localisation information but needed to provide the desired output. This information will be used by internal ASTP processes to enable, improve, or validate localisation information.

2.1.1.1.18 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 SUBSET-023 [1].

2.1.1.1.19 ASTP true acceleration

The real signed acceleration of the ASTP along the track centreline. It is expressed using the ASTP 1D reference frame (refer to definition 2.1.1.1.2).

2.1.1.1.20 ASTP true position

The real position of the ASTP reference point along the track centreline. It is expressed using the ASTP 1D reference frame (refer to definition 2.1.1.1.2). or a geocoordinate reference frame (refer to definition 2.1.1.1.4).

2.1.1.1.21 ASTP true speed

The real absolute speed of the ASTP reference point along the track centreline. It is expressed using the ASTP 1D reference frame (refer to definition 2.1.1.1.2).

2.1.1.1.22 Trusted localisation information

Localisation information processed by the ASTP achieving safety requirements for safe relevant data (e.g., valid position, valid speed…).

Note: this trusted position is the view from the ASTP, there is no link with the position status (unambiguous, ambiguous, valid, invalid…) at the ETCS system level.

2.1.1.1.23 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.

2.1.1.1.24 Velocity

ASTP reference point speed expressed in a ASTP 3D reference frame (refer to definition 2.1.1.1.3).

For additional definitions please refer to

- Chapter 6.2 about position, speed, acceleration and confidence interval definitions
- SUBSET-023 [1], ERTMS/ETCS Glossary.

3 ASTP OBJECTIVES

3.1 CURRENT ETCS TRAIN LOCALISATION PRINCIPLES

In the current ETCS specification (see for more details chapter 3 of SUBSET-026 [2]) the train position is determined always longitudinal along the track, regardless of the complexity of the track layout. The train position is defined as the relative position of the train front end in relation to a reference location (e.g., balise group). This principle of train localisation is called 1D positioning. The balise group identifies a unique common absolute reference location between the on-board and the trackside which is called when acknowledged by the on-board last relevant balise group (LRBG). Therefore, the train position is the distance of the estimated train front end position from the LRBG.

The position report information includes:

- The estimated train front end position, defined by the estimated distance from the LRBG to the train front end.
- The train position confidence interval (sets the safety boundaries for the estimated position), defined by the min/max safe front end.
- Directional train position information in reference to the balise group orientation of the LRBG (position of the train front end from the side of the LRBG, train orientation, train movement direction).

The confidence interval of the train front end position depends on the travelled distance from the LRBG and shall consider L_DOUBTOVER and L_DOUBTUNDER defined by:

- The on-board over-reading amount and under-reading amount (reading accuracy plus the error in detection of the balise group location reference).
- The location accuracy of the balise used as LRBG (Q_LOCACC).

The following figure depicts the ETCS principles of the train front end positioning, the estimated train front end and the confidence interval (min safe front end, max safe front end).

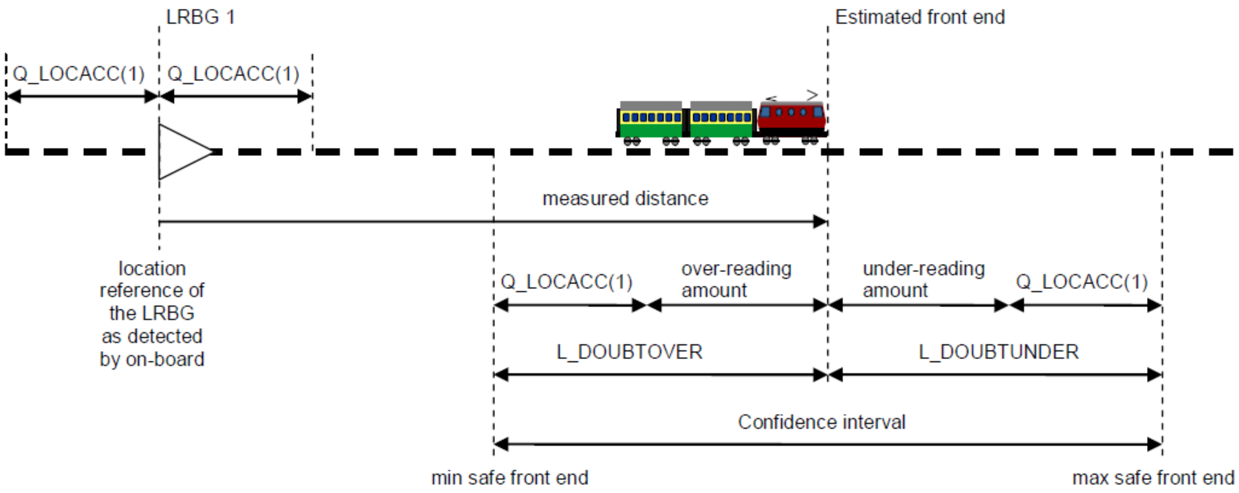


Figure 5: Train confidence interval and train front end position

(SUBSET-026 [2], chapter 3, figure 13c)

The odometry system of current ETCS implementations is based on wheel revolution sensors and additional sensors. The performance requirement of the accuracy of the odometry is defined as a linear model of the measured distance from the LRBG. The current specification for the performance of the odometry is described in chapter 5.3.1.1 of SUBSET-041 [4] .

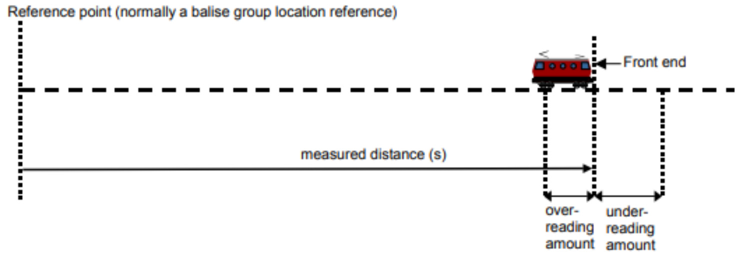
Description	Accuracy of distances measured on-board
Start Event	not applicable
Stop Event	not applicable
Value	for every measured distance s the accuracy shall be better or equal to ± (5m + 5% s), i.e. the over reading amount and the under reading amount shall be equal to or lower than (5m + 5% s). 
Notes	This performance requirement includes the error for the detection of a balise location, as defined in the Eurobalise specifications. Also in case of malfunctioning the on-board equipment shall evaluate a safe confidence interval.

Figure 6: Accuracy of distances measured on-board

(SUBSET-041 [4], chapter 5.3.1.1)

The performance model of the confidence interval increases in relation to the travelled distance from the LRBG depending on the accuracy of odometer equipment until it is reset when the ETCS-OB determines a new LRBG (see SUBSET-026 [2] figure 13a, reset of confidence interval and relocation, on change of LRBG).

3.2 ASTP MAIN OBJECTIVES

This chapter is providing general information, objectives to drive the definition, the specification of the ASTP. This chapter has to be seen as a general introduction of the goals to be achieved. Details, specific figures or rationale are not provided and will be introduced, when necessary, in the following chapters of this document.

The Advanced Safe Train Positioning solutions should provide more accurate position and speed, which will provide possibilities of optimising headway as well as energy train control assistance, allowing energy saving and densification of trains with less trackside equipment (e.g., reduction of the number of balises). ASTP "Advanced Safe Train Positioning" will reduce maintenance costs and improve availability within equivalent safety considerations.

From the absolute safe ASTP position, the ASTP can derive localisation information in a 1D reference frame. This ASTP localisation information is share not only with the automatic train protection (ATP hosted by the EVC) but also with other on-board actors (e.g., class B ATP, ATO-OB, TCMS…) or trackside actors (e.g., TMS…) through a modular and scalable system, standardised interface is a key objective of the ASTP architecture. The ASTP is an on-board system part of the CCS-OB.

The ASTP shall provide ASTP localisation information such as ASTP 1D position along the track relative to a reference location, speed and acceleration of the vehicle where the ASTP is installed which complies with the current ERTMS/ETCS principle (distance and position qualifier from a LRBG and a speed) and can also provide additional new localisation information such as:

- The ASTP track Id.
- The ASTP reference point absolute (3D) geographic positioning (Long, Lat, Alt).
- The ASTP vector velocity within the 3D coordinate system based on the track axis.
- The ASTP vector acceleration within the 3D coordinate system based on the track axis.
- The attitude (roll, pitch, and yaw angles) and angular rates of the vehicle where ASTP sensors are installed.

The location information in 3D is required by new needs as the perception, incident management functions.

This localisation information is determined by the ASTP based on computation of data provided by sensors and supporting information (e.g., digital map, augmentation data, routing information) upon availability. Refer to chapter 5.2.5.2 for different implementation variants.

A more complete description of the functions, the desired localisation outputs and inputs can be found in chapter 7.1 and D21.2 [17]

For providing the 1D positioning, ASTP is using a reference location. As of now, the reference location is a LRBG (balise principle) but to take full advantage of the Map Data, in the future, any designated point of the track on the map could be used as a reference location if the designated point is shared with all 1D users of ASTP (e. g. onboard users, trackside users).

The ASTP is providing localisation information using its own reference frames. Based on this localisation information and potentially additional dynamic data related to the train operation users can derive their localisation information using their own reference frame. For example, ETCS-OB hosted by the EVC can be in charge to transform this localisation information to the train front end ETCS reference frame.

As a conclusion, the ASTP architecture facilitates opening the space for new sensor technologies to, among other things, resolve the dependency on today's balises that are seen as a "single-technology choice" for reference locations. Despite the tendency of reducing trackside assets such as balises and moving towards enhanced on-board localisation sensor technologies, the performance of the localisation system is seen as a key requirement to improve the capacity and the availability of the line operation, and shall be further improved, i.e., higher accuracy of the estimated position/speed and (more regularly) reducing the confidence interval to a minimum.

4 OPERATIONAL CONTEXT AND USERS' NEEDS

This section aims to describe the operational context and to identify the high-level users' needs.

4.1 LIST OF RAILWAY USERS

The following figure identifies all stakeholders of the railway system.

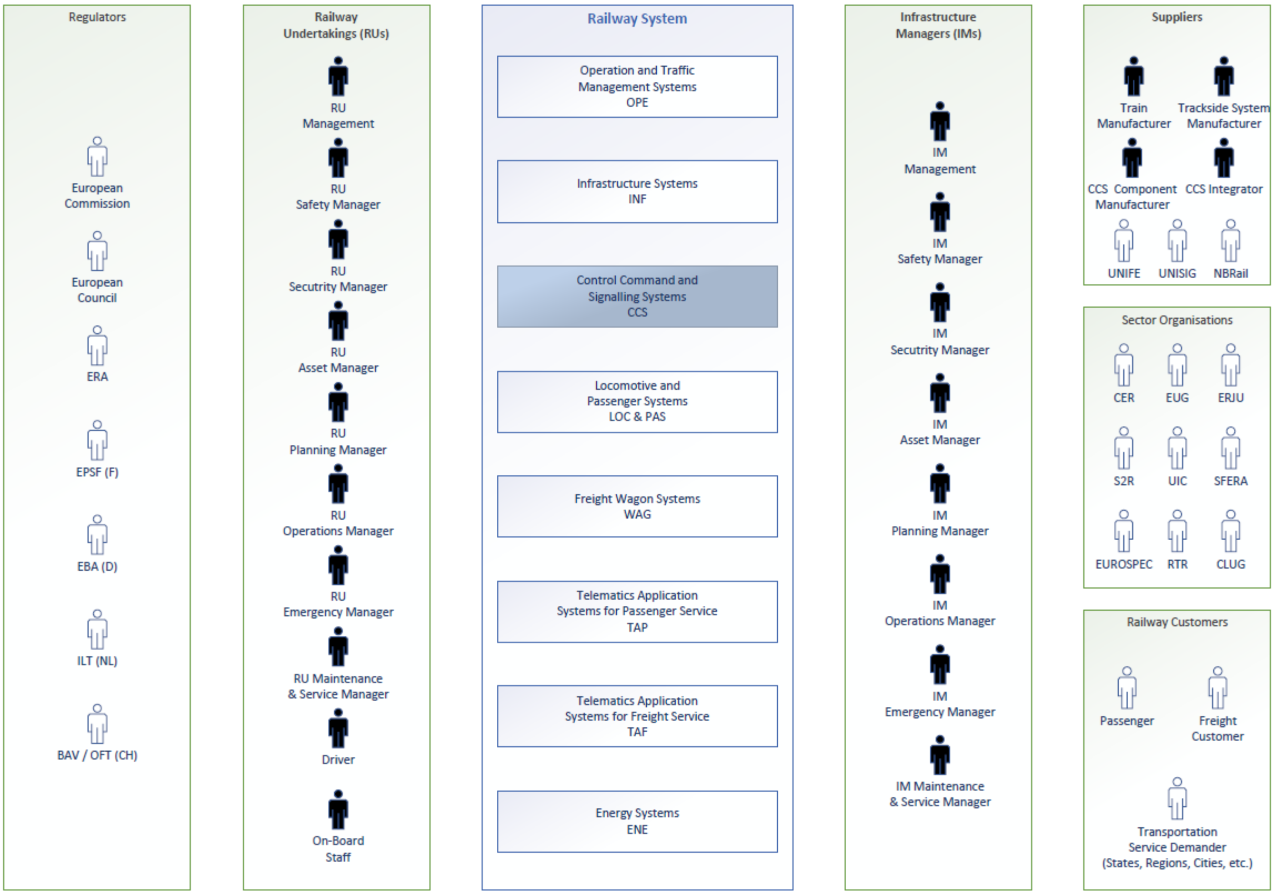


Figure 7: Stakeholders of the railway system

Among all stakeholders of the railway system, the Infrastructure Managers and the Railway Undertakings are the two main users directly involved in the interest of deploying a more efficient ASTP to fulfil much better their operational needs and to reduce the overall costs.

4.1.1 Infrastructure managers

From Figure 7 infrastructure managers are covering different domains. Asset, Operation, Maintenance & Service infrastructure managers are the one interested in a more efficient ASTP to make train traffic management more productive and reliable and to cut down the maintenance costs by a reduction of assets.

4.1.1.1 Train traffic Management and Operation

Infrastructure managers may use data provided by onboard systems to improve:

- Train Traffic Management System with real time and precise train positioning, speed.
- Timetable operation, theoretical performance analysis and operation statistics.
- Passenger info (station, web info) with real time and precise train positioning.
- Incident management by knowing the real time and precise train positioning during an emergency call.

4.1.1.2 Maintenance of the infrastructure

Infrastructure managers may use data provided by onboard systems to improve their predictive and corrective maintenance.

For example, cross-reference data between balise detection, train speed, train position and digital map for several trains may help to spot (non-exhaustive list):

- A balise failure (none of the trains detect the balise).
- A balise weakness (several trains miss the same balise).
- A slip and slide zone.

4.1.1.3 Impact of improved localisation on Infrastructure manager assets

Improved localisation may have a positive impact on Infrastructure manager assets following three possible major improvements:

- Positioning performance with less or no eurobalises leading to the reduction of the eurobalises installed or trackside assets (e.g., track circuit).
- Capacity performance of the line thanks to smaller confidence interval.
- On-board track selectivity determination with the required safety level leading to the reduction of the installed trackside train detectors.

4.1.1.4 Infrastructure Managers High-Level users' needs

The list of High-Level users' needs here-below gathers the needs that are significant for the definition of the ASTP. Depending on specific cases of line operation, configuration, some of them might not be required (e.g., improving the capacity of the line is not required for a regional line).

4.1.1.4.1 IM needs to increase the capacity of line (see [16]).

4.1.1.4.2 IM needs to make the line operation more efficient and reliable by getting train position with better accuracy and reliability (see [16]).

4.1.1.4.3 IM needs to reduce the need for physical repositioning points (see [16]), compared to current ETCS specifications (physical balise).

4.1.1.4.4 IM needs to minimise the need for virtual repositioning points reported into the digital map shared by on-board and trackside.

4.1.1.4.5 IM needs to make more efficient the approach to a point of a line where the permitted speed decreases/increases (shorten the distance between the point the train shall respect the new permitted speed and the physical point the speed reduction/increase applies).

4.1.1.4.6 IM needs to reduce the time to release movable devices (switches, LXs) by minimising the train confidence interval for applications where moveable devices command/release is based on the train position report (on-board centric track vacancy proving).

4.1.1.4.7 IM needs to reduce the time of lowering/raising LXs barriers (reduction of the time the LX barriers are down) minimising the train confidence interval for applications where LXs command is based on the train position report (on-board centric proof of track vacancy).

4.1.1.4.8 IM needs to reduce infrastructure maintenance costs (e.g., by attaching 3D coordinate to the trackside failure detected by the on-board).

4.1.1.4.9 IM needs to have a train localisation system performing in all physical rail environments (urban, rural, tunnel, forest…).

4.1.1.4.10 IM needs to have a train localisation system performing under all types of electrical traction systems used for commercial trains in Europe.

4.1.1.4.11 IM needs to have a train localisation system performing in all types of rail infrastructure (e.g., metallic bridge, concrete bridge, different type of sleepers, different types of points, track on slab, track with ballast…).

4.1.2 Railway Undertakings

From Figure 7 RU managers are covering different domains. Asset, Operation, Maintenance & Service RU managers are the one interested in a more efficient ASTP to make train operation more productive and reliable and to cut down the maintenance costs by making the maintenance and the train fleet update easier by introducing a modularity concept.

4.1.2.1 Train operation

Railway undertakings may use data provided by ASTP to improve:

- Train operation by optimizing train speed and headway.

- Ability to embed automatic driving (GoA2 to GoA4).
- Remote train operation by allowing control of train from a remote driver.
- Energy saving by fine tuning of speed, acceleration, and braking.
- DAS (driver advisory system) by delivering precise information to the driver.
- Passenger info (on-board) by delivering precise information to RU's customers.

4.1.2.2 Train maintenance

Railway undertakings may use data provided by ASTP to improve their predictive and corrective maintenance.

For example, some maintenance functions that could be improved by the ASTP data:

- Failure logger to record train data, CCS-OB technical events with localisation data.
- Maintenance of the ASTP.
- Train preventive maintenance (mileage).

4.1.2.3 Impact of modular localisation subsystem on Railway Undertakings' assets

A modular localisation subsystem is a major improvement to ease maintenance and especially updates and upgrades of the subsystem. Localisation sensors life cycles being shorter than railway life cycles, easing the upgrades and the certification process by embedding a modular architecture or modular logical block is a major improvement for the railway operators.

4.1.2.4 Railway Undertakings high level users' needs

4.1.2.4.1 RU needs to make the train operation more efficient and reliable by getting train position with better accuracy and reliability.

4.1.2.4.1.1 RU needs to make more efficient and safer the approach to an EoA (quicker and allow the train to stop closer to the EoA) even without release speed. Note: In presence of a release speed ETCS train trip functionality is triggered when the ETCS-OB crosses the EOA with its min safe front end in ETCS level 2 or with its min safe antenna in ETCS level 1.

4.1.2.4.1.2 RU needs to limit the use of the release speed while approaching an EoA. Note: not using the release speed, makes the train to stop at the EoA under the supervision of the ETCS.

4.1.2.4.1.3 RU needs to stop train at accurate positions. Note: This will allow for instance ATO-OB to stop the train accurately in station and automatic shunting or joining operation.

4.1.2.4.1.4 RU needs to make more efficient the operation of some train devices (e.g., lowering/raising pantograph, opening/closing traction breaker, airtightness devices…).

4.1.2.4.2 RU needs a localisation system covering all type of trains over Europe:

4.1.2.4.2.1 RU needs a localisation system for train running all over Europe.

4.1.2.4.2.2 RU needs a localisation system for train running from 0 km/h until the maximum speed allowed by train operation (e.g., 500 km/h).

4.1.2.4.2.3 RU needs a localisation system for all types of vehicle and traction systems used for trains in Europe.

4.1.2.4.3 RU needs a localisation system backward compatible with legacy ETCS trackside system.

4.1.2.4.3.1 RU needs a localisation system full compliant with the localisation information required by the SUBSET 026 [2].

4.1.2.4.4 RU needs a localisation system that reduces the maintenance and integration tasks.

4.1.2.4.5 RU needs a localisation system that allows upgradability of the localisation system at lower costs, with minimum effort and no impact on the other CCS-OB equipment. In the case there is no change of the interfaces.

4.1.2.4.6 Environmental conditions, RU's needs

The localisation system shall be fully operational when meeting all the following conditions.

4.1.2.4.6.1 RU needs a localisation system that achieves all requirements (functional and non-functional) when performing under all weather conditions (including severe conditions, temperature, altitude, rain, snow, fog, wind…) which allow train operations in Europe.

4.1.2.4.6.2 RU needs a localisation system that achieves all requirements (functional and non-functional) when performing under all light environmental conditions (e.g., night, darkness, sunlight…).

4.1.2.4.6.3 RU needs a localisation system that achieves all requirements (functional and non-functional) when performing under all physical rail environments such as station areas, urban areas surrounded with high buildings, forests, deep valley, etc.

4.1.2.4.6.4 RU needs a localisation system that achieves all requirements (functional and non-functional) when performing in an on-board vehicle environment whose characteristics (temperature, pressure, EMC, pollutions, pressure, water proofing, vibration and shock, chemical, fire prevention, etc.) shall be considered during the design phase.

4.1.2.4.6.5 RU needs a localisation system that not prevent the correct operation of all other components present inside the vehicle environment.

4.1.2.4.6.6 RU needs a localisation system that achieves all requirements (functional and non-functional) when performing over all types of rail infrastructure such as tunnels, bridges, with or without catenary, concrete track, ballast track, etc.

4.2 List of Train Operational Scenario

4.2.1 Operational scenarios definition and localisation needs.

For deriving functional and non-functional requirements for ASTP, operational settings for track bound railway vehicles are defined. For each setting the impact on the localisation system is described. At this stage only a qualitative assessment is made. Quantitative requirements will be derived in chapter 6 and D21.2 [17].

Setting Description	Speed profile	Remarks	Area affected	Localisation need
Moving (A train is travelling between planned stops.)				
High Speed – High Density Line	Above 0 km/h up to 500 km/h	Minimum Headway Time [1]: Below 120 s	Any	Localisation accuracy +-5m. 1/2CI <=60m
High Speed – Low Density Line	Above 0 km/h up to 500 km/h	Minimum Headway Time[1]: Above 120 s	Any	Localisation accuracy +-5m 1/2CI <=60m
Low Speed – High Density Line	Above 0 km/h up to 160 km/h	Minimum Headway Time[1]: Below 120 s	Any	Localisation accuracy +- 5m 1/2CI <=60m
Low Speed – Low Density Line	Above 0 km/h up to 160 km/h	Minimum Headway Time[1]: Above 120 s	Any	Localisation accuracy +-5m 1/2CI <=60m
Clearing a level crossing	Above 0 km/h up to 160 km/h	Maximum closure time [2] : 150s	Level crossing area	Localisation accuracy +-5m

[1] Minimum time between heads of 2 trains

[2] Time during which the level crossing is closed.

Setting Description	Speed profile	Remarks	Area affected	Localisation need
				1/2CI <=60m
Clearing a standard point area with regard the headway	Any	Maximum release time: 2s	standard point area	Localisation accuracy +-5m 1/2CI <=10m
Clearing a critical point area with regard the headway	Any	Maximum release time: 0.5s	critical point area	Localisation accuracy +-5m 1/2CI <=10m
Stopping (A train is coming to a halt at the EoA, stopping point)				
Stopping at a buffer stop	Speed profile in accordance with the train braking capability to come to a train stop at the buffer.		Track segment before a buffer stop	Localisation accuracy +- 5m 1/2CI <=10m
Stopping at an operational stop	Speed profile in accordance with the train braking capability to come to a train stop at the operational stop.		Predefined stopping point for operation, e.g.: platforms, level crossings	Localisation accuracy +- 5m 1/2CI <=10m
Stopping at a signal	Speed profile in accordance with the train braking capability to come to a train stop at the signal stopping point.		Any point on the line, stopping point not critical for operation	Localisation accuracy +-5m 1/2CI <=10m
Stabled (A train has stopped and is not in operational use)				

Setting Description	Speed profile	Remarks	Area affected	Localisation need
Parked with connection (The train is parked and has a connection to the track side; train sends train position report)	0 km/h		Station, shunting area, depot, siding	Localisation accuracy +- 5m ASTP needs to be active 1/2CI <=10m
Parked without connection (The train is parked and has no connection to the track side)	0 km/h		Station, shunting area, depot, siding	Localisation accuracy +-5m TTD needs to be available 1/2CI <=10m
Shunting (Making and dividing trains, moving vehicles between shunting areas or to stations)				
Passive Shunting Supervised Manoeuvre	0 km/h up to 40 km/h		Areas that are allowed for shunting by national regulations	Localisation accuracy +-5m Change of direction needs to be identified
Coupling and Splitting				
Approach to a vehicle to be coupled (A train unit approaches another train unit to be coupled to form one train, this, if TTD exists, typically involves entering an occupied track)	10km/h down to 0 km/h	Solving overlapping track occupancy is a mission of the APS and out of scope for this document.	Station, shunting area	N/A
Splitting (A train Unit is split into two independent train units)	10km/h down to 0 km/h	Solving overlapping track occupancy is a mission of the APS and out of scope	Station, shunting area	N/A

Setting Description	Speed profile	Remarks	Area affected	Localisation need
		for this document.		
Start of Mission				
Start of mission from power down	0 km/h	Time to mission start 5mn		Time to first valid position from cold start has to be defined
Start of Mission from power up	0 km/h	Time to mission start 1mn		Time to first valid position from warm start has to be defined

Table 2: Train operational scenarios

From Table 2, high level user's train movement scenario can be synthetised:

4.2.1.1.1 Train movements within station area and track sections

- Description
  - Train movements within station area and track sections.
  - Depending on the train type, train configuration, train is running at a speed up to the maximum authorized line speed.
- Expected performance
  - ASTP shall achieve the full performance (e.g., trusted and accurate localisation information). Note: From Table 2, the performance requested on the ½ CI is different if the train is stopping or if the train is running.
- Acceptable degraded operation
  - Move the train under Staff Responsible mode in the case localisation information is not trusted.
- Unacceptable cases
  - ASTP true position is outside the confidence interval.
  - ASTP true speed is outside the confidence interval.
  - ASTP true acceleration is outside the confidence interval.
  - No valid speed.

4.2.1.1.2 Start of Mission:

- Description:
  - Train is prepared to start a mission (move in safety and respecting timetable). To be noticed that Start of Mission can follow powering up the train.
  - Train is at standstill.
- Expected performance
  - Valid and accurate localisation information without the need to move the train.
- Acceptable degraded mode
  - After start of mission is ended without trusted localisation information, train movement can be required to help acquiring a trusted localisation information.
- Unacceptable cases
  - Incapacity to get trusted localisation information in less than 5 minutes whatever after the train movement is standstill or moving.
  - ASTP true position is outside the confidence interval.
  - ASTP true speed is outside the confidence interval.
  - No valid speed.

4.2.1.1.3 Shunting movements and supervised manoeuver

- Description
  - Train is manoeuvred at low speed.
- Expected performance
  - Trusted localisation information under supervised manoeuver.
- Acceptable degraded mode
  - Shunting manoeuvre at low speed (<40km/h).
- Unacceptable cases
  - Incapacity to get trusted localisation information in less than 5 minutes.
  - ASTP true position is outside the confidence interval.
  - ASTP true speed is outside the confidence interval.
  - No valid speed.

4.3 List of ERTMS modes of operation

Since ASTP is part of the ERTMS environment, chapter 4.5.2 of SUBSET-026 [2] figure 1 active functions table defines active functions of the ERTMS depending on modes of operation.

From this table, 5 sets of functions are selected that require localisation information:

- Check data consistency.
- Report train position.
- Monitor speed and distance.
- Protect against undesirable train movements.
- Other functions. For each elementary function part of each set, we determine the ASTP needs in term of external inputs and outputs.

The aim of Table 3 is to identify the ASTP external inputs and outputs focusing on data required by the ETCS.

ETCS On-board-Functions	ASTP focused Assumption	Comment
	Check Data Consistency	
Check linking consistency	Data provided by ASTP: - ASTP reference point position f(LRBG position) - Position confidence interval	Safety related
Check balise detection degradation	Data provided by ASTP: - ASTP reference point position f(LRBG position) - Position confidence interval	Not safety related
Check balise crosstalk while expecting repositioning information	Data provided by ASTP: - ASTP reference point position f(LRBG position) - Position confidence interval	Safety related
	Report Train Position	
Report train position when train reaches standstill	Data needed by ASTP: - LRBG identification Data provided by ASTP: - ASTP reference point position f(LRBG position) - Position confidence interval - ASTP speed	Safety related
Report train position when there is a mode change		
Report train position when train integrity confirmed by driver		
Report train position when loss of train integrity is detected		
Report train position when train front/rear passes an RBC/RBC border (only level 2)		
Report train position when train rear passes a level transition border (from level 2 to 0, NTC, 1)		
Report train position when change of level due to trackside order		
Report train position when change of level due to driver request		

Report train position when establishing a session with RBC Report train position when a data consistency error is detected (only level 2) Report train position as requested by RBC… … or Report train position at every passage of an LRBG compliant balise group		
Monitor speed and distance based on		
MA, release speed, mode profile, non protected LX start location, and route unsuitability location Gradient MRSP Allowed distance to run in Staff Resp. mode Supervised Manoeuvre MA, release speed, non-protected LX start location	Use outputs of determine train speed and position functions.	Safety related
Protect against Undesirable Train Movements		
Roll Away Protection Unauthorised Direction Movement Protection	Use outputs of determine train speed and position functions.	Safety related
Other functions		
Manage RBC/RBC Handover (only level 2) Check of odometer accuracy thresholds Storage of accumulated underestimation / overestimation in measuring the movements over a defined total distance	Use outputs of determine train speed and position functions.	Safety related

Table 3: Exhaustive analysis of ERTMS on-board inputs and outputs needs in the scope of ASTP

4.4 OPERATIONAL NEEDS FROM NEW USERS' APPLICATION

4.4.1 Automatic Train Operation

Automatic Train Operation over ETCS part of ETCS baseline 4 is defined through the system requirements specification subset-125 [6], the ATO-OB/ ATO_TS FFFIS application layer subset 126 [7] and the ATO-OB/ ETCS-OB FFFIS application layer subset 130 [8].The document ERTMS/ATO Operational requirements [21] is issued.

From subset-125 chapter 10.2 ATO-OB/ETCS-OB interface chapter 10.2.5 position data defines requirements. Subset-130 packet 6 ETCS_ATO_Dynamic defines all localisation data requested by the FFFIS application layer subset-126 the ATO-OB (see chapter 6.2.2.2).

In the current architecture the ETCS-OB is in charge of the interface with the ATO-OB. From the ASTP requirements we need to ensure that localisation information provided to the ETCS-OB complies with the ATO-OB needs, in other words, means that by localisation information received from the ASTP, ETCS-OB can provide requested localisation data to the ATO-OB.

Note: in the future architecture, ATO-OB could access localisation information directly from the ASTP.

From performance, the position counter shall be estimated less than 200 ms before the beginning of sending of the corresponding packet.

For position, speed accuracy no specific requirements are defined. In the scope of WP21, results from technical note #6 come to the following ATO needs: position accuracy +-5m,

4.4.2 Automatic Processing Module

The APM component substitutes driver and train attendant responsibilities for reacting in case of incident (e.g., react on incident, monitor alarm signals and derailment, change running direction, manage supervision status, monitor weather conditions). It is partly based on the analysis of the train surrounding by a perception system. This type of perception system requires new specific data that needs to be provided by the ASTP such as:

- The absolute (3D) geographic positioning (Long, Lat, Alt).
- The vector velocity within the 3D coordinate system based on the track axis.
- The vector acceleration within the 3D coordinate system based on the track axis.
- The attitude (roll, pitch, and yaw angles) and attitude rates of the vehicle where ASTP sensors are installed.

4.4.3 Futur Railway Mobile Communication System

The FRMCS system provides communication services in the railway system. It provides services for voice communication but also for video and data. It provides also complementary services like location service for onboard users. The location data handled by the FRMCS can be determined by the FRMCS or external sources. In this context an interface between the ASTP and the FRMCS is foreseen to provide precise localisation data.

4.4.4 Other users

The table in Appendix B is defining a first list of possible on-board users of data provided by the ASTP. For each user the table identifies possible needs of data from the ASTP. When the overall CCS-OB architecture will be finalised, this table will be accordingly updated.

5 ASTP BOUNDARIES ASSUMPTIONS AND CONSTRAINTS

ASTP is part of the CCS-OB and will interact with ETCS-OB and several other constituents that can provide data or consume ASTP data.

The aim of this chapter is to define the scope to be considered by the ASTP and to present a migration strategy approach.

5.1 SYSTEM UNDER CONSIDERATION AND ASTP BOUNDARIES

5.1.1 System under consideration

The ASTP is a constituent of the CCS-OB system. It shares information from other on-board constituents and provides to users localisation information.

The ASTP is a safe (up to SIL4 depending on the function / data provided) CCS-OB logical component that uses its own localisation sensor data and additional supporting information (e.g., information provided by other constituents such the Digital Register) to provide ASTP location output information safely and reliably. The ASTP based on absolute positioning should be able to provide the relative and absolute position of the ASTP reference point, as well as kinematic parameters such as speed, acceleration or attitude of the vehicle, angular rate.

The ASTP sensors to provide localisation data are for example of the following (non-exhaustive) types: GNSS receiver, inertial sensors, rotational sensors, radar-based sensors, optical sensor…

In the scope of the present document, ASTP is considered as a logical component with identified interfaces. The ASTP can be hosted on a dedicated hardware platform or hosted on a common platform that can host several other functionalities.

This document and D21.2 [17] are considering the ASTP as a black box, defining the input and output information of the ASTP. Definition of the internal functions, the internal architecture and the technological, sensors choices are not part of WP21 scope.

The architecture assumptions are based on the legacy ETCS architecture but when necessary OCORA [14] results are taken into account.

5.1.2 ASTP boundaries

5.1.2.1 ASTP in the CCS-OB architecture

The determination of localisation information following SUBSET-026 [2], chapter 3 principle (1D relative train front end position, speed, acceleration), are the results of ASTP and ETCS on-board system. The role of the ASTP by providing absolute and relative safe positioning in the overall CCS-OB architecture shall be considered. Shall the ASTP provide 1D and 3D localisation information to all on-board users? Or should the ASTP is limited to provide only 3D localisation information to users, the ETCS determines the 1D localisation information based on ASTP data and then provides 1D localisation information to on-board users?

The following part of this chapter, answering to the question, presents two possible functional architectures between these two components of the CCS-OB.

To determine the 1D localisation information, the CCS-OB components shall assign a co-ordinate system in accordance with principles describes in chapter 3 figure 2b of SUBSET-026 [2].

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

1. Function 1: Determination of the train front end. The train front end shall be considered as the side of the train where the cab is active. The determination of the active cab shall follow the chapter 3.6.1.5 of SUBSET-026 [2].
2. Function 2: Determination of the reference location (e.g., LRBG). This function provides the reference location identifier to be used. It is based on balise co-ordinate principle defined in chapter 3.4.2 of SUBSET-026 [2]. It is noted that the reference location is oriented.
3. Function 3: Determination of the relative distance from the reference location (e.g., LRBG). This function determines the position of the train front end with regard the side of the reference location, the train orientation and the direction running based on information provided by function 1 and function 2. The function determines the distance travelled and its confidence interval based on ASTP localisation data.

To allocate these functions two type of architectures are presented:

1. ETCS oriented architecture: Based on ASTP localisation information determined by using the reference frame of the ASTP and the reference location, function 1, 2 and 3 are allocated to the ETCS on-board system to provide data in accordance with the ETCS co-ordinate system. In this case, the 3D localisation information is using the reference frame of the ASTP, the ASTP is providing localisation information using its own reference frames (1D, 3D…). The ETCS has to forward the 1D localisation information to users. From system point of view users have two providers of localisation information depending on its type 1D train front end or ASTP localisation information.
   The following Figure 8 depicts the architecture and the function allocation.

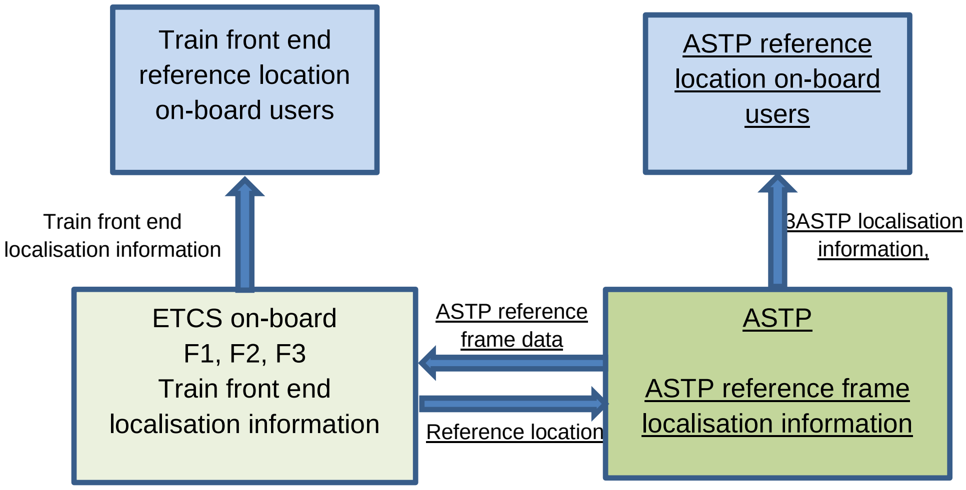


Figure 8: ETCS oriented architecture, function allocation

2. ASTP oriented system architecture: In this architecture functions 1 and 2 are allocated to the ETCS-OB system. The ETCS will provide to the ASTP the side of the train to be taken into account as the train front end and the reference location to be used. Function 3 is allocated to the ASTP. Based on static or dynamic configuration data (orientation of the ASTP in the train, distance between ASTP sensors and train front end) and data received from the ETCS (reference location, train front end side), the ASTP can determine all localisation information and be considered the provider to all on-board users of the 1D train front end reference frame and ASTP localisation information using ASTP reference frames. On-board users have only one provider of localisation information.
   The following Figure 9 depicts the architecture and the function allocation.

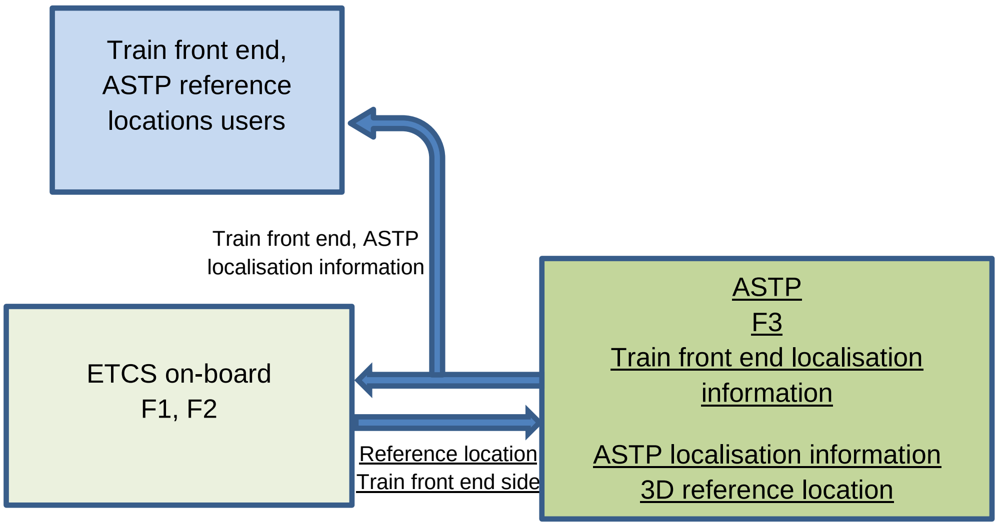


Figure 9: ASTP oriented system architecture, function allocation

In the following parts of this document and deliverable [17] we have considered that the ASTP shall provide only localisation information using its own reference frames. Based on this localisation information and additional data, users can derive its own localisation information. In particular the ETCS-OB can derive the 1D localisation information in accordance with principles of subset-026 [2].

Thus, the ETCS oriented system architecture is selected.

For more information see Appendix D: Technical note #1.

5.1.2.2 Functions not part of the ASTP

Among CCS-OB constituents some functions, some logical functional blocks, some devices could be part of the ASTP. The following assumptions are made on the ASTP boundaries and define functions that are not considered as part of the ASTP:

a) Generation and transmission of the Train Position Report (chapter 3.6.5.1.4 of SUBSET-026 [2],).
b) Determination of the train rear end position (chapter 3.6.4.4.1, 3.6.5.2 of SUBSET-026 [2]).
c) Determination of the train front end (chapter 3.6.1.5 of SUBSET-026 [2]).
d) Determination of the train length (chapter 3.6.5.2 of SUBSET-026 [2]).
e) Determination of the train integrity status (TIMS-status).
f) Detection of cold movement (CMD).
g) Determination of standstill (chapter 3.14.4 of SUBSET-026 [2]).
h) Determination of track occupancy.
i) Determination of the LRBG.
j) Detection and transmission of Eurobalise telegram for the virtual balises.
k) Physical balises reader and forwarding Eurobalise telegram (ETCS-OB/BTM).
l) Management of the Map Data between the trackside and the on-board (On-board Digital Register management and functions see document [18]).

When required, data provided by those external functions or devices are considered as ASTP inputs.

The acquisition of those data will be defined as ASTP input functions.

For more information see Appendix E: Technical note #2.

5.1.3 Supporting information

The ASTP can use the following supporting information to process the output information and make it more reliable and more accurate.

A synthesis of the supporting information is shown in the following Figure 10.

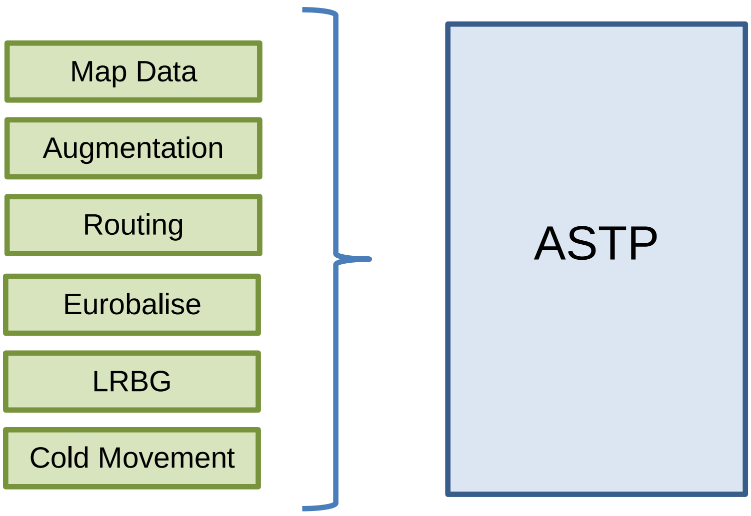


Figure 10: ASTP supporting information

From Figure 10, the following chapters describe the supporting information. They are not mandatory to be used. The use of some of them depends on the ASTP configuration on-board or supplier solution (e.g., augmentation). Depending on technological solution other supporting information can be required. In this case, providing this additional supporting information needs to be agreed. WP22 shall determine which ones are mandatories to achieve the performance.

5.1.3.1 Map Data

Map Data describes the track and trackside infrastructure information. This information provides absolute information of track layout and topological information of the track network. This valuable information can be seen as a sensor and used in the fusion logic to determine the absolute or relative position of the ASTP reference point on the track network.

Track and trackside infrastructure information are provided in the form of structured Map Data.

The ASTP has an interface with the Digital Register on-board to get the Map Data.

Digital register is also in charge to manage the Map Data (versioning, validating) and to download Map Data from the Digital Register trackside.

Map Data definition, life cycle of the Map Data such as generation, validation, compiling of Map Data, Digital Register principles, functionalities and overall architecture are defined in D27.1[18].

The ASTP shall receive Map Data under WGS84 coordinate system.

5.1.3.2 Augmentation data

Augmentation data is providing information such as GNSS augmentation (e.g., EGNOS) that can be regarded by the sensors and/or fusion logic to improve the overall performance. Augmentation data leads to more accurate localisation information (along-track position, along-track speed) and faster estimation of accurate localisation after start-up of the ASTP in operation. It provides integrity on the position information. It enhances localisation information to support functionalities such as track selectivity.

The augmentation data is provided through the Signal in Space (SiS) or by the trackside augmentation system to the ASTP.

Note: In some scenarios, as dense urban areas, the Signal in Space might be unavailable. and the trackside augmentation would be the appropriate configuration (to be managed at ASTP level). Nonetheless for some specific applications like regional line, or for track not equipped with trackside augmentation infrastructure, the SiS based solution could be prioritised.

5.1.3.3 Routing information

An interlock list of point status according to the (safe) train path uniquely assigned to a train/vehicle and mapped against the Map data commonly shared by onboard and trackside. This information is seen useful to validate the determined position by the ASTP against track selectivity, e.g., at start-up after vehicle has moved during power-off mode (degraded mode). It might also be used to determine track selectivity, e.g., if the vehicle position is known prior to passing a switch point and to decide whether it turned left or right.

For more information about the decision to use point status see Appendix F: Technical note #4.

5.1.3.4 Eurobalise telegram

Eurobalise telegram information (e.g., balise header see chapter 8.4.2.1 of SUBSET-026 [2]) is needed to consider passed balises in the fusion logic of the absolute position determination along with respective map data (by retrieving geo-coordinates of the Track Edge Point representing the balise passed).

The Eurobalise telegram information is provided without any filter (e.g., when linking information is used and stored on-board, and the balise is not included in the linking information) from the ETCS. In the case the balise is affected by a virtual balise cover the Eurobalise telegram information shall not be provided.

Note: To process the Eurobalise data, the ASTP needs the identification of the Eurobalise antenna (the one that received the Eurobalise telegram) and its position from the ASTP reference point.

5.1.3.5 Last relevant reference location

Last reference location identifier in the representation of an LRBG or a virtual reference location embedded in the map data is needed to refer a determined position by ASTP to the reference location (LRBG or Virtual reference location) and estimated distance (e.g., used for ASTP_SF-001: Provide Safe ASTP 1D Position chapter 7.1.2).

The last relevant reference location (e.g., LRBG or virtual reference location) is provided by the on-board automatic train protection (ETCS_OB).

5.1.3.6 Cold movement status

Information about whether an engine/train has moved or not during ETCS' "no power"-mode to consider the information as part of the initialisation of the localisation system. Sometimes, slight movements can occur, for example during coupling. The train is considered as moved if the movement makes a displacement of more than 2m.

The cold movement status is provided by the cold movement detector.

5.2 ASTP OPERATION REQUIREMENTS AND CONSTRAINTS

5.2.1 Operation requirements

The following assumptions are derived from the operational needs.

5.2.1.1.1 ASTP shall achieve all requirements (functional and non-functional) while a train is running all over Europe.

5.2.1.1.2 ASTP shall achieve a minimum start-up time compatible with operational requirements (time to move the train after the cab is active).

5.2.1.1.3 ASTP shall allow ETCS to start in supervised mode (e.g. Full supervision) in the case trusted ASTP position is provided by the ASTP before ETCS SoM ended and any train movement started.

5.2.1.1.4 ASTP shall allow the reduction of distances run in unsupervised mode, without the need for ETCS physical balises, after ETCS SoM without valid position.

5.2.1.1.5 ASTP shall provide ASTP speed and distance run after ETCS SoM.

5.2.1.1.6 ASTP shall be considered in failure mode if the ASTP cannot provide the speed or the distance run.
Note: ASTP speed is mandatory to move the train.

5.2.1.1.7 ASTP shall ensure the fulfilment of functional and non-functional requirements without the need for human intervention (unless for maintenance purposes).

5.2.1.1.8 ASTP shall be operational in NTC, ETCS Level 1, ETCS Level 2 and ETCS Hybrid Level 2. Full performance shall be achieved in ETCS Level 2 and ETCS Hybrid Level 2.

5.2.2 Operation constraints

The following constraints are derived from the operational needs.

5.2.2.1.1 ASTP shall allow an improvement in terms of RAM and LCC compared to the legacy on-board odometry solutions used in the ETCS domain and considering the possible differences in terms of life duration.

5.2.2.1.2 ASTP shall serve the safety integrity needs of the ETCS users (e.g. ETCS-OB, ATO-OB, TMS, maintenance and diagnostic, asset management, passenger info, etc.).

5.2.2.1.3 ASTP shall enable the introduction of future technological solutions (sensors, algorithms, computing platforms) without affecting the safety case of any vital constituents of the ASTP users.

5.2.2.1.4 ASTP shall contribute to the improvement of the capacity of the railway line.

5.2.3 ASTP mechanical constraints and positioning on trains, design constraints and specific configuration parameters

5.2.3.1.1 Being a generic application, ASTP will be deployed in several type of trains, locomotives.
Note: ASTP may not be a monolithic module, embedding several types off sensors in different locations in the train. For example, GNSS antenna and BTM antenna are not installed at the same location and the distances between those items and the ASTP reference point are different.

5.2.3.1.2 ASTP can be installed on any wagon of the train.

5.2.3.1.3 ASTP will need a specific set of static train data (Configuration Data as position of sensors in the vehicle, position of eurobalise antennae)

5.2.3.1.4 ASTP design needs to ease installation on new trains and in refurbished trains.

5.2.3.1.5 ASTP shall be designed to allow upgradability with minimum effort and no impact on the other CCS-OB equipment (functional and non-functional requirements). In the case there is no change of the interfaces. The main goal is to make future evolution easily.

5.2.3.1.6 ASTP could be scalable if reduced costs can be expected when lower performance is required.

5.2.3.1.7 Maintenance optimization shall also be considered minimizing calibration operations in case of a component replacement.

5.2.4 ASTP interfaces

In today's ETCS implementations, the odometry functionality is part of the monolithic ETCS On-Board Unit.

5.2.4.1.1 Since innovation cycles for the ASTP (not necessarily related to hardware upgrades) are expected to occur more frequently than for the remaining part of the ETCS On-Board Unit (e.g., ETCS-OB), it is essential that the ASTP is a separate logical component, containing just the functionality needed to locate safely and reliably the train and its orientation on the track and determining associated kinematic parameters of the vehicle.

5.2.4.1.2 With a separation between ETCS-OB and ASTP functionality, guiding principles such as modularity and single responsibility are fulfilled leading to reduced complexity in terms of testing and certification of conformity.

5.2.4.1.3 Standardising the external interfaces of ASTP allows to leverage new localisation technologies in the future without the need to modify the remaining part of the ETCS On-Board functionality.

With standardised ASTP interfaces in place (e.g., that cover performance, technical interface conformity and the allocated tolerable hazard rate), any change to the internal ASTP not impacting the interface would not trigger a re-certification (homologation) of the entire ETCS On-Board Unit.
The list here-below provides some changes that should be taken into consideration:

a) adding new types or generations of sensors (e.g., from a simple GPS to a multi-frequency multi-constellation GNSS receiver).

b) improving fusion algorithms output quality (e.g., higher accuracy).

c) considering additional standardised data sources in the fusion algorithms (e.g., train routing information, augmentation information delivered through terrestrial dissemination).

5.2.4.1.4 Sharing localisation information not only with ETCS-OB (logical component of CCS-OB) but also with other on-board actors through a standardised interface is a key requirement.

5.2.4.1.5 The ASTP architecture shall facilitate the use of new sensor technologies that could provide an accurate position, providing more possibilities compared to today's scenario where only physical balises are taken as reference locations to determine the actual position.

5.2.4.1.6 As of now, the reference location is a LRBG but to take full advantage of the Digital Map, in the future, any designated point of the track on the map could be used as a virtual reference location.

5.2.4.1.7 The ASTP architecture intends to break the strong coupling of the on-board ETCS logic and balise technology (LRBG) to allow vendors to produce industry-independent localisation products by adhering to the standardised interfaces.

5.2.4.1.8 The ASTP at the logical block view can be seen as a black box with the following already interfaces:

5.2.4.1.8.1 Providing output localisation data (localisation information, kinematic data) using ASTP reference frames to any users. Here-below some potential users of on-board subsystems that can use ASTP localisation information

1. ERTMS applications (ETCS-OB)
2. JRU
3. TCMS (panto, doors…)
4. TIU
5. ATO-OB
6. APM
7. DAS-OB
8. SCV (signal converter)
9. NTP
10. TDS
11. Virtual Train Coupling System
12. Detection of virtual balise and telegram generator
13. Passenger information system
14. Online monitoring system
15. Digital Register
16. FRMCS

Note: The Appendix B is providing a first function allocation by user.

5.2.4.1.8.2 Acquiring supporting information such as:

1. Map Data from the Digital Register on-board
2. Augmentation data from trackside augmentation data
3. Routing information from ETCS
4. Static train configuration data (optional)
5. Eurobalise telegram from the ETCS-OB/BTM
6. Last relevant reference location (LRBG or Virtual reference location) from the ETCS-OB
7. Cold movement status from cold movement detector

5.2.4.1.8.3 Exchanging data with technical supporting functions such as:

1. Time to/from control time.
2. Authentication to/from Control cybersecurity access.
3. Maintenance data to/from Online Monitoring system.

5.2.4.1.9 It is assumed that static configuration data are stored in the ASTP. It is noted that in the OCORA architecture (see document [14]) a dedicated logical block Configuration Data Storage is defined to store all static data required by the CCS-OB.

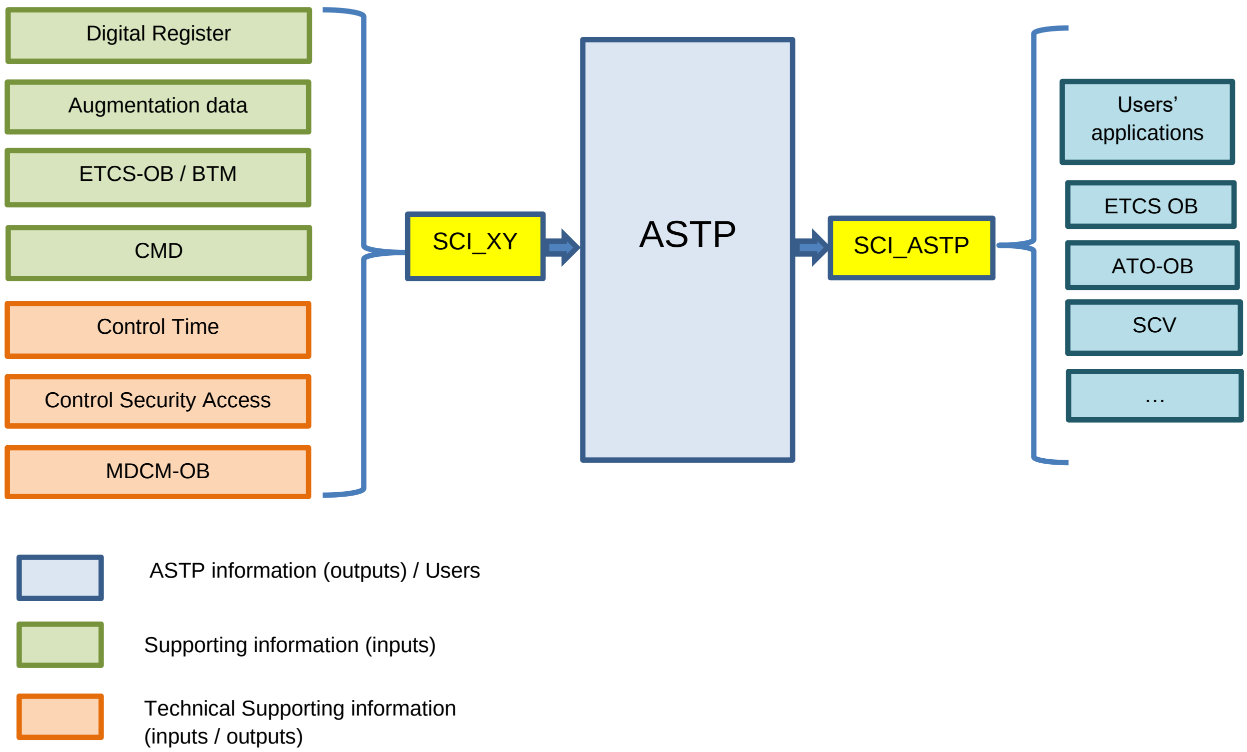


Figure 11: ASTP input and output standardised common interfaces

5.2.4.1.10 To achieve the modularity and exchangeability goals the interfaces shall be standardised. The technical specifications of the interfaces are not part of this document and D21.2 [17].

5.2.4.1.11 This document and D21.2 [17][17] address the functional specification of the interfaces mainly by identifying the data exchanges between the ASTP and the CCS-OB constituents that provide information to the ASTP and CCS-OB users' application. For the trackside users' applications, it is assumed that at least one on-board user's application is providing the interface.

5.2.4.1.12 The following figure identifies the input interfaces between logical blocks, devices and ASTP to acquire supporting information, and the output interface to provide information to the users' application.

5.2.5 ASTP variants and migration constraints

5.2.5.1 Impact of non-available ASTP supporting information

In this section, the impact of supporting information considered not mandatory for the ASTP system are briefly analysed and discussed. Despite declaring some components as "not mandatory" hereafter, ASTP shall achieve a considerable performance increase compared to today's specification in SUBSET-026 [2] and SUBSET-041 [4].

From the list of supporting information defined in chapter 5.2.4.1.8.2 in order to provide flexibility during the migration phases, the following supporting information is considered not mandatory:

1. Map Data from the Digital Register on-board
2. Augmentation data from trackside augmentation data
3. Routing information from ETCS

The availability of this supporting information can depend on the migration strategy put in place to introduce the ASTP in project deployment.

5.2.5.2 Migration constraints

As presented in chapter 5.2.5.1 the availability or unavailability of variants may impact the performance of the ASTP as specified in this document and D21.2 [17]. In some migration scenarios, an existing line may be operated with trains equipped with legacy odometry systems and trains equipped with the ASTP system. In this context a first step in the development of the ASTP shall achieve at the minimum the following goals:

5.2.5.2.1 The table is to be read as follows: What is the impact/limitation on the ASTP system with or without “xyz” (e.g., Digital Map registe on-board) information available.

Component / Function	With	Without
Digital Map Register On-Board	Digital maps together with Routing Information can be used as supporting information by the sensor fusion logic of the ASTP to reduce positioning errors arising in GNSS/INS sensors (e.g., due to the gradient and curve of the tracks) and in general to improve the ASTP positioning performance when using GNSS/INS sensors. In addition, digital maps are considered as critical inputs needed by ASTP for safe absolute train positioning.	Reference locations used for safe absolute train positioning are limited to physically installed objects detected by the train such as balises in the track bed. Solutions depending on absolute GNSS positions and/or track geometry signatures are not feasible for safe train front end 1D position as required by ETCS. Especially, the usage of 3D information in the sensor fusion logic to map match GNSS and balises to reference locations on track edges is not feasible.
Route control	The point status of the train path uniquely assigned to a train/vehicle. This information is seen useful to determine the train path ahead and to validate the determined position by the ASTP against track selectivity. It might also be used to determine track selectivity, e.g., if the	Track determination in some cases cannot be solved and would require installing physical balises.

	vehicle position is known prior to passing a switch point and to decide whether it turned left or right.	
Augmentation (AUG) data from trackside	An ASTP that uses GNSS sensors for safe absolute train positioning needs GNSS augmentation data (e.g., EGNOS) in order to meet the positioning accuracy and the safety logic. Further details on rationale see chapter 7.1.13 ASTP_SF-103: Acquire Augmentation	Both safety and positioning performance of the safe absolute train positioning output of ASTP, making use of GNSS sensors, will be adversely impacted if no GNSS augmentation (e.g., EGNOS) service is available/used.

Table 4: Impact of non-available ASTP supporting information

5.2.5.2.2 ASTP shall be developed as an on-board independent component from the core ETCS system. It is essential that the ASTP is a separate logical component, containing just the functionality needed to locate safely and reliably the train and its orientation on the track and determining associated kinematic parameters of the vehicle.

5.2.5.2.3 ASTP shall implement and fulfil requirements of the standardised interfaces as defined in this document and [14]. Standardised input interfaces need to be implemented by ASTP only if needed by the internal ASTP logic, e.g., Augmentation might or might not be relevant depending on the sensor mix used.

5.2.5.2.4 Software updates shall be the first choice to ease the update of the ASTP during migration phases.

5.2.5.2.5 ASTP shall ensure backward compatibility. The aim is to operate the line with trains using legacy odometry systems and ASTP systems without changing physical locations of installed balises nor to introduce exportation constraints, limitations to the legacy ETCS trackside system.

5.2.5.2.6 ASTP shall meet improved odometry performance. The performance as specified today in SUBSET-026 [2] and SUBSET-041 [4] shall be achieved with an improvement of the odometry accuracy from 5% to 2% of the distance run (see chapter 5.3.1.1 of SUBSET-041 [4]). To be noticed that 2% is defined in X2R5-D5.5 D5.5 Roadmap and migration strategy from X2R5 [19].

5.2.5.2.7 ASTP shall ensure operation according to the implementation variants in chapter 5.2.5.1. Impacts and limitations of each variant need to be carefully analysed to choose the best solution for the given use cases of the IM and/or RU.

5.2.5.3 Migration strategy

The migration strategy and the definition of the various steps may depend on the IM and/or RU. Once the last step of the migration strategy is deployed, the ASTP shall achieve all performance as specified in this document and D21.2 [17][17].

As an example, the integration of the ASTP as defined in this document and D21.2 [17], could foresee a two-step approach to the final target.

1. The first step could be the achievement of the modularity goals (constraints 1 and 2) and a first enhancement of the accuracy and the confidence interval with respect the train position and the speed (constraint 4). If the ASTP could achieve this performance (constraint 4) without track side support (constraints 3 and 5), then the system would already be improved.
2. The second step would consider that track side is providing all foreseen supporting information and the on board is fitted with the ASTP system allowing full integration and full performance.

This two-step approach allows in a migration definition to equip first all on board units of the line with the ASTP system and already take benefits from it. And on a second step to obtain full integration and full performance and eventually trackside asset reduction.

A migration definition with first deployment on the trackside of the supporting information and then retrofitting of the train fleet with the ASTP could also be envisaged. Nevertheless, in this case, during the first step we cannot take advantage of the first performance improvement.

The following migration matrix (Figure 12) represents all possible case scenarios and performance achievement for a migration strategy.

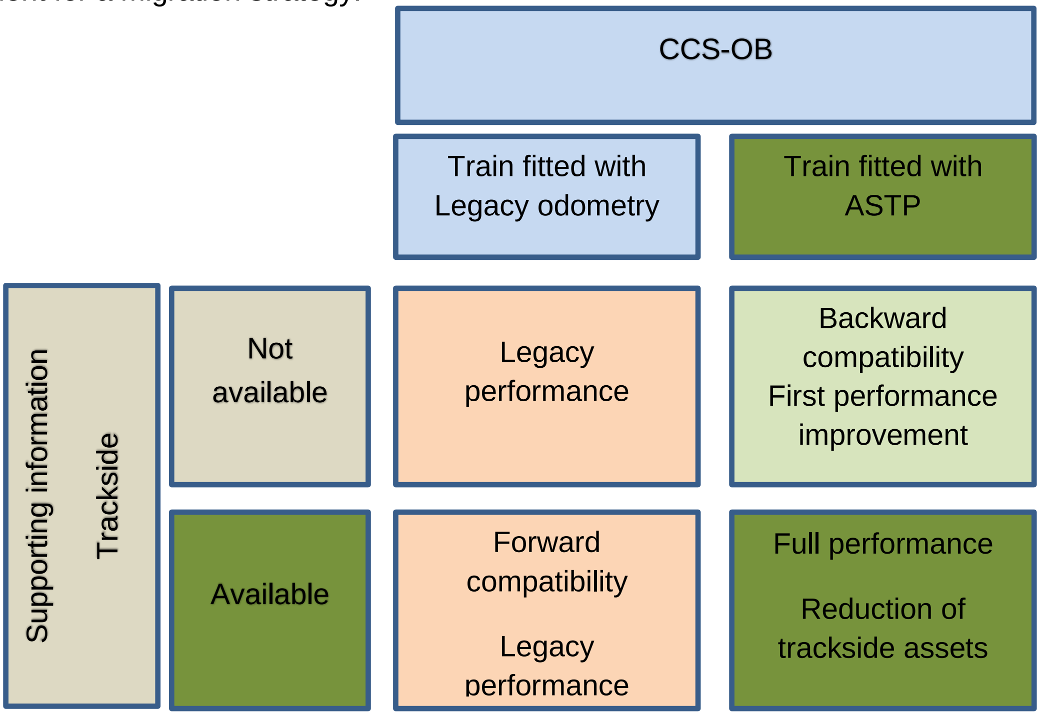


Figure 12: Migration matrix

6 ACCURACY, PERFORMANCE AND CAPACITY

6.1 INTRODUCTION

The confidence interval and the accuracy for position, speed and acceleration influence the operational performance of a line in term of capacity, travel time or capability to stop within an acceptable operational interval. The confidence interval and the accuracy can be used in three user's contexts.

1. **Assessment of the capacity of the line:**
   The maximum theoretical confidence interval and the accuracy models for position and speed define a set of operational limits that are used as parameters to offline assess the capacity of the line, to build the train timetable. This set of limits defines the values that the system shall not exceed to achieve the defined performance.
2. **Safe train operation in accordance with driving rules:**
   The real time values of the confidence interval and the accuracy for position, speed and acceleration are used by the ETCS to supervise the movement of the train and to react accordingly. The confidence interval and the accuracy values allow the driver or the ATO-OB to drive safely the train in accordance with operational rules. The ETCS allows to stop the train at a sight distance to the signal, to stop the train at the stopping point with accuracy. The confidence interval and the accuracy have also an influence on specific movements to be performed in accordance with operational regulations (e.g., splitting/ coupling train, shunting in area, park train…). The confidence interval and the accuracy values for position are also used by the trackside system to determine the track occupancy, to grant the movement authority domain to the ETCS-OB. When the real time values of the confidence interval exceed the set of limits used to assess the capacity of the line, the travel time or the stopping accuracy can be impacted.
3. **Management of track conditions:**
   The real time values of the train position confidence interval and the accuracy allows to inform the driver and/or the train of a condition in front of the train. Depending on the type of the track conditions, the confidence interval and the accuracy for position can have an impact on the travel time (e.g., to open/close a main power switch, to lower/raise a pantograph…)

As the ASTP is assumed to have more degrees of freedom in terms of used inputs and provided outputs, the current terminology of the ERTMS localisation is updated with some new terms. The chapters 6.2.1 to 6.2.4 provide complementary definitions of the ETCS Location Principles, Train Position (chapter 3 of SUBSET-026 [2]) to clarify the user's contexts of the confidence interval and the associated values.

Definitions provided in chapter 6.2.1 to 6.2.4 make a clear separation between the performance values and the real time values of the confidence interval.

6.2.1 Position

The accuracy of the estimated ASTP reference point position is the difference between the estimated ASTP position and the ASTP true position along the track axis.

The quality of the estimated ASTP position accuracy shall be defined with a probability level.

The Max Accepted Position Underestimation (MAPU) is a limit to the underestimation (SUBSET-026 [2], L_DOUBTUNDER) of the estimated ASTP position along the track axis before it has an impact on operation.

If the underestimation of the estimated distance exceeds the MAPU, then the positioning function availability figure as defined in section 7.3.2. is impacted. In other words, the difference between the max safe ASTP and the estimated ASTP position is greater than the MAPU.

Rationale: If the underestimation of the estimated distance exceeds the MAPU, then the operational performance may be impacted (e.g., large underestimated distance will have an impact on permitted speed of the train), leading to a reduction of the capacity of the line. Therefore, when the underestimation of the confidence interval exceeds the MAPU, this loss of performance due to the positioning function is counted in the ASTP unavailability figure (see chapter 8.2).

If the underestimation of the estimated distance exceeds the MAPU, then the safety of the ASTP position outputs is not affected.

As it cannot be assumed that the MAPU is never exceeded, there will be an availability requirement, i.e., the amount of time the MAPU may be exceeded within a specific time interval.

The Max Accepted Position Overestimation (MAPO) is a limit to the overestimation (SUBSET-026 [2], L_DOUBTOVER) of the estimated ASTP position before it has an impact on operation.

If the overestimation of the estimated distance exceeds the MAPO, then the positioning function availability figure as defined in section 7.3.2. is impacted. In other words, the difference between the estimated ASTP position and the min safe ASTP is greater than the MAPO.

Rationale: If the overestimation of the estimated distance exceeds the MAPO, then the operational performance may be impacted (e.g., large overestimated distance will have an impact on the permitted speed of the following train, on the clearance of a switch area), leading to a reduction of the capacity of the line. Therefore, when the overestimation of the confidence interval exceeds the MAPO loss of performance due to the positioning function is counted in the ASTP unavailability figure (see chapter 8.2).

If the overestimation of the estimated distance exceeds the MAPO, then the safety of the ASTP position outputs is not affected.

As it cannot be assumed that the MAPO is never exceeded, there will be an availability requirement, i.e., the amount of time the MAPO may be exceeded within a specific time interval.

The Max Accepted Position Confidence Interval (MAPCI) is the sum of the MAPU and MAPO. It is only used for explanations and clarifications, to get a better understanding about the position inaccuracy. It is not used for specifying a requirement.

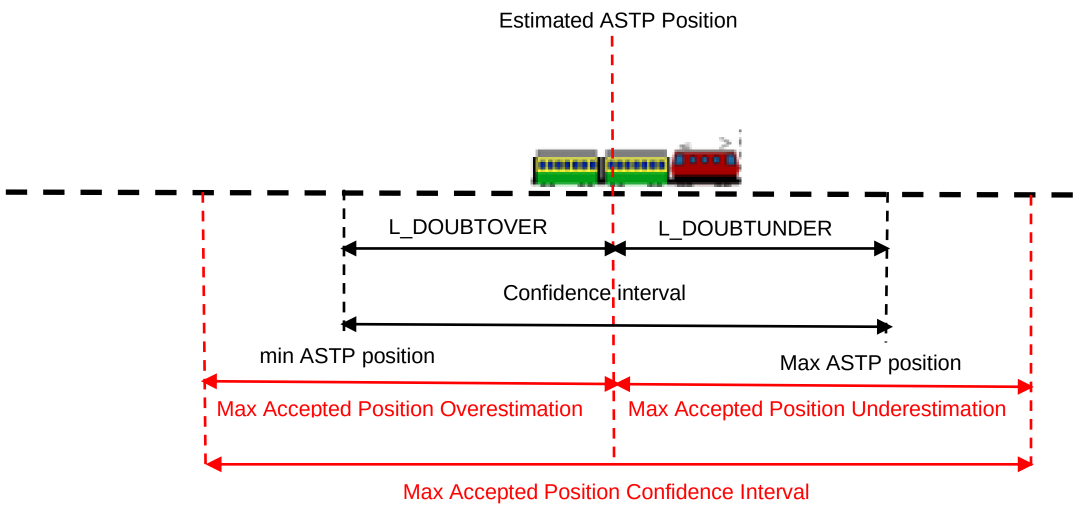


Figure 13: Visualisation of newly introduced terms, considering ASTP reference point position.

The black terms describe estimated values by the ASTP [2]. The red values describe the required performance values (new introduced terms).

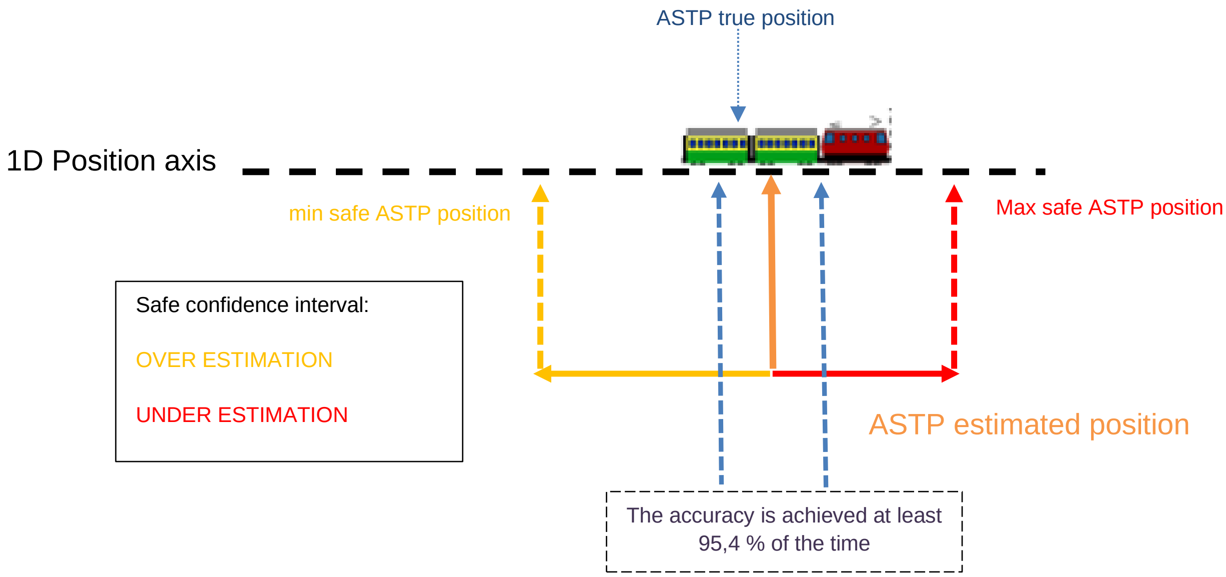


Figure 14: Illustration of the 1D position dataset toward ASTP reference point.

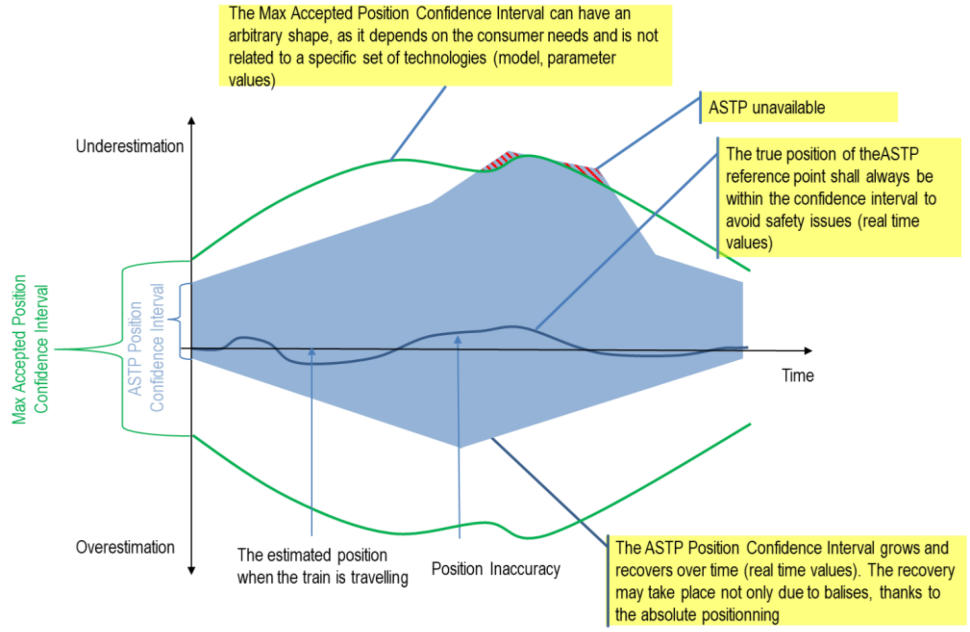


Figure 15: Visualisation of the MAPCI, CI, Unavailability.

6.2.2 Speed

The accuracy of the estimated ASTP speed is the difference between the estimated ASTP speed and the ASTP true speed.

The quality of the estimated ASTP speed accuracy shall be defined with a probability level.

The Max Accepted Speed Underestimation (MASU) is a limit to the underestimation of the estimated ASTP speed before it has an impact on operation.

If the underestimation of the estimated ASTP speed exceeds the MASU, then the speed function availability figure as defined in section 7.3.2. is impacted. In other words, the difference between the maximum safe speed and the estimated train speed is greater than the MASU.

Rationale: If the underestimation of the estimated train speed exceeds the MASU, then the operational performance may be impacted (e.g., large underestimated train speed will have an impact on the speed profile of the train), leading to a reduction of the capacity of the line. Therefore, when the underestimation of the confidence interval exceeds the MASU, this loss of performance due to the speed function is counted in the ASTP unavailability figure (see chapter 8.2).

If the underestimation of the estimated ASTP speed exceeds the MASU, then the safety of the ASTP relevant speeds output is not affected.

As it cannot be assumed that the MASU is never exceeded, there will be an availability requirement, i.e., the amount of time the MASU may be exceeded within a specific time interval.

The Max Accepted Speed Overestimation (MASO) is a limit to the overestimation of the estimated train speed before it has an impact on operation.

If the overestimation of the estimated ASTP speed exceeds the MASO, then the speed function availability figure as defined in section 7.3.2. is impacted. In other words, the difference between the estimated train speed and the minimum safe speed is greater than the MASO.

Rationale: If the overestimation of the estimated train speed exceeds the MASO, then the operational performance may be impacted (e.g., large overestimated train speed will have an impact on the speed profile of the train), leading to a reduction of the capacity of the line. Therefore, when the overestimation of the confidence interval exceeds the MASO, this loss of performance due to the speed function is counted in the ASTP unavailability figure (see chapter 8.2).

If the overestimation of the estimated ASTP speed exceeds the MASO, then the safety of the ASTP output is not affected.

As it cannot be assumed that the MASO is never exceeded, there will be an availability requirement, i.e., the amount of time the MASO may be exceeded within a specific time interval.

The Max Accepted Speed Confidence Interval (MASCI) is the sum of the MASU and MASO. It is only used for explanations and clarifications, to get a better understanding about the speed inaccuracy. It is not used for specifying a requirement.

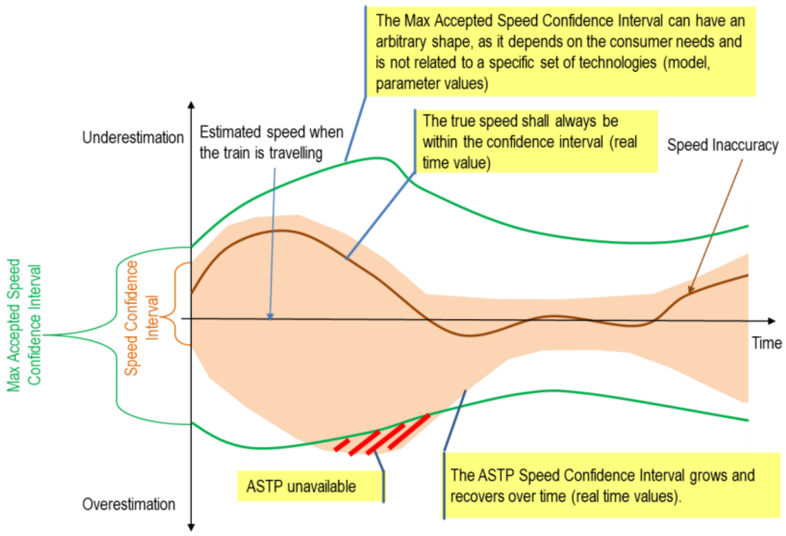


Figure 16: Visualisation of the estimated and Max Accepted Speed Confidence Interval.

6.2.3 Acceleration

The accuracy of the estimated ASTP acceleration is the difference between the estimated ASTP acceleration and the true ground ASTP acceleration.

The stability of the acceleration should be taken into account to avoid functional and ergonomic issues.

The quality of the estimated ASTP acceleration accuracy shall be defined with a probability level.

The Max Accepted Acceleration Underestimation (MAAU) is a limit to the underestimation of the estimated ASTP acceleration before it has an impact on operation.

If the underestimation of the estimated ASTP acceleration exceeds the MAAU the acceleration, function availability figure as defined in section 7.3.2. is impacted. In other words, the difference between the maximum safe acceleration and the estimated train acceleration is greater than the MAAU.

Rationale: If the underestimation of the estimated ASTP acceleration exceeds the MAAU, then the operational performance may be impacted (e.g., large underestimated train acceleration will have an impact on the distance between all points of the EBD and EBI curves), leading to a reduction of the capacity of the line. Therefore, when the underestimation of the confidence interval exceeds the MAAU, this loss of performance due to the acceleration function is counted in the ASTP unavailability figure (see chapter 8.2).

If the underestimation of the estimated ASTP acceleration exceeds the MAAU, then the safety of the ASTP relevant acceleration outputs is not affected.

As it cannot be assumed that the MAAU is never exceeded, there will be an availability requirement, i.e., the amount of time the MAAU may be exceeded within a specific time interval.

The Max Accepted Acceleration Overestimation (MAAO) is a limit to the overestimation of the estimated train acceleration before it has an impact on operation.

If the overestimation of the estimated ASTP acceleration exceeds the MAAO the acceleration function availability figure as defined in section 7.3.2. is impacted. In other words, the difference between the estimated train acceleration and the minimum safe acceleration is greater than the MAAO.

Rationale: If the overestimation of the estimated train acceleration exceeds the MAAO, then the operational performance may be impacted, (e.g., large overestimated train acceleration will have an impact on the braking curve) leading to a reduction of the capacity of the line. Therefore, when the overestimation of the confidence interval exceeds the MAAO, this unavailability of the acceleration function is counted in the ASTP unavailability figure (see chapter 8.2).

If the overestimation of the estimated train acceleration (as per §7.1.4) exceeds the MAAO then the safety of the ASTP relevant acceleration outputs is not affected.

As it cannot be assumed that the MAAO is never exceeded, there will be an availability requirement, i.e., the amount of time the MAAO may be exceeded within a specific time interval.

The Max Accepted Acceleration Confidence Interval (MAACI) is the sum of the MAAU and MAAO. It is only used for explanations and clarifications, to get a better understanding about the acceleration inaccuracy. It is not used for specifying a requirement.

6.2.4 Capacity Constraints and Confidence Interval Performance

The maximum accepted confidence interval limits regarding the estimated position (MAPU, MAPO) or the estimated speed (MASU, MASO) of the train influence the offline assessment of the line capacity.

The impact of the real-time confidence interval on the transportation plan of the line depends on the operational buffer and areas where the train traffic has small margin (e.g., split of traffic, releasing of switch, stopping in station).

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

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

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

a) **Area not constrained by the confidence interval**: Mainline track, track areas between stations. There is no critical location to achieve the operational headway in this area. Train is travelling usually at the track operational speed. The capacity of the area is not constrained by the confidence interval, the train characteristics as the safe braking distances and the acceleration make the capacity performance (The confidence interval is small against the safe braking distance and does not influence the capacity).

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

c) **Stopping performance**: The confidence interval influences the train location stopping accuracy. To provide an answer to user's needs (see requirements 4.1.2.4.1.1), to stick to train driving operational rules and to avoid using the release speed, the train has to stop at the operational stopping point. In this case a small confidence interval is required to avoid a train to stop too far from the forecasted operational stop.

6.3 MODELS OF CONFIDENCE INTERVAL AND IMPACT ON THE CAPACITY

The goal of the ASTP is to improve the performance of the existing odometry system and to provide an absolute safe train positioning by using a new set of sensors (e.g., GNSS, IMU…) assisted by Map Data of the track network. For more information see technical note #5.

These technologies are based natively on absolute referencing principles and are giving the following characteristics:

- The train positioning is by nature absolute,
- The absolute repositioning is done continuously (not only when passing a balise),
- Relative positioning to a reference location can be done easily (thanks to the Map Data),
- The train position confidence interval model does not depend anymore on the travelled distance and the error model of the wheel sensor (e.g., depends on the quality of GNSS signals and other factors such as IMU drift, time elapsed between absolute repositioning…).

Based on the principle of the absolute positioning, the train position confidence interval limits cannot follow a linear model from a reference location depending on the measured distance.

In the following chapters 6.3.1, 6.3.2 and 6.3.3 the existing ETCS model is presented, then two proposals are made with their advantages and drawbacks, one model based on speed dependent, the second one on fixed values, at last in chapter 6.3.4 a conclusion is presented.

6.3.1 Existing ETCS model

The model of accuracy is defined in SUBSET-041 [4] and the confidence interval in chapter 3.6.4 of SUBSET-026 [2],. The train position confidence interval model is based on odometer error and is of the following form:

$$\frac{1}{2}\,TrainPositionConfidenceInterval = QLOCACC + 5m + 5\% * s$$

Where:

- Q_LOCACC is the accuracy of the balise location (see definition chapter 7.5.1.115 of SUBSET-026 [2],)
- s is the measured distance from the reference location.

Associated to this model of the confidence interval for position, a principle to limit the maximum value of the confidence interval is presented in SUBSET-026 [2]. It is based on a reset of the confidence interval to a minimum value when the ETCS-OB is passing over a reference location e.g., physical balise. The distance between LRBG determines the maximum value of the confidence interval. During the engineering phase of a line, the location of the balises can be chosen to achieve the operational performance.

The following Figure 17 is presenting the reset principle based on physical balises.

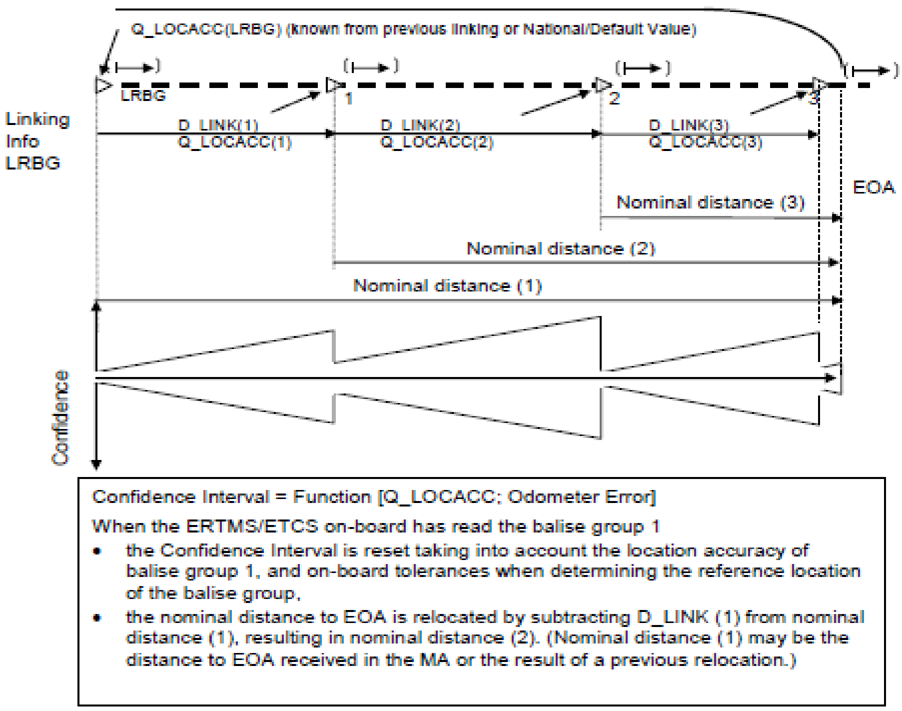
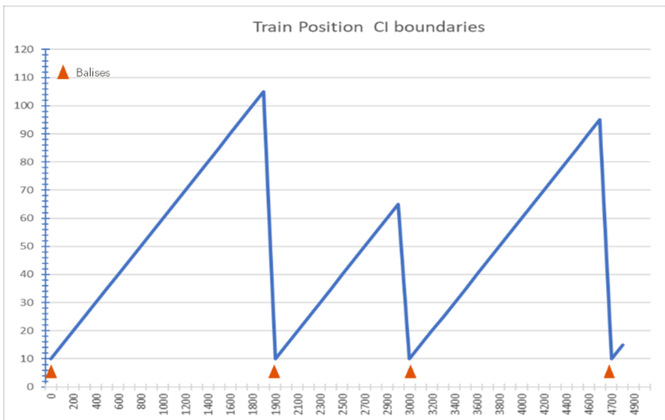


Figure 17: Reset of confidence interval and relocation, on change of LRBG ([2])

The following Figure 18 is showing as an example of the resulting model on a track with balises and a Q_LOCACC of 5m.



X axis is the distance travelled by the train in meter

Y axis is the limits of the confidence interval in meter

Figure 18: Example of train position confidence interval limits shape (X, Y axes are in meter)

From the ETCS model definition the following characteristics can be deduced:

1. The ETCS train location confidence interval and estimated position models are based on the odometry principles.
2. The absolute repositioning is done at a reference location that is a specific location of the track (where a balise group defined as a LRBG is installed).
3. The relative positioning is done continuously.
4. The values of the confidence interval and the accuracy limits increase continuously and linearly depending on the measured distance (based mainly on the principle of the wheel sensor error model).
5. The confidence interval limits MAPU and MAPO and the accuracy are reset to minimum values when an absolute positioning is confirmed (LRBG detection).

These principles induce the following consequences:

1. The absolute positioning is linked to specific reference locations of the track network (where repositioning balises are installed).
2. The train position confidence interval limits MAPU and MAPO are deterministic with regards to the train location on the track network and depend on reference location (balise positioning) on the track.
3. The train speed has no influence on train position confidence interval limits.

6.3.2 Speed dependent model

The proposed speed dependent train position confidence interval model is defined by the following formula:

$$\frac{1}{2} TrainPositionConfidenceInterval\ (MAPU, MAPO) = Max(10m, 1s * V_{train})$$

From the model definition, the following characteristics are deduced:

- The model does not refer to any reference location.
- The model is depending only on the train speed whatever is its location on the track network. Lower train speed requires smaller confidence interval (e.g., for train running up to 340km/h the confidence interval is in the range of [10, 94] m).

- On the network train may run at any speed between 0 km/h to the maximum authorised speed.

PROS

- The determination of the confidence interval limits is simple, the limits are deduced from the train speed.
- The minimum and the maximum limits are deduced from the maximum authorised speed (train or track speed).

CONS

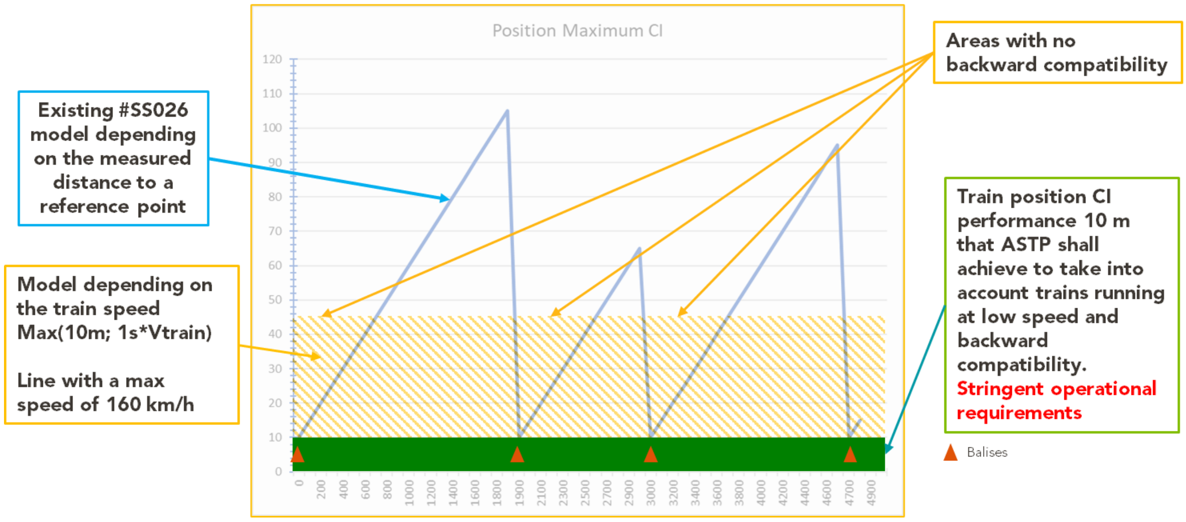
- The train position confidence interval limits are not deterministic with regards to the train position on the track network. However, a minimum and a maximum can be determined.
- Different type of trains (e.g., freight train, suburban train, passenger train…) have different confidence interval limits. A freight train due to its low speed can require a small confidence interval limit.
- **The ASTP shall achieve the performance of the model at any point of the track network**
    - The ASTP shall achieve train position confidence interval limits less or equal to 10 m at any point of the track network (e.g., during disturbance of traffic, train will run at low speed).
    - This consequence goes beyond the user's need: no need of such small confidence interval limits when two trains are running at low speed e.g., under on sight driving mode, when train is stop in line…
    - This consequence reduces the formula to

$$\frac{1}{2} TrainPositionConfidenceInterval = 10m$$

    - Achieving the performance of the model at any point of the track network seems not to be realistic.

Comparison with the existing ETCS model performance:

The following figure shows in blue the confidence interval shape provided by the existing ETCS model. The yellow area shows the shape of the speed dependent formula for a line with train running at 160 km/h. We can see that in some areas the formula is improving the performance but, in some others, it is not the case. However, if the performance of 10 m can be achieved at any point of the line a real improvement is made.



X axis is the distance travelled by the train in meter.

Y axis is the limits of the confidence interval in meter.

Figure 19: Comparison of confidence interval limits performance between existing ETCS and speed dependent models

6.3.3 Fixed values model

Based on the operational constraints defined in chapter 6.2.4 two types of areas (area with constraints and area with negligible constrained area) with their relevant confidence interval position limits are defined.

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

Area with constraints on the confidence interval or the accuracy with regards to the capacity or operational regulation: Station area, traffic node (specific point), stopping point (EoA), limit of authority (LoA). The area with constraints is considered only if the train comes to a stop.

Note: Area with constraints is defined geographically. During the design phase, checking of the environment or adding mitigation measure (e.g., add a balise) can be done to ensure that the ASTP can achieve the confidence interval in the area. During offline performance analysis, the area with constraint is taken into account only if the train comes to a stop. Consequently, all areas outside areas with constraints or train passing through an area with constraints without stopping, are considered as areas with negligible constraints.

For more information see Appendix G: Technical note #5 and Appendix H: Technical note #6.

Type of areas	MAPO, MAPU (1/2 MAPCI)
Area with negligible constraints	60m
Area with constraints	10 m

Table 5: Confidence interval model

Estimated position accuracy performance.

Type of areas	Estimated position accuracy along the track with a defined probability of p=95.4%
Area with negligible constraints	+/- 5 m
Area with constraints	+/- 5 m

Table 6: Estimated position accuracy performance

Note: for the accuracy the two types of areas are kept, in case in the future different figures could be required.

From the model, the following characteristics are deduced:

- The ASTP position confidence interval limits MAPO, MAPU remain linked to the ASTP location on the track network (located on area with constraints or not).
- The model does not refer to any reference location.
- The model does not depend on the train speed.
- The accuracy is based on a probability, it diverges from the SUBSET-041 [4]
- Definition where accuracy shall be interpreted as the size of the CI.

The main interests are:

- The confidence interval limits are deterministic with regards to the train position on the track network.
- The choice of area can take into account specific environments e.g., track areas with weak/ no GNSS signal, tunnel, station…

The model provides efficient ways to improve the performance of the network by asking performance only on specific areas, Comparison with the existing ETCS model performance:

The following

Figure 20 shows in blue the confidence interval shape provided by the existing ETCS model. The green area shows the shape of the confidence interval limits where in this model are fixed values (e.g., 50m, 10m). We can see that in some areas the formula is improving the performance but, in some others, it is not the case.

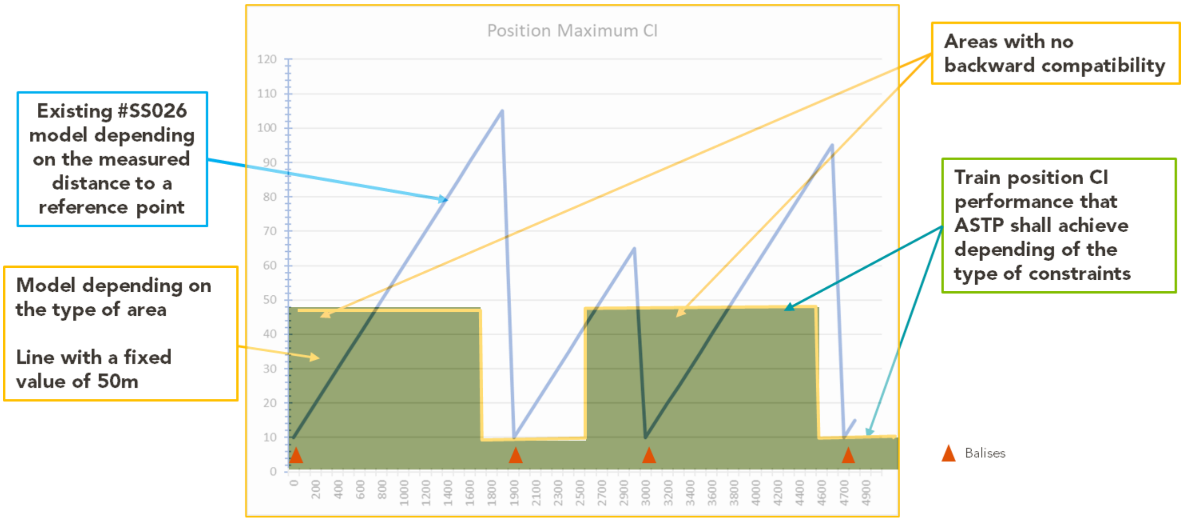


Figure 20: Comparison of confidence interval limits performance between existing ETCS and fixed values models

6.3.4 Conclusion and recommendation for the confidence interval model

Simulations have been performed with the two proposed models. They show some improvement on the capacity of the line. The main issue with regards the capacity is to achieve a small confidence interval when trains are arriving/leaving to/from stations. For the performance requirement, the speed dependent model has a major issue in achieving the performance anywhere on the network. The fixed value dependent model is closer to the real operational needs and seems to be achievable. Nevertheless, a way for the ASTP to identify on which type of area the train is running needs to be more analysed in details.

In a first approach the fixed values model is recommended.

For more information see Appendix G: Technical note #5 and Appendix H: Technical note #6.

7 ASTP FUNCTIONAL REQUIREMENTS

From the Operational context and users' needs chapter 4 and the ASTP boundaries assumptions and constraints chapter 5 the following chapter derives the system functions that the ASTP shall achieve. The ASTP is considered as a black box, ASTP system functions are not describing the inner functions of the ASTP but the system functions in interface required for exchanges with the environment of the ASTP (to users, from providers of data).

7.1 SYSTEM FUNCTIONS

7.1.1 Purpose, Notation, Overview

In the following sub-chapters System Functions (SF) of the ASTP are described based on one of the three prefixes:

a) Provide (ASTP_SF-**0xx**): Output function of ASTP

b) Acquire (ASTP_SF-**1xx**): Input function of ASTP

c) Control (ASTP_SF-**2xx**): Bi-directional function of ASTP covering aspects such as timing, authentication, authorisation, diagnostics, and maintenance

Each system function, SF is described with a rationale for its purpose and its data properties.

Uncertainties between the ASTP reference frame and the reference frame of the user are not part of the provided information, users shall consider this behaviour. For example, in the case, there is a not rigid link between the ASTP and the train front end, additional uncertainties shall be considered by the user.

A graphical overview of system functions in scope of ASTP is illustrated in

Figure 21.

The Appendix B is providing a first ASTP output functions used by subsystems.

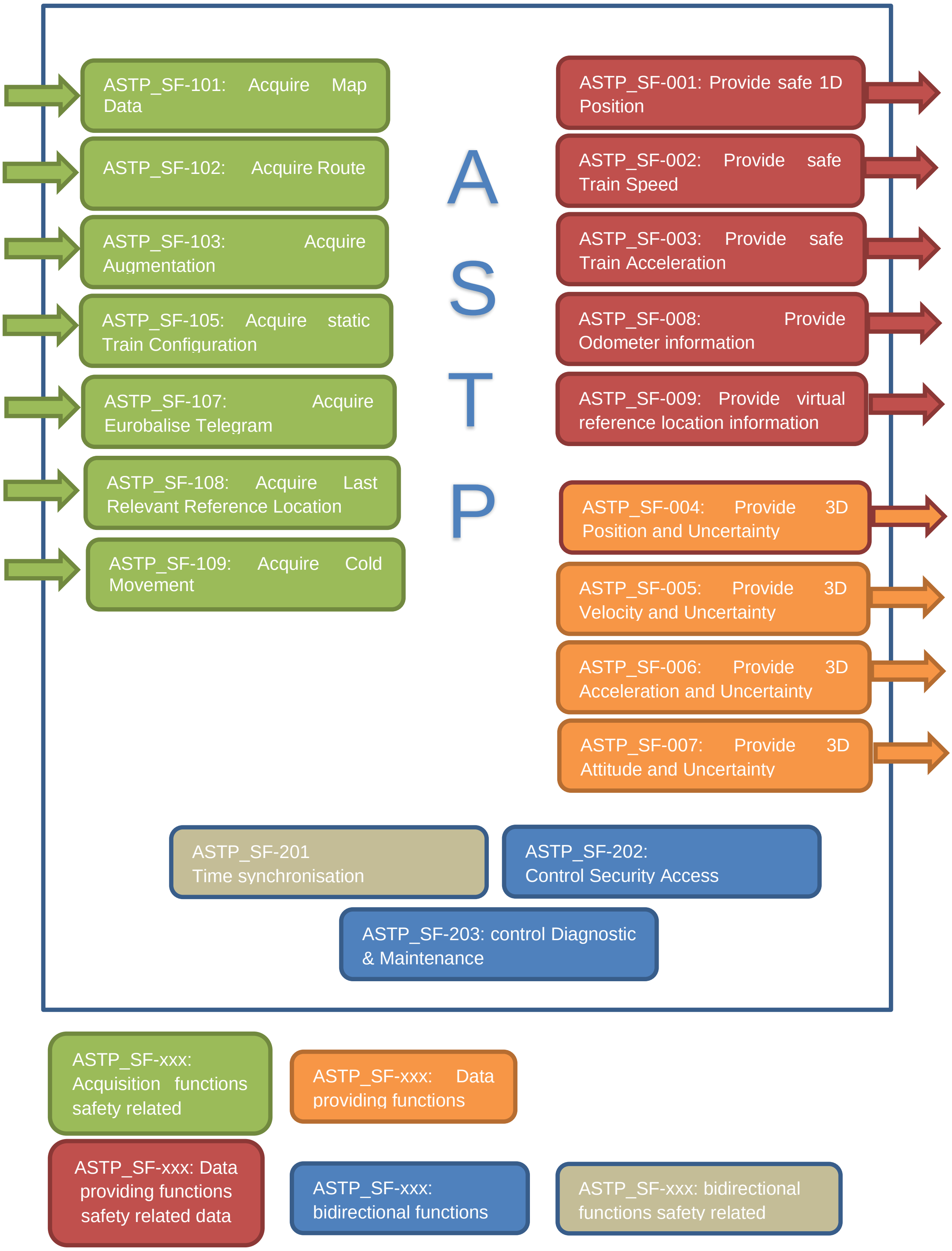


Figure 21: System Functions of Localisation On-Board (ASTP).

7.1.2 ASTP_SF-001: Provide Safe ASTP 1D Position

Rationale: This safety related function provides the 1D position of the ASTP reference frame. It follows the localisation-related logic needs of the current ETCS specification SUBSET-026 [2] regarding the determination of the longitudinal train front end position along the route, regardless of the complexity of the track layout. The information provided by this function is limited at the level of the ASTP reference frame. From this information, CCS-OB users can perform transformation to their own needs (e.g., ETCS-OB to perform the train front end position).

7.1.2.1.1 Data properties

Following, a list of identified data properties that are provided as part of the function's output. Data property terms used in this function are illustrated in Figure 22.

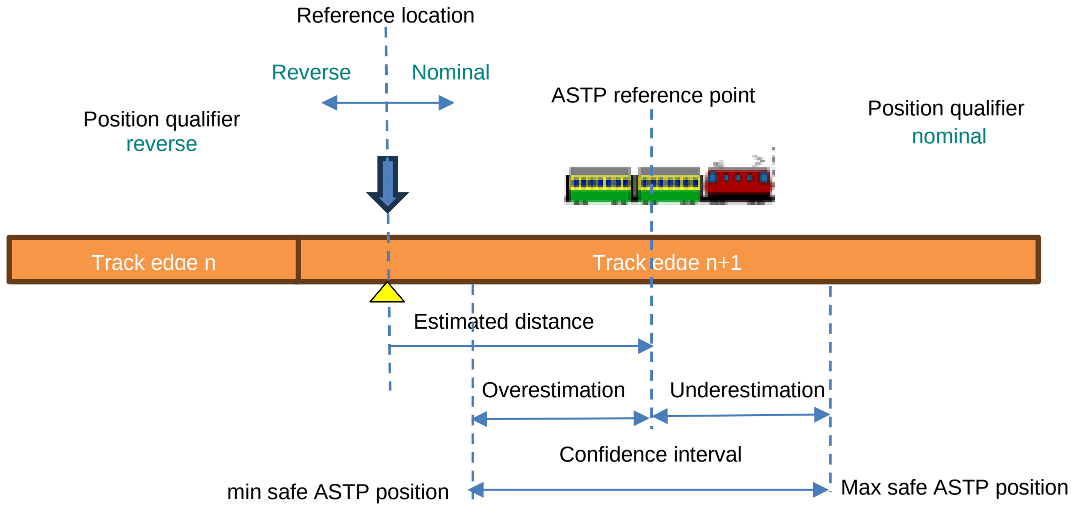


Figure 22: Illustration of terms used in ASTP_SF-001: Provide safe ASTP 1D Position.

Reference location id. Unique identifier of the element from which an estimated distance is given. Comparable to NID_LRBG but not limited to balise technology (SUBSET-026 [2]), i.e., could be any point on the track edge. The reference location id is determined by either of the two options:

a) Reference balise group id is received through function ASTP_SF-108: Acquire Last Relevant Reference Location and passed through this function.

b) ASTP determines the reference location by supporting information of the Map Data.

Position qualifier. It tells on which side of the reference location the estimated ASTP position is. Comparable to Q_DLRBG but using the ASTP reference frame and not limited to balise technology (SUBSET-026 [2]).

Estimated distance. Distance along the track between the last relevant reference location and the estimated ASTP reference point position. Comparable to D_LRBG but using ASTP reference frame and not limited to balise technology (SUBSET-026 [2]). The list of ETCS location items using this information is provided in SUBSET-026 [2] Chapter 3.6.4.2.4 Table 2a.

Underestimation of the estimated distance. The safe distance along the track the ASTP reference frame may have travelled further than the estimated ASTP position. Comparable to L_DOUBTUNDER but at the level of the ASTP and not limited to balise technology (SUBSET-026 [2]). The list of ETCS location items using this information is provided in SUBSET-026 [2] Chapter 3.6.4.2.4 Table 2a.

Overestimation of the estimated distance. The safe distance along the track the ASTP reference frame may have travelled shorter than the estimated ASTP position. Comparable to L_DOUBTOVER but at the level of the ASTP and not limited to balise technology (SUBSET-026 [2]). The list of ETCS location items using this information is provided in SUBSET-026 [2] Chapter 3.6.4.2.4 Table 2a.

Track edge id. Identifier of the track edge on which the estimated ASTP position is located. By using a Map Data, the parameter "position qualifier" can be derived based on the "reference location id" and the "track edge id". Only populated if system is using a Map Data based on a node/edge-model

Validity timestamp. Time stamping of the output, i.e., the time when the localisation information was valid. Rationale: Needs to be safe to help users to decide on freshness of information.

Function status. Health of the system function and its output information.

7.1.3 ASTP_SF-002: Provide safe ASTP Speed

Rationale: This safety related function provides the ASTP 1D reference frame speed. The information provided by this function is limited at the level of the ASTP reference frame. From this information, CCS-OB users can perform transformation to their own needs (e.g., ETCS to perform the train speed data).

7.1.3.1.1 Data properties

Following a list of identified data properties that are provided as part of the function's output.

Movement direction. Direction of train movement in relation to the direction of the ASTP reference frame X axis. (positive/negative)

Estimated ASTP speed. Absolute (1D) estimated speed value along the track, referred to the vehicle where the ASTP is installed.
Note: the error of the estimated speed value assessed along the track or along the carriage axis is negligible see appendix C.

Underestimation ASTP speed. The safe upper bound of the speed of the vehicle where the ASTP is installed.

Overestimation ASTP speed. The safe lower bound of the speed of the vehicle where the ASTP is installed.

Validity timestamp. Time stamping of the output, i.e., the time when the localisation information was valid. Rationale: Needs to be safe to help users to decide on freshness of information.

Function status. Health of the system function and its output information.

7.1.4 ASTP_SF-003: Provide safe ASTP Acceleration

Rationale: This safety related function provides the acceleration of the ASTP reference frame. The information provided by this function is limited at the level of the ASTP reference frame. From this information, CCS-OB users can perform transformation to their own needs (e.g. ETCS to perform the train front end position).

7.1.4.1.1 Data properties

Following a list of identified data properties that are provided as part of the function's output.

Estimated ASTP acceleration. Signed (1D) estimated acceleration value along the track, referred to the ASTP reference frame X axis direction.

Underestimation ASTP acceleration. The safe upper bound of the acceleration of the vehicle where the ASTP is installed.

Overestimation ASTP acceleration. The safe lower bound of the acceleration of the vehicle where the ASTP is installed.

Validity timestamp. Time stamping of the output, i.e., the time when the localisation information was valid. Rationale: Needs to be safe to help users to decide on freshness of information.

Function status. Health of the system function and its output information.

7.1.5 ASTP_SF-004: Provide 3D Position and Uncertainty

Rationale: This non safe function outputs the absolute estimated ASTP position along with an uncertainty in the absolute position reference frame. The information provided by this function is, for example, beneficial for diagnostic purposes or can be consumed by the Passenger Information Systems (PIS) to visualise the position of the train in a map to passengers or by the Automatic Processing Module.

7.1.5.1.1 Data properties

Following, a list of identified data properties that are provided as part of the function's output.

3D Position. 3-axis coordinates of the ASTP position. These coordinates are track constrained.

3D Position uncertainty. Covariance matrix of the 3-axis coordinates, from which, among other things, the standard deviation of the 3D position can be determined.

Coordinate system: Type of coordinate system for 3-axis coordinates, WGS84.

Track edge id. Identifier of the track edge on which the estimated 3D ASTP position is located. Only populated if system is using a Map Data based on a node/edge-model.

Validity timestamp. Time stamping of the output, i.e., the time when the localisation information was valid.

Function status. Health of the system function and its output information.

7.1.6 ASTP_SF-005: Provide 3D Velocity and Uncertainty

Rationale: This non-safe function outputs the estimated velocity, referred to the 3D ASTP reference frame along with an uncertainty in a 3D reference frame. The information provided by this function is, for example, beneficial for diagnostic purposes or can be consumed by the Passenger Information Systems (PIS) to visualise the speed and direction of the train in a map to passengers.

7.1.6.1.1 Data properties

Following, a list of identified data properties that are provided as part of the function's output.

3D Velocity. Value given for the different axes in reference to the 3D ASTP reference frame.

3D Velocity uncertainty. Covariance matrix of the velocity value per axis, from which, among other things, the standard deviation of the 3D velocity can be determined.

Validity timestamp. Time stamping of the output, i.e., the time when the localisation information was valid.

Function status. Health of the system function and its output information.

7.1.7 ASTP_SF-006: Provide 3D Acceleration and Uncertainty

Rationale: This non-safe function outputs the estimated acceleration, referred to the 3D ASTP reference frame, along with an uncertainty in the 3D reference frame. The information provided by this function is, for example, beneficial for diagnostic purposes.

7.1.7.1.1 Data properties

Following, a list of identified data properties that are provided as part of the function's output.

3D Acceleration. Value given for the different axes in reference to the 3D ASTP reference frame. Output related to the position where sensors providing the information are installed.

3D Acceleration uncertainty. Covariance matrix of the acceleration value per axis, from which, among other things, the standard deviation of the 3D acceleration can be determined.

Validity timestamp. Time stamping of the output, i.e., the time when the localisation information was valid.

Function status. Health of the system function and its output information.

7.1.8 ASTP_SF-007: Provide 3D Attitude (rotational angles) and Uncertainty

Rationale: This non-safe function outputs the estimated attitude and angular rate in attitude using the attitude ASTP reference frame, along with an uncertainty in the attitude reference frame. If this set of data shall be representative of the attitude of the first vehicle, the ASTP shall be installed in this vehicle. The information provided by this function is, for example, beneficial for diagnostic purposes.

7.1.8.1.1 Data properties

Following, a list of identified data properties that are provided as part of the function's output.

Attitude. Absolute rotational angles (yaw, pitch, roll) related to the carriage where sensors providing the information are installed.

Attitude uncertainty. Covariance matrix of the rotational angles, from which, among other things, the standard deviation of the rotational angles can be determined.

Angular rate. Angular speed of rotational angles (yaw, pitch, roll) related to the carriage where sensors providing the information are installed.

Angular rate uncertainty. Covariance matrix of the angular rate of rotational angles, from which, among other things, the standard deviation of the angular rate of rotational angles can be determined.

Validity timestamp. Time stamping of the output, i.e., the time when the localisation information was valid.

Function status. Health of the system function and its output information.

7.1.9 ASTP_SF-008: Provide Odometer information

Rationale: The odometer information that includes current values of estimated distance, direction, estimated speed, confidence interval of measurement of distance, of the speed is needed to satisfy STM requirements (SUBSET-035 [3] e.g., §12) and initialisation requirements (see chapter 7.2). The estimated distance shall not be reset as long as the ASTP is powered-on. For example, the train driver travels in Staff Responsible (SR) mode until a reference location is identified and confirmed.

This data is provided at the level of the ASTP, conversion can be required by users to fully comply with SUBSET-035. Mainly side A of the ASTP could not be side A at the level of the train.

The odometry data shall comply with performance of function ASTP_SF-001: Provide Safe ASTP 1D Position 7.1.2.

7.1.9.1.1 Data properties

Following a list of identified data properties that are seen useful as part of the function's output.

Estimated distance travelled. Distance along the track travelled since ASTP was powered on. A positive movement direction is defined as a movement in the forward direction in relation to side A of the vehicle where the ASTP is installed and is indicated with an increasing distance value (SUBSET-035 [3]). A negative movement direction is defined as a movement in the backward direction in relation to side A and is indicated with a decreasing distance value (SUBSET-035 [3]). Comparable to D_Est (SUBSET-035 [3]).

Estimated distance max. The most positive position of the vehicle with all over- and under-reading amounts accumulated since the last power-on of ASTP. Comparable to D_Max (SUBSET-035 [3]).

Estimated distance min. The most negative position of the vehicle with all over- and under-reading amounts accumulated since the last power-on of ASTP. Comparable to D_Min (SUBSET-035 [3]).

Estimated ASTP speed. Absolute (1D) estimated speed value along the track, referred to the vehicle where the ASTP is installed. Speed has a positive value for movement in the forward direction in relation to side A, negative value for movement in the backward direction in relation to cab A. (SUBSET-035 [3] §12.2.1.1).

Maximum ASTP speed. The higher speed of the vehicle where the ASTP is installed. Comparable to V_Max (SUBSET-035 [3] §12.2.1.2).

Minimum ASTP speed. The lower speed of the vehicle where the ASTP is installed. Comparable to V_Min (SUBSET-035 [3] §12.2.1.3).

Validity timestamp. Time stamping of the output, i.e., the time when the localisation information was valid. This time information allows an STM to extrapolate distance to fit its algorithms and processing cycles (SUBSET-035 [3]).

Function status. Health of the system function and its output information.

7.1.10 ASTP_SF-009: Provide virtual reference location

Rationale: To take advantage of the Digital Map, virtual reference location can be defined. In this case, this safety related function outputs the reference location information detected by the ASTP. This information is used by the ETCS-OB to determine the last reference location (e.g. LRBG) when passing a virtual reference location (as it is done with physical balises).

7.1.10.1.1 Data properties

Following a list of identified data properties that are seen useful.

Reference location id. Identity number of a reference location within the country or region defined (NID_RL).

Region id. Identity number of the country or region the reference location is located (NID_C SUBSET-026 [2]).

Orientation: It tells the orientation of the reference location

Validity timestamp. Time of virtual refence location, i.e., the time when the ASTP detects the virtual reference location.

7.1.11 ASTP_SF-101: Acquire Map Data

Rationale: The acquisition of Map Data shall follow the principles defined in the scope of WP27.

Map Data is used by sensor fusion algorithms that are based on absolute positioning determination. The needs and quality of Map data shall be defined in the scope of WP22.

7.1.12 ASTP_SF-102: Acquire Route

Rationale: The point status of the train path uniquely assigned to a train/vehicle. This information is seen useful to validate the determined position by the ASTP against track selectivity. It might also be used to determine track selectivity, e.g., if the vehicle position is known prior to passing a switch point and to decide whether it turned left or right.

The WP22 needs to status on the need of this function, and in the case it is required, data and properties of data shall be defined.

7.1.13 ASTP_SF-103: Acquire Augmentation

Rationale: Augmentation data is supporting information such as GNSS augmentation that can be regarded by the sensors and/or fusion logic to improve the overall performance. Augmentation data leads to more accurate and safe localisation information (along-track position, along-track speed) and faster estimation of accurate localisation after startup of the ASTP in operation. It enhances 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.

7.1.13.1.1 Data properties

Operational requirements, safety requirements and system feared events will be defined under EGNOS project.

7.1.14 ASTP_SF-105: Acquire static ASTP Configuration

Rationale: Static ASTP configuration data containing disposition information, such as, the sensor/antenna installation location, the ASTP reference location.

7.1.14.1.1 Data properties

This is an optional function if these data are centralised at the train level (see chapter 5.2.4.1.9) If the function is not used, data shall be stored in the ASTP (e.g., ASTP reference point in the vehicle, orientation of the x axis, sensor, antenna position in the vehicle…).

7.1.15 ASTP_SF-107: Acquire Eurobalise Telegram

Rationale: Eurobalise telegram information (e.g., balise header) is needed to consider passed balises in the fusion logic of the absolute position determination along with respective map data (by retrieving geo-coordinates of the Track Edge Point representing the balise passed).

7.1.15.1.1 Data properties

Following a list of identified data properties that are seen useful as part of the function's output.

Balise group id. Identity number of a balise group within the country or region defined (NID_BG, SUBSET-026 [2]).

Region id. Identity number of the country or region the balise group is located (NID_C SUBSET-026 [2]).

Position in group. Defines the position of the balise in the balise group (N_PIG, SUBSET-026 [2]).

Eurobalise antenna id. Identity number of the antenna receiving the telegram (NID_ANTENNA, SUBSET-130 [8])

Distance antenna: Distance from the antenna to the ASTP reference point

Validity timestamp. Time of balise passage, i.e., the time the balise reader is over the centre of the balise.

7.1.16 ASTP_SF-108: Acquire Last Relevant Reference Location

Rationale: Last Relevant Reference location in the representation of an LRBG or a Last Relevant Virtual Reference Location, is needed to refer a determined position by ASTP to the last reference location (e.g. LRBG or virtual reference location id) and estimated distance (e.g., used for ASTP_SF-001: Provide Safe ASTP 1D Position).

7.1.16.1.1 Data properties

Following a list of identified data properties that are seen useful as part of the function's output.

LRRL id. Identity of last relevant reference location: balise group (NID_LRBG SUBSET-026 [2]) or identity of the virtual reference location (NID_RL).

Reference location orientation passing. (e.g., balise, virtual reference location) Nominal (ascending order of position of the balise within the balise group, toward nominal orientation of the reference location) or reverse.

Validity timestamp. Time of balise group passage, i.e., the time the balise reader is over the centre of the reference balise of the balise group.

7.1.17 ASTP_SF-109: Acquire Cold Movement

Rationale: Information about whether an engine/train has moved more than 2 m (SUBSET-026-3.15.8.1.1 [2])or not during ETCS' "no power"-mode to consider the information as part of the initialisation of the localisation system.

7.1.17.1.1 Data properties

Following a list of identified data properties that are seen useful as part of the function's output.

Movement flag. Indicates, if a movement took place in general.

7.1.18 ASTP_SF-201: Time synchronisation

Rationale: Accurate time information is used to timestamp localisation information (position, speed, etc.) to know exactly where a train/vehicle has been at a certain point in time. Localisation information with accurate time information. This is a generic function available not to ASTP only and needs to be further discussed and specified.

a) It is mandatory to have a common time between onboard and trackside.

b) It simplifies error and event analysis as events are logged with accurate time information.

c) It allows to reject information in case of outdated data (e.g., message overhauls).

This is a bi-directional function. Besides using time information by ASTP through this function, ASTP may provide time information to this function, e.g., if collected directly through its sensors (e.g., GNSS).

As time information is used by ASTP in safety as well as in non-safety functions, it needs to fulfil both requirements.

Notice: Train Time and Localisation Service (TTLS) is introduced in Subset-147. TTLS only handle non safe information and cannot support safe absolute time reference or differential time stamping. TTLS cannot then fulfil the safety needs of ASTP_SF-201.

7.1.18.1.1 Data properties

This is a generic function available not to ASTP only and needs to be further discussed and specified.

7.1.19 ASTP_SF-202: Control Security Access

Rationale: Generic function to authenticate and authorise users and technical systems and grant/deny access.

7.1.19.1.1 Data properties

This is a generic function available not to ASTP only and needs to be further discussed and specified.

7.1.20 ASTP_SF-203: Control Diagnostic & Maintenance

Rationale: This function provides means for system health, performance measurement and fault recovery. The information provided by this function can be used by other functional blocks in CCS-OB to determine the state of the ASTP. This function could evaluate the effect of the fault at a system level and execute appropriate recovery manoeuvre. Example: Multiple trains report for the same track sections deviations between the geometric track information provided by the Map Data and the integrity measures estimated by sensors of ASTP.

The function also allows to perform maintenance tasks for ASTP, e.g., to reboot a specific component, to install software updates, etc.

7.1.20.1.1 Data properties

This is a generic function available not to ASTP only and needs to be further discussed and specified.

System Status. This information is given out by the system functions to be able to determine the state of ASTP. With the system status the functions expecting output from ASTP can determine if the output is healthy. For more information about the healthiness of the system functions see chapter 9.3.2.

Real time data: to be defined in a future release (e.g., real time accuracy of estimated data if available, confidence interval data…).

7.2 START OF MISSION AND ASTP INITIALISATION

Start of Mission procedure occurs when the ERTMS/ETCS on-board is in Stand-By mode and a desk is open. The driver has a request to a start of mission in the one of the following operational scenario:

1. Once the train is awake.
2. Once shunting movements are finished.
3. Once a mission is ended.
4. Once a slave engine becomes a leading engine.

In all of these situations the ERTMS/ETCS onboard is in Stand-By mode. The differences will come from the status of the on-board stored data (valid, invalid or unknown) depending on the previous situations.

One main goal of the start of mission is to make a check first by the ERTMS/ETCS onboard of these stored data (level, position…) and then to get a validation from the RBC. Depending on the results of these onboard and trackside checks the mission can be started in different ERTMS/ETCS modes.

For instance, to start in Full Supervision mode the position of the train needs to be valid at the level of the ERTMS/ETCS onboard and the trackside. In the case the position is invalid or unknown the train has to be run under other ERTMS/ETCS modes (e.g., Staff responsible) until a valid position is declared.

For more details see Start of Mission procedure chapter 5 of SUBSET-026 [2].

7.2.1.1.1 One main goal of the introduction of the ASTP is to provide at its level a valid position to the ERTMS/ETCS onboard as fast as possible from power on event. This will allow to start a mission in full supervision mode and in level 3 to move the train without any specific initialisation procedures. The way the trackside will accept this train localisation is not the purpose of this document.

7.2.1.1.2 The SoM brings some constraints to the ASTP. To be efficient the trusted localisation data shall be available before entering in the SoM procedure.

7.2.1.1.3 At the end of the SoM procedure, to be able to run the train whatever is the ERTMS/ETCS mode, the ASTP shall provide the train speed ASTP_SF-002: Provide safe ASTP Speed and distance run ASTP_SF-008: Provide Odometer information data in accordance with the performance requirements.

From the 4 operational situations two operational scenarios are identified at the level of the ASTP.

1. The ASTP was not switched off and remains powered,
2. The ASTP was switched off and it is powered on before entering in the SoM procedure.

In the first scenario, depending on the localisation status before entering in the SoM procedure, the ASTP can provide a trusted localisation or not. The train had run on area where the ASTP cannot perform localisation outputs (e.g., area such as a yard with no input data such as reference location, Map Data, no GNSS signal…)

1. The ASTP can provide trusted localisation (LRBG, Track Id…known). The SoM can be done with a valid position at least from the ERTMS/ETCS on-board view. There is no need of specific initialisation phase.
2. The ASTP cannot provide trusted localisation. The ASTP shall enter in an initialisation phase. The SoM can be done with a valid or unknown position depending on the time the ASTP is able to provide a trusted localisation. During this time the ASTP shall provide train speed and distance run.

The second scenario requires to define the initialisation phase of the ASTP after power on. The initialisation phase can be split in two subcases hot and cold start:

1. Subcase Hot start: The ASTP can store the last known location before it was switched off. After the ASTP is powered on, a check of the stored data integrity and thanks to the cold movement detection status (check that the train has not moved more than 2 m during the train was off, for more information see Appendix I: Technical note #8), the last known location can be considered as trusted. During this time, the ASTP can align its sensors and processing to this location. The SoM can use this localisation data as trusted.
2. Subcase Cold start: This case happens when the ASTP has an invalid or unknown position, or movement detected by the CMD. In this case the ASTP thanks to the Map Data and sensors data will try to get on time a trusted localisation. Depending on the initialisation time and the location of the train, getting a trusted localisation on time is not guaranteed. In this case the ASTP will stay with an invalid or unknown localisation until the ASTP can recover a trusted localisation. This could happen because the train has moved and the ASTP cannot determine valid localisation, or more time is given before the train starts to move. During this time the ASTP shall enter in a degraded mode providing ASTP speed and distance run since ASTP was powered on until it can provide a trusted position.

7.2.1.1.4 From the operational point of view the ASTP shall initialise itself at power-on and fulfil operational capability thereafter.

8 ASTP NON FUNCTIONAL REQUIREMENTS

This chapter presents high-level non-functional requirements.

8.1 RELIABILITY

8.1.1.1.1 The failure occurrence of ASTP impacting the operation shall be derived from 96S126 [12].

8.1.1.1.2 The occurrence of sudden variation (e.g., sudden increase of the confidence interval while the train is following a braking curve) or loss of ASTP localisation information by a safety relevant user due to the lack of valid data (e.g., lack of message, data is too old, etc.) leading to a brake intervention (service brake or emergency brake) shall be less than $2*10^{-6}$/h (one brake intervention per year for a fleet of 10 trains operated during 14 hours per day).

8.1.1.1.3 User subsystem with safety constraints shall considered data with ageing time >= 1s outdated.

8.1.1.1.4 The occurrence of ASTP not operational (major failure, ASTP is not providing any output) shall be less than 1 event every 10 years.

8.2 AVAILABILITY

8.2.1.1.1 The ASTP shall provide services with a high rate of availability to avoid any impact on train operation.

8.2.1.1.2 The ASTP is considered as available if it provides localisation information to users and if the confidence intervals are within the MAPCI (position), MASCI (speed) and MAACI (acceleration).

8.2.1.1.3 If the performance of the ASTP (e.g., confidence intervals are outside of MAPCI (position), MASCI (speed) or MAACI (acceleration)) induces more than 1mn of train delay during one hour of train operation, the delay of time is accounted in the overall unavailability of the ASTP.

8.2.1.1.4 If the ASTP is not providing data at the defined frequency, the ASTP is considered as unavailable during this time.

8.2.1.1.5 The ASTP shall have an overall availability of 99,998% per month. The justification for this figure is given in Appendix A: ASTP availability justification target.

8.2.1.1.6 The ASTP shall have a rugged design. The failure of one sensor or one component shall not lead to an outage of the ASTP outputs.

8.2.1.1.7 The ASTP shall be available and achieve full performance under all type of train behaviour, operation (e.g., train slip/slide, train coupling, train splitting…).

8.3 MAINTENABILITY

8.3.1.1.1 Maintenance costs can negatively affect life cycle costs. For this reason, the system shall be designed in such a way that maintenance work is minimal.

8.3.1.1.2 The railway operator shall be able to carry out the maintenance himself or it shall be possible for the railway operator to outsource the maintenance work to another company that is officially certified by public authorities to carry out maintenance work.

8.3.1.1.3 The long-term maintenance strategy shall include damage-dependent (past) and preventive (forward-looking) measures.

8.3.1.1.4 To detect systematic malfunctions early and to carry out preventive maintenance, the system shall record relevant diagnostic and maintenance information and share the same, if available, with a diagnostic and maintenance system. This will increase the overall system availability.

8.3.1.1.5 Maintenance measures shall be carried out in such a way that the system can be operated within the defined RAMS requirements for the entire system life cycle.

8.3.1.1.6 ASTP shall be able to self-diagnose.

Rationale:

Self-diagnostic capability is necessary to minimise maintenance activities and consequences the failure of accuracy targets would have on ASTP users.

8.3.1.1.7 The results of the self-diagnose shall be able to determine the replaceable unit to be replaced.

8.3.1.1.8 The Mean Repair Time (MRT) shall be less than 15 minutes as per EN50126 [11].

8.3.1.1.9 The ASTP's design and maintenance concept shall meet a Mean Time To Restore (MTTR) ≤ 1h. The Mean Time to Restore (MTTR) is defined in EN50126 [11]. The time elapsed to restore starts when the failure occurs and ends when the ASTP is ready for service. The administrative delay (MAD), Logistic Delay (MLD) shall not be counted into the MTTR.

8.4 SECURITY

8.4.1.1.1 The ASTP shall fulfil System Pillar recommendations from:

- SP-PRAMSS 30_Secure Component Specification [22]
- SP-PRAMSS 40_Secure Communication Specification [23]
- SP-PRAMSS 50_Shared Security Services Specification [24]
- SP-PRAMSS 60_Security_Program_Requirements [25]

8.4.1.1.2 The ASTP shall fulfil requirements and recommendations for cybersecurity as specified in CLC/TS 50701 [10] with the purpose to demonstrate that the system is up to date from a cybersecurity perspective and that it meets and maintains the target level of security for the entire system life cycle.

8.4.1.1.3 The ASTP security shall be ensured by using means and technologies in accordance with project security plan.

8.4.1.1.4 ASTP shall be resilient to signal spoofing, jamming (e.g. GNSS, Balise signals…) attacks. Appropriate detection measures of such conditions and mitigation measure to counter such attacks shall be addressed to keep the integrity of the ASTP.

8.5 ENVIRONMENT

8.5.1 Environmental conditions

8.5.1.1.1 The ASTP system shall function under the environmental conditions defined in 97S066 [15]

8.5.2 Migration constraints

Due to the mode of operation or the implementation of variants the following constraints shall apply:

8.5.2.1.1 The ASTP shall be used under various operational configurations.

8.5.2.1.1.1 Train equipped with the ASTP can run on tracks not equipped with a data radio communication system. In this case lower performance is acceptable that will be further specified.

8.5.2.1.1.2 Train equipped with the ASTP can run on tracks with no Map Data available. In this case lower performance is acceptable that will be further specified. Without Map Data, ASTP (in combination with trackside assets, e.g., balises) shall achieve at least the performance as specified today in SUBSET-026 [2] and SUBSET-041 [4] for backward compatibility purposes in such a case.

8.5.2.1.1.3 Train equipped with the ASTP can run on track with no Augmentation data available. In this case lower performance is acceptable that will be further specified. Without augmentation data, ASTP (in combination with trackside assets, e.g., balises) shall achieve at least the performance as specified today in SUBSET-026 [2] and SUBSET-041 [4] for backward compatibility purposes in such a case.

8.5.2.1.1.4 Train equipped with the ASTP could not receive Route Control information. In this case after the system is powered on, it is allowed to move the train to the next balise to confirm the reference location and therefore to determine the track edge id. The distance to be run under such condition shall not be too long (avoid to move the train under no full supervision mode for a long distance).

9 ASTP OPERATIONAL SCENARIO

9.1 ASTP SCENARIO

Chapters 4.1 to 4.4 are defining train operation scenarios, user's needs, and environmental conditions under which the ASTP shall perform. To achieve the fulfilment of train operation scenarios the ASTP scenario can be synthetised in three steps:

1. ASTP is no powered: During this state the ASTP is not performing.
2. ASTP initialising absolute position: Following powering on the train, the ASTP is switched on. During this phase the ASTP is initialising by itself. This step lasts until the ASTP can recover a trusted position. During this step, the train can be at standstill or running providing a least speed and distance run.
3. ASTP is operating: The train is following its operational scenario (running, stopping,…). After ASTP ended the initialising step (first trusted position is available), ASTP is performing under various environmental and operation conditions (e.g., open sky track, tunnel, dense areas with building, stop in station…). Depending on the environment and sensor status, output functions can be in a nominal or degraded state. This step lasts until the ASTP is switched off (train ended its operation and it is powered off). Nominal mode and degraded mode are discussed in chapter 9.3

The following Figure 23 represents a state chart of the ASTP scenario.

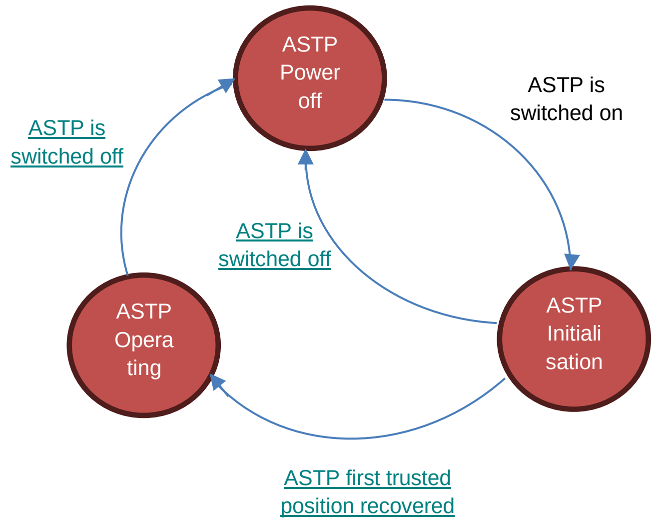


Figure 23: ASTP scenario synthetised by a state chart

9.2 INITIALISATION STEP

For more detailed information about the initialisation step see chapter 7.2

9.2.1.1.1 After ASTP is powered on and its initialisation phase is achieved, it is expected that the ASTP can recover a trusted position before the train moves (start of mission under nominal mode).

9.2.1.1.2 In the case ASTP cannot recover a trusted position before the train moves, the ASTP shall provide the train speed and distance run data in accordance with the performance requirements until a trusted position is determined. During this time the functions ASTP_SF-002: Provide safe ASTP Speed, ASTP_SF-008: Provide Odometer information are in nominal mode and ASTP_SF-001: Provide Safe ASTP 1D Position is in degraded mode.

9.3 OPERATING STEP

As soon as the ASTP recovers a trusted localisation it enters in an operating step. During this step, the train is following its operation and the ASTP is providing localisation information. Nonetheless depending on the environment and sensors status, some data may not fulfil performance requirements. For each output function two status are considered, nominal and degraded.

9.3.1 Nominal mode

The ASTP is providing various output functions (see chapter 7.1). Each output function is providing a data set.

9.3.1.1.1 An output function of ASTP is considered in nominal mode when the flow of data set provided complies with the full specification, achieving the accuracy and, for the safety-relevant data, ensuring the safety requirements such as the THR. The data flow shall also achieve the timing constraints.

9.3.1.1.2 A flag (specific to the function) named health of the system function is set to indicate to the users' application that the function is performing in nominal mode.

9.3.1.1.3 Some sensors can be sensitive to their environment or their condition of operation. These external conditions can have an impact on the sensor behaviours and therefore under some conditions the output functions cannot achieve the full specification. Nevertheless, the function shall achieve the full specification under the following external conditions :

- During train running under the various scenarios listed in chapters 4.2 to 4.4.
- While slip/slide events occur during train movement.
- While train is travelling through a tunnel.
- While train is travelling in an urban area, forest, mountain…

- In general, while train is travelling in the railway European environment (infrastructure types, track environment, weather conditions, traction power type, train type, electromagnetic interferences…).

9.3.2 Degraded mode

9.3.2.1.1 An output function of ASTP considered in degraded mode when its set of data flow doesn't comply with the full specification, a data is not achieving the accuracy or is not provided, or the timing constraints are not fulfilled.

9.3.2.1.2 For the safety relevant data, if safety requirements cannot be achieved the data shall not be provided.

9.3.2.1.3 A flag named health status is set to indicate to the users' application that the function is performing in degraded mode.

9.3.2.1.4 It is the responsibility of the users' applications to accept or reject data of a function that is in degraded mode.

9.3.2.1.5 The following list is identifying some events under which a function can be in degraded mode. These are examples, the list is not exhaustive.

- Some sensors are not performing as expected (e.g., calibration of a sensor is not done), the function cannot provide some output data or data are not within the expected accuracy.
- Some supporting information is not available (e.g., augmentation data, routing information...)
- One sensor is in failure, the function cannot provide some output data or data are not within the expected accuracy.
- Sensor device based on radio signal is facing spoofing, interferences, jamming during a time or a distance. These parameters are not specified in this release, more investigations are required to determine the values.

10 DISSEMINATION OF ASTP LOCALISATION INFORMATION

10.1 CONVERTION TO USER REFERENCE FRAME

ASTP is forwarding to all CCS-OB users localisation information.

This localisation information is expressed using ASTP fixed reference frames attached to the vehicle where the ASTP is installed. Users, if needed, based on this localisation information can transform them to their own reference frame to deduce their localisation information.

The conversion is possible if the users get a set of parameters:

- Orientation of the vehicle where the ASTP is installed with regard to the train orientation
- Distance between the ASTP reference point and their reference point

Note: The conversion can reduce the quality of data.

10.2 IMPORTANCE OF THE TRAIN ORIENTATION

The following figure is highlighting the importance of the train orientation with regards to the ASTP 1D localisation information for deriving the localisation information.

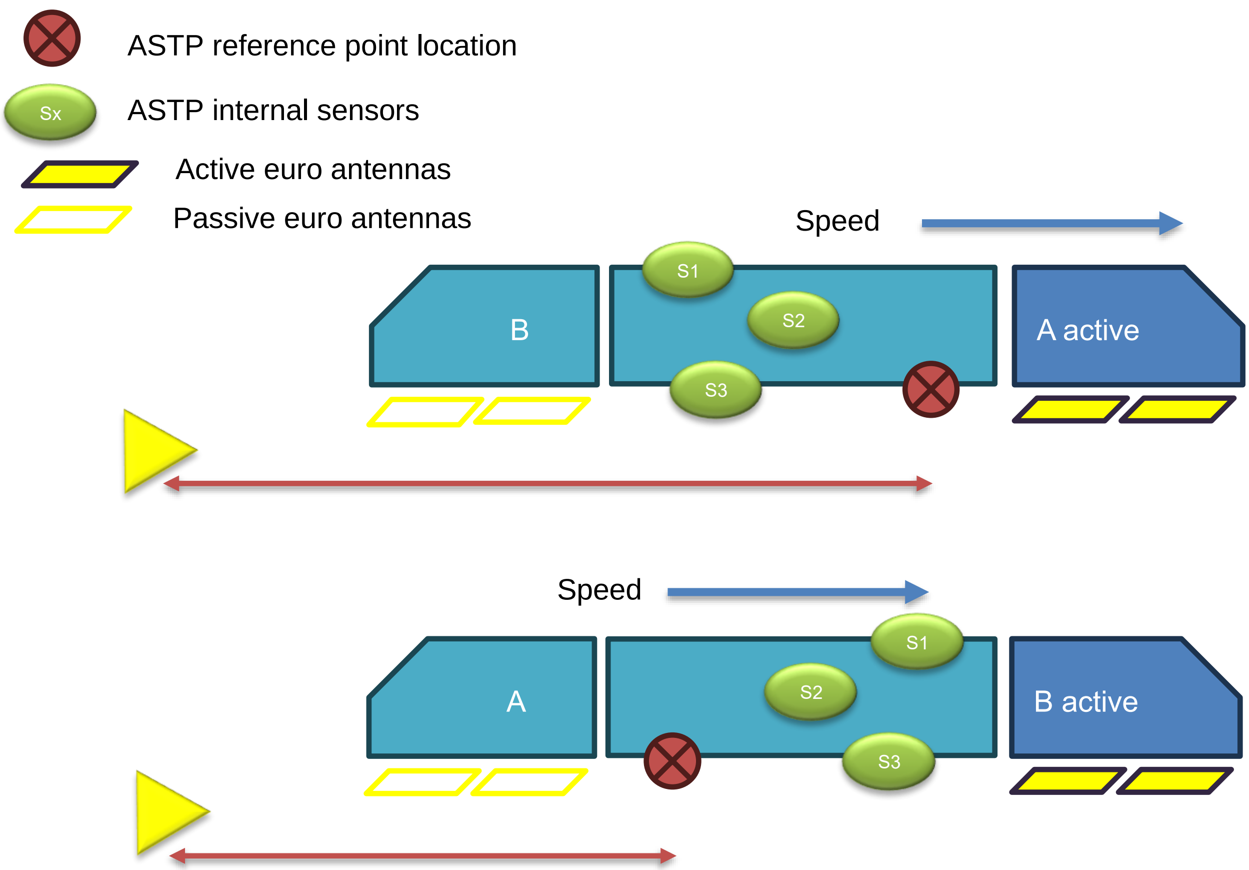


Figure 24: Effect of the train orientation

From the Figure 24 the following items are identified:

- The red lines show the distance from a reference location determined by the ASTP. The distance seen by the ASTP depends on the train orientation. Users has to take into account this effect.
- The same effect applies when the ASTP reference point is on one side of the reference location and the train front end in the other side. In this case the position qualifier is different.

10.3 USE OF ASTP LOCALISATION INFORMATION BY USERS

To make the transformation from ASTP fixed reference frame to users' reference frame, users shall know the position of their reference frame to the ASTP reference frame. Depending on the type of the train, the train operation, this configuration data can be static or dynamic.

The following Figure 25 depicts the ASTP with 3 users.

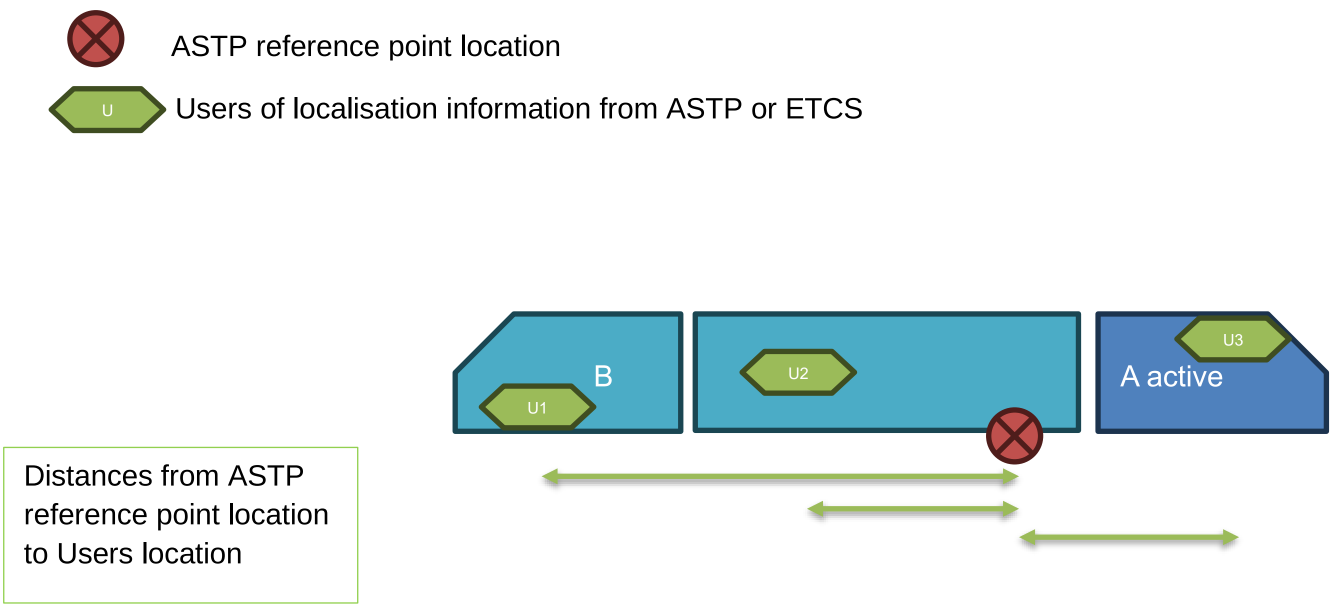


Figure 25: Users location reference frame with regards to the ASTP fixed reference frame

The following Figure 26 shows the importance of the orientation and the distance to users to transform the localisation data provided by the ASTP.

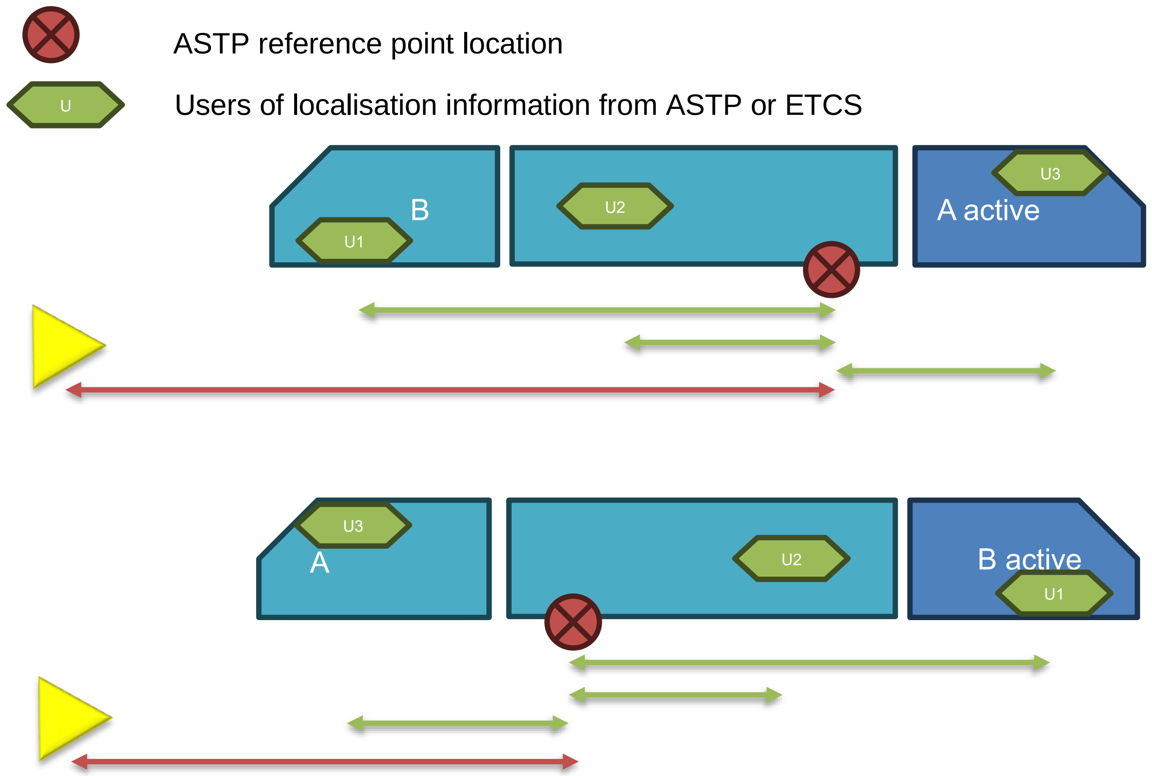


Figure 26: Derivation by users of localisation information from the ASTP

Green lines defined the distance between users' reference frames and the ASTP reference frame. Red lines show the distance of the ASTP reference point to the ASTP reference point location and the impact of the train orientation.

10.4 Track edge selectivity

The ASTP is determining the track edge taken into account the position of the ASTP reference point. Depending on the distance between the ASTP reference frame and the train front end the track edge id may differ. In this case the user (e.g. ATP/ETCS) has to determine the track edge ID.

The following Figure 27 shows the issue

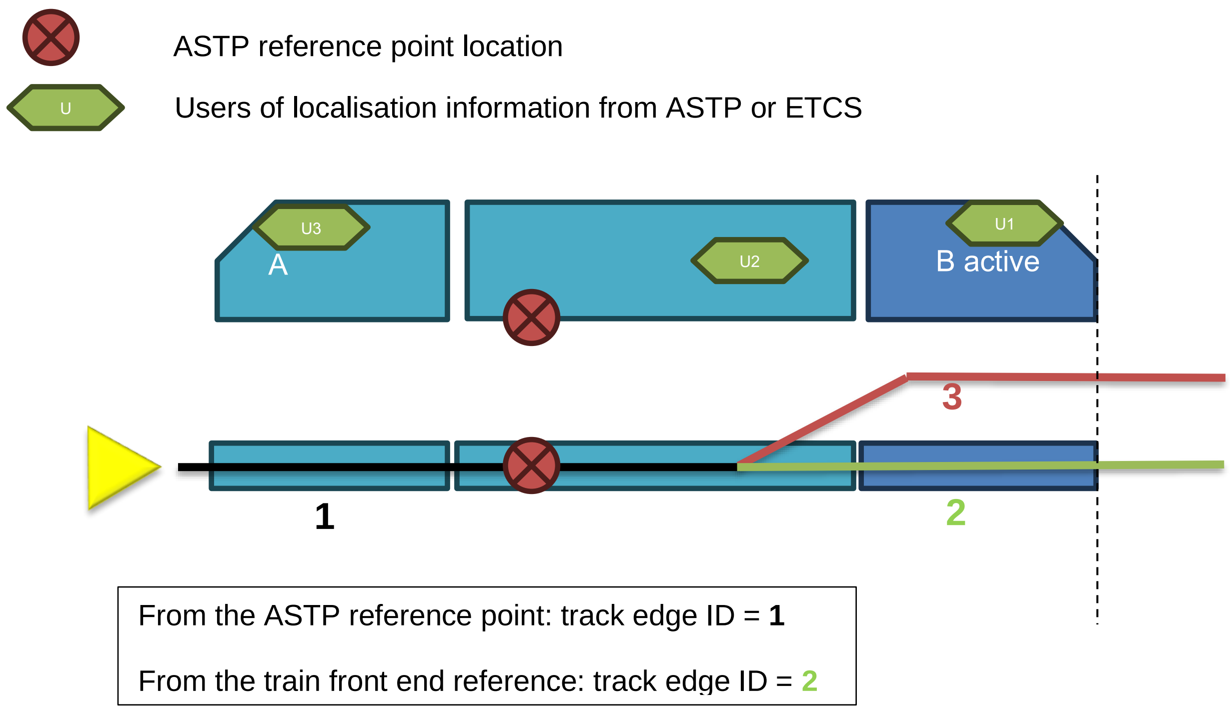


Figure 27: Track edge selectivity

11 EXPORTED CONSTRAINTS

This chapter makes a summary of constraints exported to components in interface with the ASTP:

11.1 ETCS-OB

11.1.1.1.1 ASTP needs the following input information from the ETCS-OB:

- LRBG, Balise message,
- Antenna Id in accordance with the message,
- Distance between the antenna and the ASTP reference point

11.2 REPOSITORY

11.2.1.1.1 The Digital Map data received by the ASTP shall use WGS84 system coordinate. Note: in the case the Map data doesn't use WGS84 coordinate system at the level of the IM, conversion shall be done before forwarding Digital Map data to the CCS-OB. This is to avoid any update of the conversion function between ETRS89 and WGS84 in the CCS-OB.

11.2.1.1.2 . Details of Map data needs shall be defined by WP22.

11.3 TRACKSIDE

11.3.1.1.1 ASTP shall receive from the trackside the point status (need to be confirmed by WP22)

11.4 EGNOS

11.4.1.1.1 ASTP shall receive from EGNOS augmentation data.

11.5 CMD

11.5.1.1.1 After power on ASTP shall receive from the CMD the status about train movement during power-off.

11.5.1.1.2 A movement is detected if the train makes a move of more than 2m.

11.6 TO LOCALISATION INFORMATION USERS

11.6.1.1.1 Localisation information is provided using the ASTP reference frames. If user requires the use of the train front end or another reference frame for localisation information, the user shall derive the localisation information to its own reference frame. Note: additional train data can be required to perform this transformation of localisation information (e.g., distance between reference frames).

11.7 SAFE TIME SYNCHRONISATION

11.7.1.1.1 Time synchronisation is required to make accurarate exchange of data with others. Safe time synchronisation is required to handle safety message. Safe time synchronisation principle needs to be defined at the level of the CCS-OB

12 CONCLUSIONS

This document published in the scope of the project R2DATO WP21 is based on the results and findings of CLUG1, X2R5, RCA and OCORA previous projects. Based on a synthesis of these projects, the document gathers main user's needs, requirements regarding the Advanced Safe Train positioning. Deliverable D21.2 derives the ASTP requirements.

Results of works done through technical notes provide solution to open issue, they are introduced in this release. This release wraps up all the knowledges of the WP21 working group at the time of the publication. Some choices on the CCS-OB architecture are made.

The main items defined in D21.1 are:

1. Architecture principles, interfaces and a proposal of function allocations between the ASTP and the CCS-OB components.
2. The principle of a reference frame attached to the ASTP to provide localisation information.
3. A preliminary list of supporting information that should help the achievement of performances.
4. A model of performance based on two fixed values. Performances are defined based on user needs and not technological dependent.

ASTP demonstrators with common architecture definitions and tests carried out in the scope of WP22 will provide feedbacks on WP21 deliverables. WP22 task 22.5 ASTP Impact -analysis shall identify the future update to be done.

Results from WP22 shall confirm the following items:

1. The principles of architecture and interfaces with the CCS-OB components.
2. The need of supporting information listed in the document.
3. The achievement of defined performances.

Concerning the identified open issues, since most of it where related to the overall CCS-OB architecture or specification (out of WP21 scope), WP21 could only provide the members points of view and proposals without considering the open issue closed. Only the System Pillar, with a broader scope of work, is able to take the right decisions to definitely close the identified open issues.

REFERENCES

List of approved documents

[1] SUSBSET-023 ERTMS/ETCS Glossary of Terms and Abbreviations issue 4.0.0 Baseline 4 R1

[2] SUBSET-026 ERTMS/ETCS System Requirements Specification issue 4.0.0 Baseline 4 R1

[3] SUBSET-035 ERTMS/ETCS Specific Transmission Module FFFIS issue 4.0.0 Baseline 4 R1

[4] SUBSET-041 ERTMS/ETCS Performance Requirements for Interoperability issue 4.0.0 Baseline 4 R1

[5] SUBSET 091 ERTMS/ETCS Safety Requirements for the Technical Interoperability of ETCS in Levels 1 & 2 issue 4.0.0 Baseline 4 R1

[6] SUBSET-125 ERTMS/ATO System Requirements Specification issue 1.0.0 Baseline 4 R1

[7] SUBSET-126 ATO over ETCS ATO-OB / ATO-TS FFFIS Application Layer issue 1.0.0 Baseline 4 R1

[8] SUBSET-130 ATO over ETCS ATO-OB / ETCS-OB FFFIS Application Layer issue 1.0.0 Baseline 4 R1

[9] SUBSET-147 ERTMS Data Applications CCS Consist Network Communication Layers FFFIS issue 1.0.0 Baseline 4 Baseline 4 R1

[10] CLC/TS 50701 Railway Applications – Cybersecurity issue august 2023

[11] EN 50126 Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability issue July 2018

[12] ERTMS Users Group/UIC - ERTMS/ETCS RAMS Requirements Specification - Chapter 2 – RAM - 96S126 issue V6

[13] LOC-OB System Definition & Operational Context LWG.Doc.022 issue 1.2

[14] OCORA-TWS01-101 Localisation On-Board (LOC-OB) High-level Requirements issue 3.1

[15] ERTMS Users Group/UIC - ERTMS/ETCS Environmental Requirements - 97S066 issue V5

[16] Enhanced onboard localisation CR 1368 issue 07 february 2020

List of snapshot documents

[17] D21.2 System requirements of ASTP system issue waiting for official release (*Snapshot document*)

[18] D27.1 Set of requirements on the Digital Register in FP2-R2DATO (*Snapshot document*)

[19] D5.5 Roadmap and migration strategy from X2R5 (*Snapshot document*)

[20] RCA.Doc.59 RCA Digital Map System Definition issue V0.5 BL04 (*Snapshot document*)

[21] ERTMS/ATO Operational requirements issue 1.15 X2RAIL4 EUG reference 13E137 (*Snapshot document*)

[22] SP-PRAMSS 30_Secure Component Specification

[23] SP-PRAMSS 40_Secure Communication Specification

[24] SP-PRAMSS 50_Shared Security Services Specification

[25] SP-PRAMSS 60_Security_Program_Requirements

APPENDIX A: ASTP AVAILABILITY JUSTIFICATION TARGET

This appendix provides the justification of the ASTP availability target. It is issued from EUG LWG LOC-OB System Definition and Operational Context LWG.Doc.022

The availability of the LOC-OB is defined to assess the performance with regard the value of the confidence interval associated to the estimated position, the estimated speed of the train. The availability is assessed on a monthly period of time.

The method used to define the availability target of the LOC-OB is based on the goal of the overall availability to be achieved at the level of a line. From the overall availability target, at the level of the line, an apportionment is made on the main systems. Finally, the LOC-OB availability target is derived.

The overall availability target of a line used in the calculation is 99,9% per month (which is not so high, in general it is more 99,97%).

This availability figure leads to a downtime of 43,2 min per month (line is operated 24H a day, 30 days per month).

The downtime is considered as the loss of time in operation (train delayed) with regard to the transportation plan. It is the time during the system is not performing as it should do leading to delay, to loss of capacity.

The three main systems considered at the level of the line are:

- Traction power and track.
- Rolling stock.
- Signalling and protection system.

The following apportionment of the down time are made between these systems.

Allocation to each subsystem		
Subsystem	Ratio	Downtime per month
Overall downtime	1	43,2 Mn
Traction power and track	0,25	10,80 Mn
Rolling stock	0,25	10,80 Mn
Signalling and protection system	0,50	21,60 Mn

Table 7: Allocation of downtime per month by subsystem

The signalling system and protection system is divided in two main parts of our interest: the on-board localisation system and the others (interlocking, ETCS trackside, ETCS on-board…).

The apportionment of the downtime used between these two parts is 1/3 to the onboard localisation system and 2/3 to the other parts. Hence the downtime allocated to the LOC-OB system is 7,2mn.

To assess the operating time of the LOC-OB, the analysis is based on a transportation plan (train planning) for main line corridor and high-speed line.

The number of trains running per hour in both directions are counted, then a mean of train running per hour can be derived (number of trains per hour during the day/24h).

Therefore, the operating time per month in minutes of the LOC-O B is: Mean Nb of train per hour * 24*60*30.

For the main line corridor, an average of 10 trains (both directions) per hour is used leading to an operating time of 432000 Mn per month.

For the high-speed line, an average of 15 trains (both directions) per hour is used leading to an operating time of 648000 Mn.

The average of 10 trains per hour for mainline corridor and 15 trains per hour for high-speed line are issued from actual line traffic plannings.

Finally, the LOC-OB availability figure is deduced for these two use cases.

	Main line	High speed line
Mean Nb of train per hour (both directions)	10	15
LOC-OB Operating minutes	432000 Mn	648000 Mn
Downtime (1/3 signalling and protection system)	7,20 Mn	7,20 Mn
LOC-OB availability	**99,9983%**	**99,9989%**

Table 8: LOC-OB availability target based on two use cases (10 and 15 trains per hour)

From this study the LOC-OB availability target is set to 99,998%.

APPENDIX B: LIST OF USER SUBSYSTEM

The following table presents a first list of users and the function allocation.

X: the function is required by the user

-: the function is not required by the user

?: the need is possible and needs to be confirmed.

The table needs to be consolidated in term of subsystem and function allocation.

	System fonction / Output fonction							
Subsystem of interest	***LOC-OB_SF-001 1D Position***	***LOC-OB_SF-002 1D Speed***	***LOC-OB_SF-003 1D Acceleration***	***LOC-OB_SF-004 3D Position***	***LOC-OB_SF-005 3D Velocity***	***LOC-OB_SF-006 3D Acceleration***	***LOC-OB_SF-007 3D Attitudes***	***LOC-OB_SF-008 Odometer information***
ERTMS applications (ETCS-OB	X	X	X	-	-	-	?	X
Juridical Recorder Unit (JRU)	X	X	X	?	?	?	?	X
Train Control and Monitoring System (TCMS)	X	X	?	-	-	-	-	?
Train Interface Unit (TIU)	X	X	-	-	-	-	-	?
Automatic Train Operation On-Board (ATO-OB)	X	X	X	-	-	-	-	-
Automatic Train Operation Vehicle (AV)	X	X	X	-	-	-	-	-
Automatic Processing Module (APM)	X	X	?	-	-	-	-	-
Driver Advisory System On-Board (DAS-OB)	X	X	?	-	-	-	-	-

Table 9: List of users and function allocation

APPENDIX C: ESTIMATED ERROR USING DIFFERENT REFERENCE FRAME

C-1 Purpose of the appendix:

In the context of the R2DATO project, the ASTP specification requires specifying the reference frame to be considered to evaluate the speed of the train, the position of the train front end.

The document evaluates the relative errors of speed, position according to the reference frame considered, mark along the track axis or reference mark along the longitudinal axis of the vehicle.

C-2 Defining reference frames

When the vehicle is inside a curve, the bogie pins follow the curve defined by the track centreline. At the bogie level, the tangent to the track centreline and the bogie pin defines the reference frame R1. The speed vector V1 is representing the train speed with respect to the reference frame R1.

The train front end is a point on the longitudinal axis of the vehicle belonging to the foremost transverse plane encompassing the foremost elements of the vehicle. The reference frame R2 is defined by the longitudinal axis of the carriage and the point representing the train front end (yellow dot).

Figure 28 presents a vehicle in a curve, the bogie pins (red dot) are following the curvature of the track, the train front end (yellow dot) and the speed vectors V1 in red representing the speed of the train on the track centreline, the speed vector V2 in yellow representing the linear speed of the train front end, the vector V3 in red representing the projection of the vector V2 on the longitudinal axis of the vehicle.

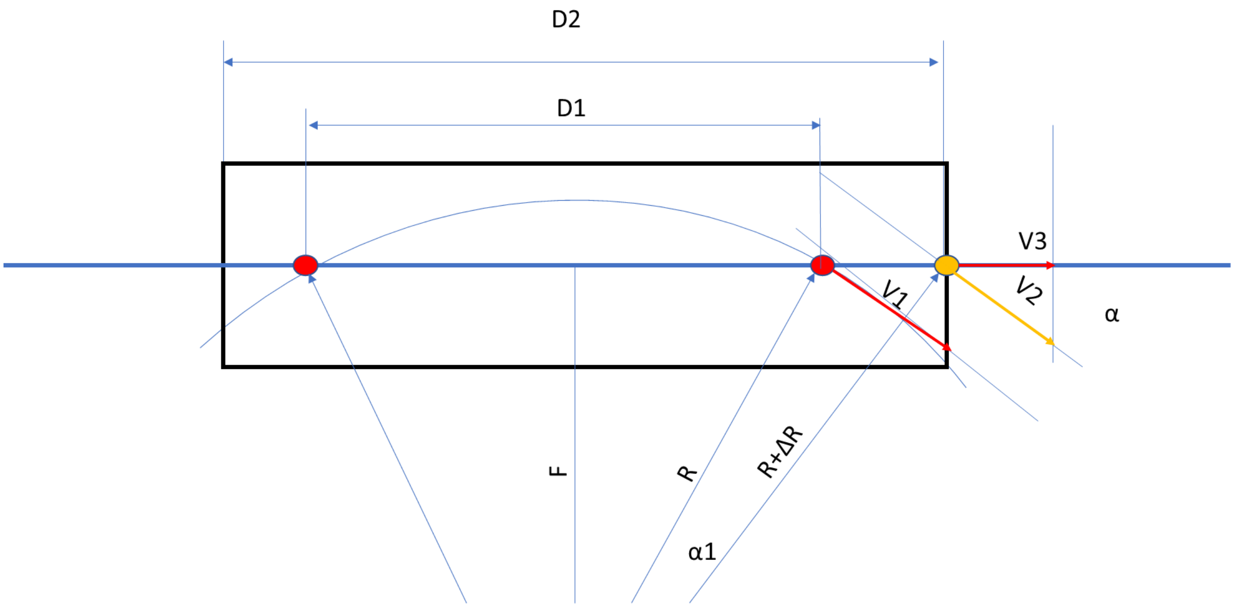


Figure 28: Different velocity vectors of a vehicle in a curve

C-3 Parameters

To evaluate speed or position errors according to the reference frames, the following parameters are taken into account.

D1: length between the pins of the 2 bogies of the vehicle.

D2: Vehicle length.

R: Radius of the curve (to the track centreline).

See Figure 28 for the definition of these parameters.

The results tables indicate for the values of the different parameters considered the errors.

C-4 Evaluation of speeds according to these reference frames

The car is in a curve of a radius R.

The linear velocity at the level of the bogie pin using the reference frame R1 is: $V1 = R * \omega$

Evaluation of the linear speed V2 at the train front end (following the tangent of the curve described by the train front end:

- The train front end is on a circle centred on the curve of the track centreline and for radius $R + \Delta R$.
- The arrow of the arc passing through the two pins is: $F = \sqrt{R^2 - (D1/2)^2}$.

- The radius of the circle passing by the train front end is $R + \Delta R = \sqrt{F^2 + (D2/2)^2}$.
- The linear velocity on the tangent passing by the train front end is $V2 = (R + \Delta R) * \omega$.
- We deduce the ratio of velocity according to the tangents as $\frac{V2}{V1} = 1 + \frac{\Delta R}{R} = \sqrt{F^2 + (D2/2)^2}/R$ as well as the relative error $\varepsilon_r = \frac{V2}{V1} - 1$.

Numerical application:

		Curve radius						
		150m	300m	600m	1200m	2400m	4800m	7000m
D1	D2	Relative error (V2-V1)/V1						
6m	10m	0,03555%	0,00889%	0,00222%	0,00056%	0,00014%	0,00003%	0,00002%
12m	17m	0,08052%	0,02014%	0,00503%	0,00126%	0,00031%	0,00008%	0,00004%
14m	22m	0,15987%	0,03999%	0,01000%	0,00250%	0,00062%	0,00016%	0,00007%
16m	24m	0,17762%	0,04443%	0,01111%	0,00278%	0,00069%	0,00017%	0,00008%
18m	26m	0,19536%	0,04888%	0,01222%	0,00306%	0,00076%	0,00019%	0,00009%

Table 10: Relative error of velocity vectors V1 and V2

The results of Table 10 show that the relative error between speeds V1 and V2 varies between 0.19% and 0.00002% for radii of curve varying from 150m to 7000m. Taking a speed of 500 km/h the maximum error is **0.27m/s.** This error is considered negligible. Note: the speed taken as a maximum evaluation is not necessarily compatible with certain radii of curve but makes it possible to determine the maximum error introduced using this reference frame.

Evaluation of the V3 speed according to the longitudinal axis of the car:

Angle of tangent and longitudinal axis $\alpha = {}^{\pi}/_{2} - \cos^{-1}\left(\frac{D2/2}{(R+\Delta R)}\right)$

$$V3 = V2 * \cos\alpha$$

$$V3 = V1 * \left(1 + \frac{\Delta R}{R}\right) * \cos\alpha$$

We have the speed ratio equal to with a relative error $\frac{V3}{V1} = \frac{\left(1+\frac{\Delta R}{R}\right)}{\cos\alpha} \varepsilon_r = \frac{V3}{V1} - 1$

Numerical application:

		Curve radius						
		150m	300m	600m	1200m	2400m	4800m	7000m
D1	**D2**	**Relative error (V3-V1)/V1**						
6m	10m	-0,0200%	-0,0050%	-0,0013%	-0,0003%	-0,0001%	0,0000%	0,0000%
10m	17m	-0,0800%	-0,0200%	-0,0050%	-0,0013%	-0,0003%	-0,0001%	0,0000%
14m	22m	-0,1089%	-0,0272%	-0,0068%	-0,0017%	-0,0004%	-0,0001%	-0,0001%
16m	24m	-0,1423%	-0,0356%	-0,0089%	-0,0022%	-0,0006%	-0,0001%	-0,0001%
18m	26m	-0,1802%	-0,0450%	-0,0113%	-0,0028%	-0,0007%	-0,0002%	-0,0001%

Table 11: Relative error of velocity vectors V1 and V3

The results of Table 11 show that the relative error between speeds V1 and V3 varies between -0.19% and 0.0000 0%for radii of curves varying from 150m to 7000m. Taking a speed of 500 km/h the maximum error is -**0.25m/s.** This error is considered negligible. Note: the speed taken as a maximum evaluation is not necessarily compatible with certain radii of curve but makes it possible to determine the maximum error introduced by using the longitudinal axis as the speed reference frame.

Conclusion: using the speed measured at the level of the bogie using the track centreline, or using the speed expressed on the longitudinal axis at the level of the train front end does introduce an error of less than 0,25m/s which can be considered as negligible.

C-5 Evaluation of position errors according reference frames

In the ETCS system the train is located according to a one-dimensional reference frame with the origin of a reference point called reference *location*. This reference point can change during the movement of the train, for example when passing a relocation balise. The measured distance corresponds to the curvilinear abscissa along the polyline representing the track centreline.

In the case using an absolute positioning system, the absolute position of the bogie pin can be determined. Thanks to the Digital Map this absolute position can be convert in a relative distance from the reference location.

Therefore, the localisation of the train front end can be deduced from the absolute position of bogie pin.

Knowing the position of the bogie pin in the one-dimensional reference frame, it is necessary to deduce the position of the train front end (see Figure 29, the yellow dot defines the train front end). To keep this notion of one-dimensional reference frame on the track centreline, in curve it would be necessary to determine the length of the arc defines by the bogie pin and the train front end on the track centreline. The train front end on the track centreline is the intersection of the circle passing by the train front end and the track centreline (see Figure 29).

This operation (calculation of the length of the arc) needs to manipulate configuration data such as the radius of the curve, the distances between the pins. To simplify the calculations, it is proposed to use the distance from the bogie pin to the train front end to determine the train front end position.

The purpose of the following calculation here-below is to evaluate the absolute error between the distance from the bogie pin of the train front end on the longitudinal axis and the arc limited by the train front end on the track centreline.

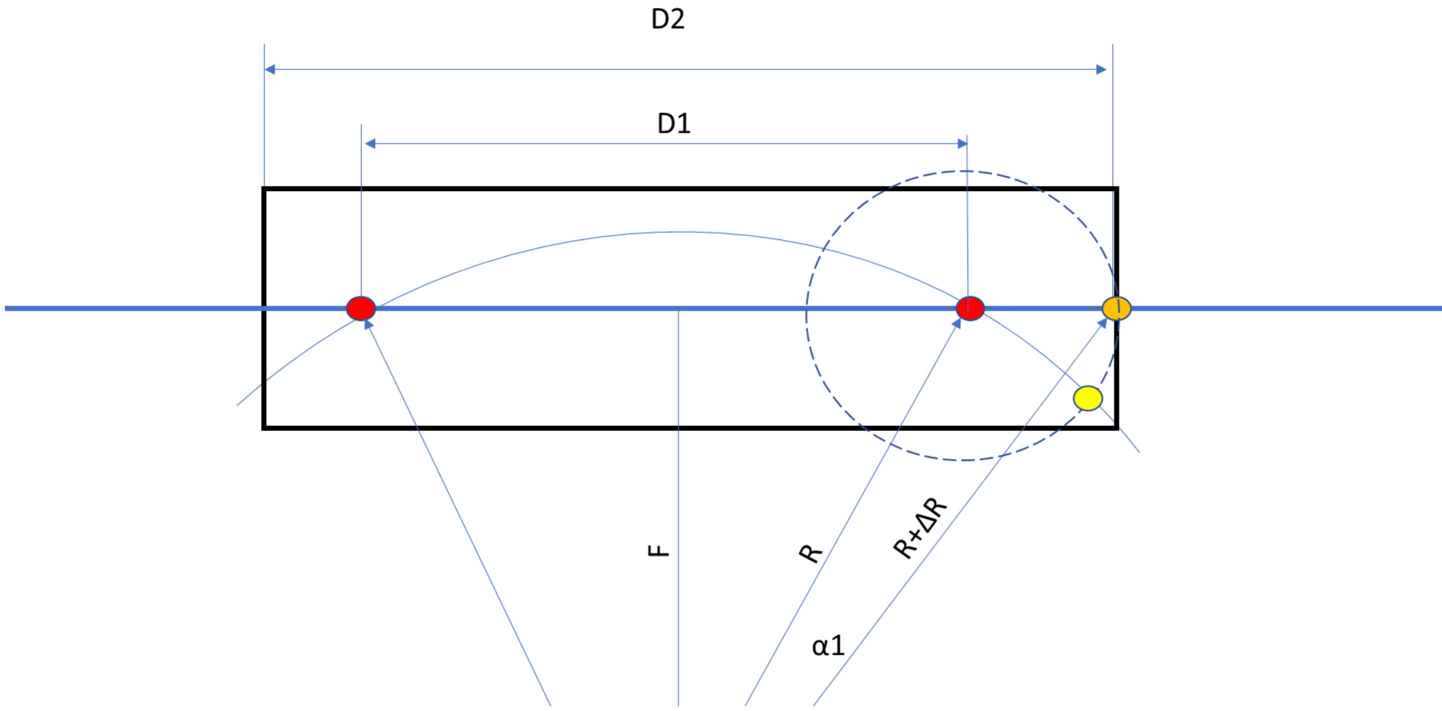


Figure 29: Train front end position determination

Let α1 be the angle formed by the radii passing at the bogie pin and at the train front end.

$$\alpha 1 = 2 * \sin^{-1}\big((D2 - D1/4)/R\big)$$

The length formed by the arc of a circle defined by the bogie pin and the point of train front end on the track centreline is $s = R * \propto_1$.

The distance between the train front end and the bogie pin $d = (D2 - D1)/2$.

We deduce the absolute error s-d= R*∝1-(D2-D1/2).

Numerical application:

D1	D2	Curve radius						
		150m	300m	600m	1200m	2400m	4800m	7000m
		Absolute error (d-s) in cm (longitudinal axis/ curvilinear length track axis)						
6m	10m	0.00148 cm	0.00037 cm	0.00009 cm	0.00002 cm	0.00001 cm	0,00000 cm	0,00000 cm
12m	17m	0.00289 cm	0,00072 cm	0.00018 cm	0.00005 cm	0.00001 cm	0,00000 cm	0,00000 cm
14m	22m	0,01185 cm	0.00296 cm	0.00074 cm	0.00019 cm	0.00005 cm	0.00001 cm	0.00001 cm
16m	24m	0,01185 cm	0.00296 cm	0.00074 cm	0.00019 cm	0.00005 cm	0.00001 cm	0.00001 cm
18m	26m	0,01185 cm	0.00296 cm	0.00074 cm	0.00019 cm	0.00005 cm	0.00001 cm	0.00001 cm

Table 12: Absolute error between the distances along the arc of a circle and the longitudinal axis

The results of Table 12 show that the absolute error between the distance from bogie pin to the train front end along the longitudinal axis or along the arc on the track centreline is a maximum of 0.012 cm for a radius of 150 m. The error introduced is therefore negligible.

Conclusion

Based on the absolute position of the bogie pin, the deduced train front end position in a 1D reference frame by using the train front end on the longitudinal axis or the train front end on the track centreline does not introduce a significant error. One or the other can be used.

APPENDIX D: TECHNICAL NOTE #1

Technical Note N°1
ASTP reference frame
Function allocation between ASTP and ETCS

Author	Saïd El FASSI (SNCF)
Partner	Bernhard Stamm (SMO) / Iban Lopetegi (CAF) / Andreas Von Kaenel (SBB) / Andreas Staudte (DB)
Date	11/06/2025
Document Code	R2D-WP21-I-SNCF-TN1-05
Status	Draft/Final

Document status		
Revision	Date	Description
01	27/05/2024	First issue
02	17/06/2024	Update following meeting
03	26/07/2024	Final issue
04	27/09/2024	Consolidated (additional statements and arguments presentred in annex)
05	11/06/2025	Reference error correction

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

1. OBJECT OF THE WHITE PAPER

1.1 Reminder of the open issue

[OI: FP2-ASTP-OPEN-ISSUE-3]: *ASTP/ETCS functions allocation*

[Open Issue]: The functions allocation between ASTP and the ETCS on-board needs to be confirmed.

[traceability]: D21.1 § 7.1.2

[Impact on ASTP]: Significant.

[Next step]: Decision to be taken with CCS onboard architects (System Pillar).

[END OI]

1.2 Issue to be resolved

Issue 1: The determination of localisation information following SUBSET-026, chapter 3 principle (1D relative train front end position, speed, acceleration), are the results of ASTP and ETCS on-board system.

The role of the ASTP in generating absolute and relative safe positioning in cooperation with ETCS, as well as in the overall CCS-OB architecture shall be clarified.

Shall the ASTP provide overall localisation service (1D and 3D localisation information) to all on-board consumers using the train front end reference frame or shall the ASTP only provide absolute and relative data using a fixed reference frame.

The note proposes to make first a review of these architectures at the CCS system level, and then to focus on the ASTP to identify their advantages, drawbacks.

2. CONTEXT

To be noticed that the texts or elements available in this chapter 2 are collected from other documents without any modifications or interpretation from the working group. The statements, facts or information present in this chapter may not reflect the ideas or point of view of the working group and are presented to help understanding and resolving the issue considering all the available points of view.

2.1 Reminder of D21.1 v11

In chapter 5.1.2.1 of D21.1, two architectures for providing localisation information are presented, ETCS oriented architecture and ASTP oriented architecture. The two following figures are extracted from D21.1

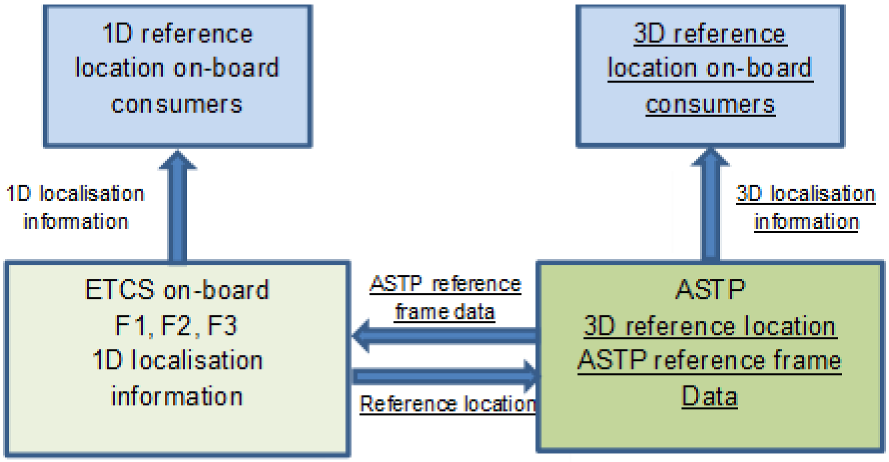


Figure 1: ETCS oriented architecture

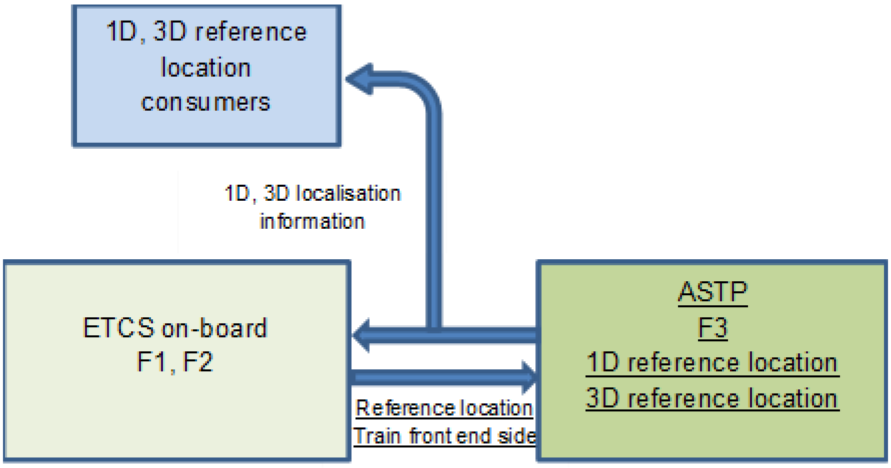


Figure 2: ASTP oriented architecture

D21.1 is making the following statement:

In the following parts of this document and deliverable, we have considered that the ASTP shall have the role of providing to all on-board consumers the 1D and 3D localisation information. Thus, the ASTP oriented system architecture is selected.

Depending on resolution of the open issue 3, the document D21.1 will be updated accordingly.

2.2 X2R5 REFERENCES

The following information is issued from relevant abstracts from X2R5 deliverable D5.5 Roadmap and migration strategy.

5.3.2 Functional Inputs

5.3.2.6 Train Dynamic Information (Safety Related Mandatory Input)

Train Dynamic information including active cab and train length. The active cab is required to understand the train orientation (see 3.6.1.5) with respect to the track orientation as defined in the digital map. The Train Length is used to calculate the offset value of the system sensors position respect to the train front of the active cab. the Train Length is safety related and the certainty of the integrity of the train is also needed to guarantee its value.

6.3.1 FSTP integration on CCS

- Scope:
  - The following proposal is targeting to provide positioning information for current ETCS TSI specification with the aim to reduce the number of balises on track. Any other use case not related to ETCS such as ATO or train integrity is out of the scope of this proposal. This means that the output functions that estimate heading, roll or pitch angles of the active cab are not part of E_ODO_OB output in this scope but it could be used for algorithm purposes (internally).

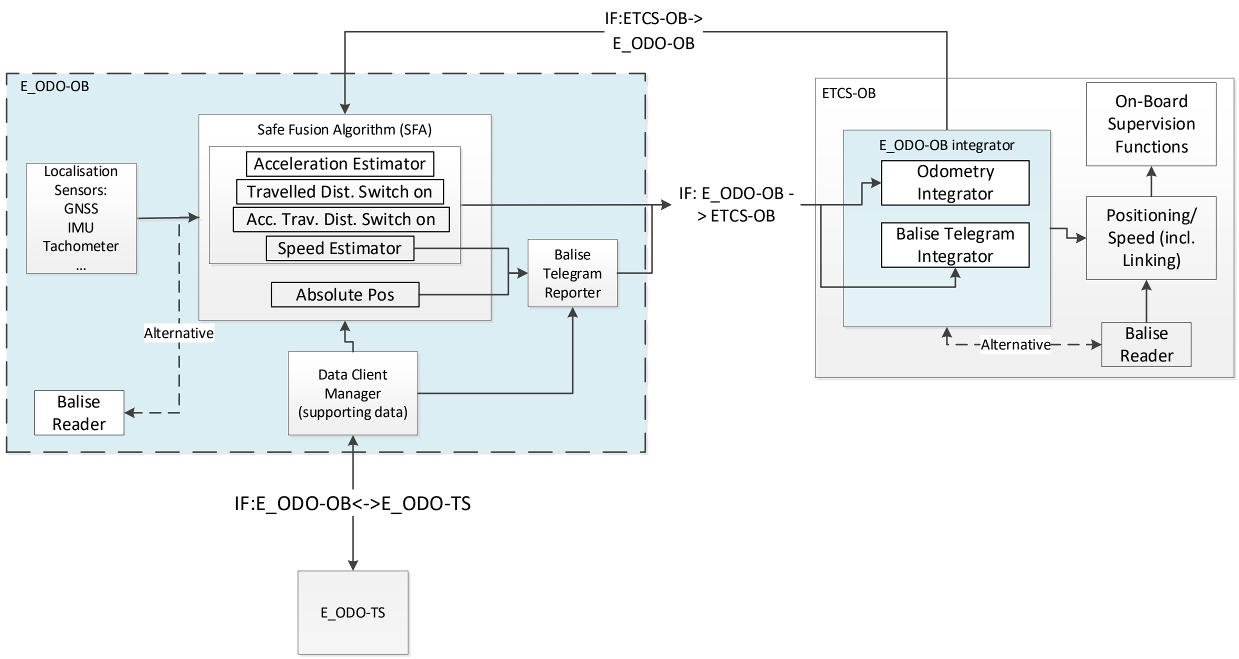


Figure 9: Architecture definition for Stream2 (upgrade in blue with respect to X2R2 defined architecture)

The *Safe Fusion Algorithm* (SFA) is the functional block that interfaces with the ETCS-OB. This functional block is divided into four main functions:

- Absolute Position Information Estimator
- Speed Estimator
- Travelled Distance since Switch On Estimator
- Accumulative Travelled Distance since Switch on Estimator
- Acceleration Estimator

The *absolute position information* from SFA is understood as the position that can be represented by a single-track edge and a distance from the start of that track edge.

For that purpose, the SFA uses data from *Sensors* functional block, *Data Client Manager* (for digital maps and augmentation information, if any) and E_ODO-OB inputs.

Since current state of the art technologies do not guarantee track discrimination with a SIL4 requirement, it is assumed that the read physical balise data is included as part of the input to the SFA. For this information there are two alternatives not decided at the stage of this proposal:

- On one hand, the physical balises read from ETCS are sent to the E_ODO-OB through the *IF: ETCS-OB->E_ODO-OB* interface.
- On the other hand, Balise reader itself is part of the E_ODO-OB sensor list and thus every physically read balises shall be reported to ETCS-OB.

Notice that the described absolute position makes a reference to a fixed point at the train vehicle in which the main sensors are installed. In other words, SFA is NOT responsible to calculate active cab's position, as this remains an ETCS-OB responsibility. However, the consumer of E_ODO-OB may require knowing this fixed point at the vehicle, which is considered a configuration information similar to the case of a tachometer sign known by ETCS-OB.

In addition, the absolute position information shall also be provided with a confidence interval which is based on the best effort of the algorithm. In other words, the CI provided by this information can shrink and grow without any restrictions.

The *speed estimator* function is responsible to estimate E_ODO-OB speed value and its confidence interval. It is expected that the estimation is used by the Balise Telegram Reporter function and by the ETCS-OB system as pure odometry information.

The *travelled distance since switch* on function is responsible to estimate travelled distance and its confidence interval since switch on. The confidence interval related to this function is a never shrinking confidence interval as it is for today's ETCS-OB odometry system. This is necessary to allow a seamless integration of this information within ETCS-OB. Notice that information is expected to be used by ETCS-OB to recalculate its confidence interval and to comply with STM requirements, see SUBSET-035 §8.3.

The *accumulative travelled distance since switch on* function is the travelled distance since switch on regardless of the direction of the travelled value, that is summing up absolute value of the travelled distance since switch on. The main purpose of this information is to facilitate the performance of the overall algorithms of E_ODO-OB.

The acceleration estimation function is responsible to estimate acceleration value. This information is necessary for ETCS-OB to comply with the A_traction value for the braking curves, SUBSET-026-3 §3.13.2.2.2.

OCORA ONBOARD ARCHITECTURE

2.2.1 Information from CCS On-Board Architecture document

At the CCS-onboard system level the document OCORA-TWS01-035 BL5 OCORA CCS On-board reference architecture presents the following information of the localisation on-board in the overall architecture. A standard communication interface is proposed to forward localisation information to all CCS on-board users.

Following information is issued from the CCS- on-board reference architecture document.

4.12 Localisation On-Board (LOC-OB)

Localisation On-Board (LOC-OB) contains the Vehicle Locator (VL) and Vehicle Locator Sensor (VLS) functionality. The Figure 16 identifies the LOC-OB component in the overall CCS-OB architecture and depicts all interfaces to all currently know CCS-OB actors and CCS-OB components.

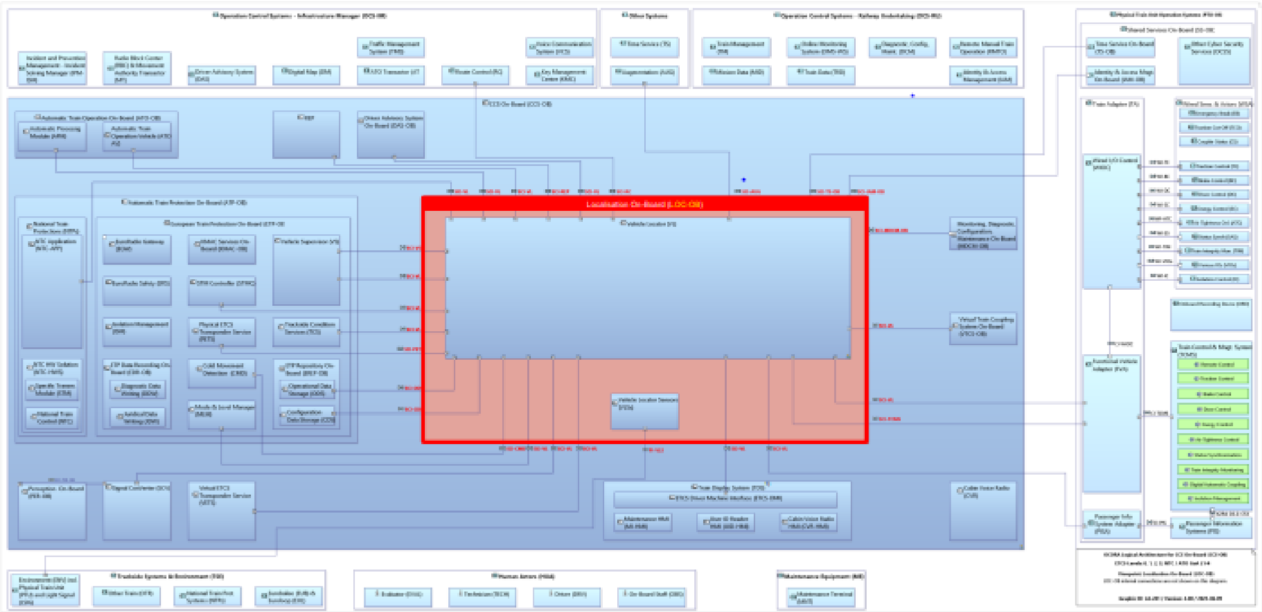


Figure 16: Localisation On-Board (LOC-OB)

6.33 SCI-VL is the standard communication interface provided by the Localisation On-Board (LOC-OB, refer to chapter 4.12) or more specifically its Vehicle Locator (VL) component. Through this interface the Vehicle Locator (VL) makes location information (absolute and relative position of the front end of the train unit, train orientation information as well as kinematic parameters such as speed, acceleration, or rotational angles) available to other components or sub-systems outside of the CCS On-Board (CCS-OB), typically these components are the Physical Train Unit Operation

Systems (PTU-OS) and the Passenger Information System (PIS) using the Passenger Information System Adapter (PISA). The components which are involved in this data exchange depends on the system capabilities required from the vehicle in the specific project. OCORA aims at providing a standard for this interface.

2.2.2 Information from Localisation on-board introduction document

Localisation on-board introduction OCORA-TWS01-100 provides the following information:

3.2 OCORA Localisation On-Board (LOC-OB) principles

Sharing localisation information not only with ATP-OB (logical component of CCS-OB) but also with other (future) on-board actors through a standardised interface is a key objective of the LOC-OB architecture. The LOC-OB shall provide localisation information such as 1D position relative to a reference point, orientation, speed and acceleration of the train which complies with the current ERTMS/ETCS principle (distance and orientation from a LRBG and a speed) and can also provide additional localisation information such as:

- The absolute (3D) geographic positioning (Long, Lat, Alt),
- The vector velocity within the 3D coordinate system based on the track axis,
- The vector acceleration within the 3D coordinate system based on the track axis,
- The attitude (roll, pitch, and yaw angles) of the coach where sensors are installed.

Localisation on-board requirements OCORA-TWS01-101 provides more detailed architecture information about system interfaces such as the required input information and system output information provided.

3. OPEN ISSUE ANALYSIS AND DECISIONS

3.1 ISSUE

The ASTP has its own reference frame to determine localisation output data from its sensors. The output data (1D, 3D …) can be provided in accordance with a fixed reference frame or expressed using the train front end reference frame.

It is noted that whatever is the reference used by the ASTP, if the ASTP is not installed in the leading vehicle of the train, the extrapolation of localisation data using the train front end reference frame can face a loss of quality. This is due to various body movements. More specifically, the attitude data shall only be considered for the vehicle body where the ASTP is installed. Thus, the attitude data can't be extrapolated in the case the ASTP is not installed in the first vehicle.

In the following chapters we define the context of the ASTP in the CCS onboard, moreover the context of localisation needs and potential users, then the fixed reference frame, the train front end reference frame. The functions to transform data from fixed reference frame to Train front end reference frame and the need of inputs data are identified. Finally, functions allocation is discussed with the identification of the advantages and drawbacks.

3.2 CCS ONBOARD ASSUMPTIONS

The CCS onboard shall allow automatic train operation from GOA1 up to GOA4.

Under the work done in projects X2R4, X2R5; TAURO, and OCORA, to achieve these goals of automation, new set of functions are identified. In this context the needs of localisation information are not limited to the ETCS core functions and to the train front end position information. Upcoming consumers like ATO, Perception, Automatic process module require train localisation information that also shall be enhanced by specific new localisation information like 3D absolute position, train heading, body attitude…

The CCS onboard architecture shall be versatile and scalable to various train configurations.

3.3 CONSUMERS OF LOCALISATION INFORMATION

From a first analysis of OCORA architecture document OCORA-TWS01-035-CCS-On-Board-(CCS-OB)-Architecture release 5, in R2DATO D21.1 deliverable chapter 5.2.5 the following consumers of the localisation information are identified in a short or long term view:

1. ERTMS applications (ATP-OB including NTC)
2. Automatic train operation (ATO-OB including APM (Automatic Processing Module) and ATO (Automatic Train Operation))
3. JRU
4. TCMS (panto, doors…), Functional vehicle adapter
5. DAS-OB

6. SCV (signal converter to provide data to the perception system)
7. Train Display System (TDS)
8. Virtual Train Coupling System
9. Detection of virtual balise and telegram generator
10. Passenger information system
11. Repository

It is noted that localisation information from consumers' requirements differ:

- Type of localisation information: 1D, 3D, heading, attitude…
- Accuracy of the data: the need of accuracy varies.
- Safety requirements: no safety constraint up to a TFFR of 10-9/h.

3.4 Localisation information

From work done in WP21 of R2DATO a first approach allows to find communalities between consumers' needs. Thus, the following localisation information shall be available to consumers to fulfil CCS onboard needs. A list of system functions is identified in D21.1 chapter 7.1:

- ASTP_SF-001: Provide Safe Train Front End 1D Position
- ASTP_SF-002: Provide safe 1D Train Speed
- ASTP_SF-003: Provide safe Train Acceleration
- ASTP_SF-004: Provide 3D Position and Uncertainty
- ASTP_SF-005: Provide 3D Velocity and Uncertainty
- ASTP_SF-006: Provide 3D Acceleration and Uncertainty
- ASTP_SF-007: Provide 3D Attitude and Uncertainty
- ASTP_SF-008: Provide Odometer information

3.5 Reference frames

3.5.1 Bogie pin reference frame

To process data from localisation sensors (wheel sensor, IMU, GNSS…) the ASTP has its own reference frame. The ASTP can provide data using a fixed reference frame for instance the bogie pin reference frame where ASTP and its sensors are installed. The bogie pin reference frame is determined by static configuration and never change (e.g., due to movement of the train or the train operational configuration).

It is a three-dimensional reference frame where localisation information is expressed on the 3 axis component values. It is defined by the carriage frame by a right trihedron. On the plan defined by the carriage floor, the x axis is the carriage longitudinal axis oriented to a side of the carriage (e.g., the closest from the ASTP), y axis is the orthogonal to the carriage longitudinal axis oriented to the left, z axis the orthogonal to the carriage floor oriented up, the origin point is the bogie pin close to the ASTP

In the case the vehicle is not fitted with a bogie, the origin point can be the front of the carriage.

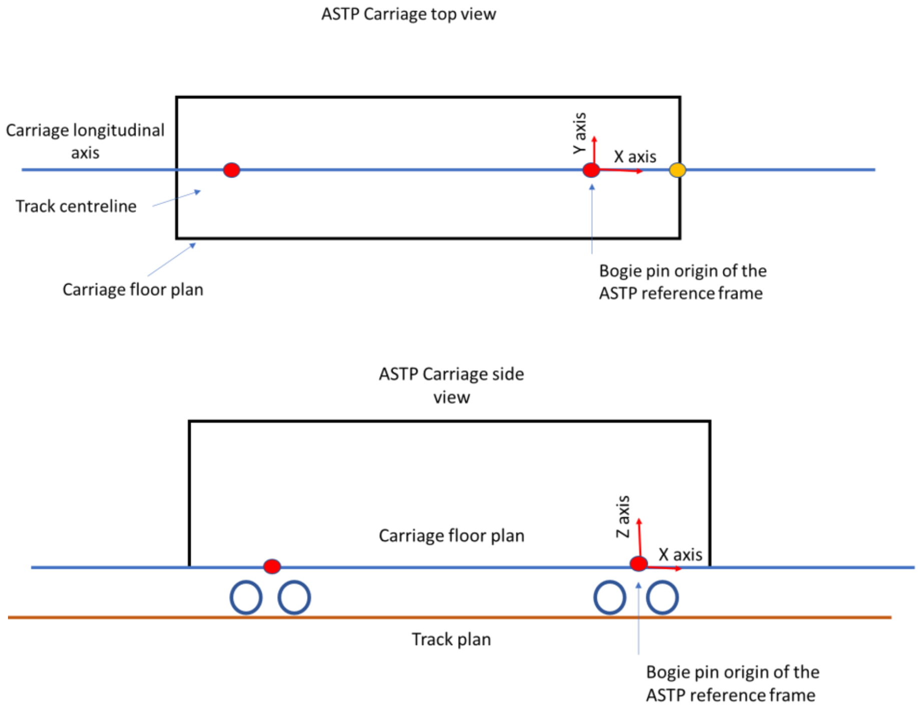


Figure 3: Bogie pin reference frame

3.5.2 Train front end reference frame

Users' application in CCS onboard (e.g., ETCS, ATO, APM…) are usually using localisation information with the train front end as the origin of the reference frame. Thus, the train front end reference frame will depend on the side of the train that shall be considered as the front of the train (in general the active CAB determines the side to be considered).

It is a three-dimensional reference frame where localisation information is expressed on the 3 axis component values. It is defined by the carriage frame by a right trihedron. On the plan defined by the carriage floor, the x axis is the carriage longitudinal axis oriented to the train front end, y axis is the orthogonal to the carriage longitudinal axis oriented to the left, z axis the orthogonal to the carriage floor oriented up, the origin point is the train front end. For more detailed information about the train front end see subset 026 chapter 3.6.1.3.4.

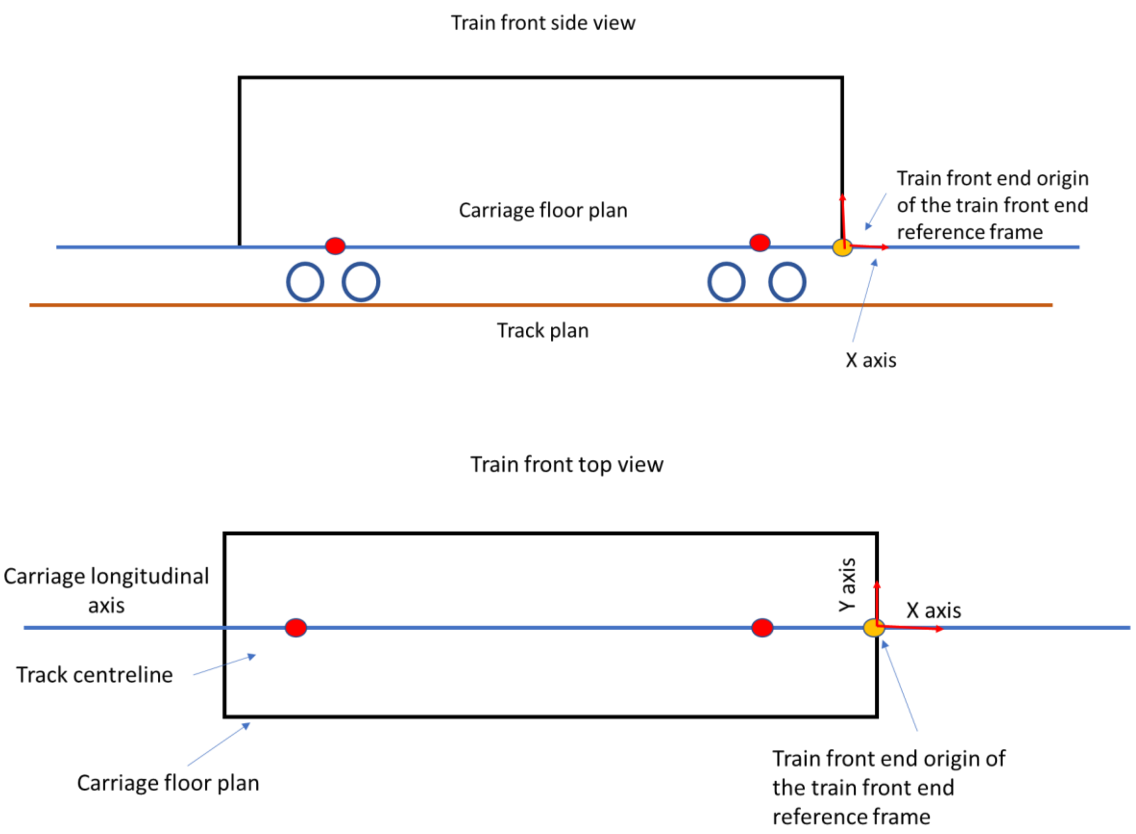


Figure 4: Train front end reference frame

By using the train front end reference frames two major issues need to be considered:

First, most trains consist of multiple vehicles, or at least multiple car bodies. This can either be for permanently coupled trainsets, such as a single TGV, multiple trainsets, or even a locomotive with waggons. Depending on the type, length and product, different ETCS installations exist. The following figure presents some examples of train configuration (the three configurations are non-exhaustive):

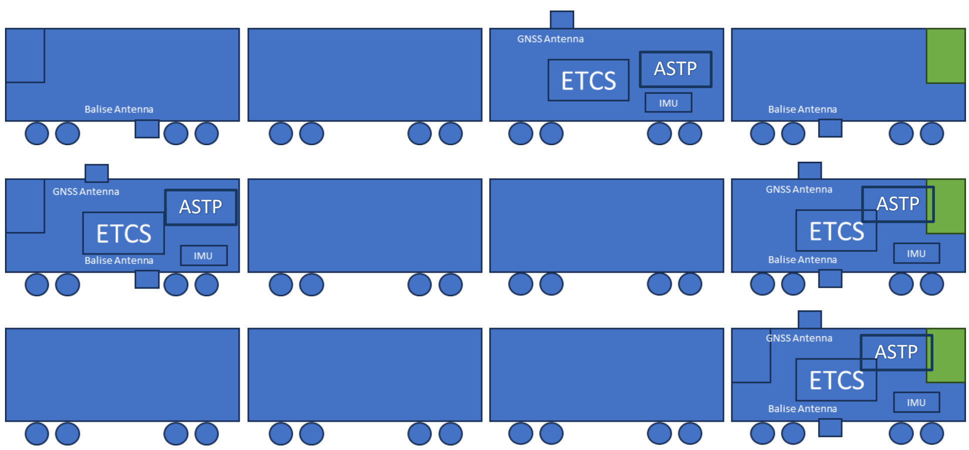


Figure 5: Examples of train configuration

Second, the vehicle body moves significantly in relation to the track. Height above the track, body angles in relation to the track and even lateral position of the vehicle body in reference to the track centreline can vary significantly when a train moves, due to sinusoidal run, centrifugal force, track cant, speed, suspension, wheel wear and mechanical mounting, as well as tilting mechanisms, if used.

3.5.3 Differences between bogie pin and train front end reference frames:

1. Bogie pin reference frame is fixed and defined by configuration and never changes during train operation. It refers to the vehicle where the ASTP is installed.
2. Train front end reference frame depends on the side of train that shall be considered as the train front end. It changes during train operation. Depending on which vehicle the ASTP is installed, the train front end reference frame can belong to another vehicle.
3. The origins of the two reference frames are distant on the x axis of the length between the train front end and the origin of the bogie pin reference frame. In other words, a translation on the x axis needs to be done to switch from the bogie pin reference frame to the train front end reference frame. The value of this translation depends on the operational configuration of the train.
4. The X and Y axis of the reference frames can be oriented in the same or reverse direction. This has an impact on the sign of the speed and acceleration but also on the heading and attitude data.
5. In the case the ASTP is not installed in the first vehicle, due to movement of bodies, effects of coupling device, increased uncertainties of localisation data, in general we are facing a loss of quality.

3.6 Localisation Service Provider

At the level of the CCS on-board architecture three types of localisation service provider architecture are presented.

1. ASTP is the localisation service provider. In this case it provides data using the train front end reference frame to all consumers. The localisation data is broadcasted over the onboard CCS data network

Figure 6 ASTP localisation service provider

2. ETCS is the localisation service provider. In this case, ASTP is providing data only to the ETCS using the bogie pin reference frame. The ETCS is making the translation to the train front end reference frame and providing all localisation data to consumers by broadcasting localisation data over the onboard CCS data network.

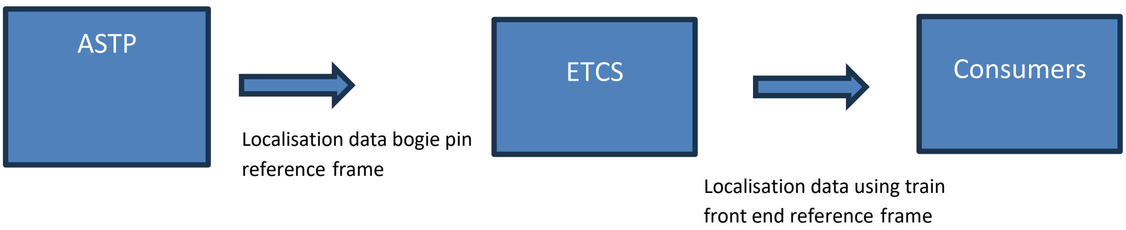


Figure 7 ETCS localisation service provider

3. The service is split between ASTP and ETCS. The ASTP is providing data using the bogie pin reference frame. The ETCS is processing the determination of 1D localisation data, speed and acceleration using the train front end reference frame. It provides this data to consumers. Consumers can also access all localisation data using the bogie pin reference frame from the ASTP and broadcasted over the data network. Consumers can use 1D localisation broadcasted by the ETCS, or based on the ASTP localisation data perform any localisation data translation to their own localisation reference frame.

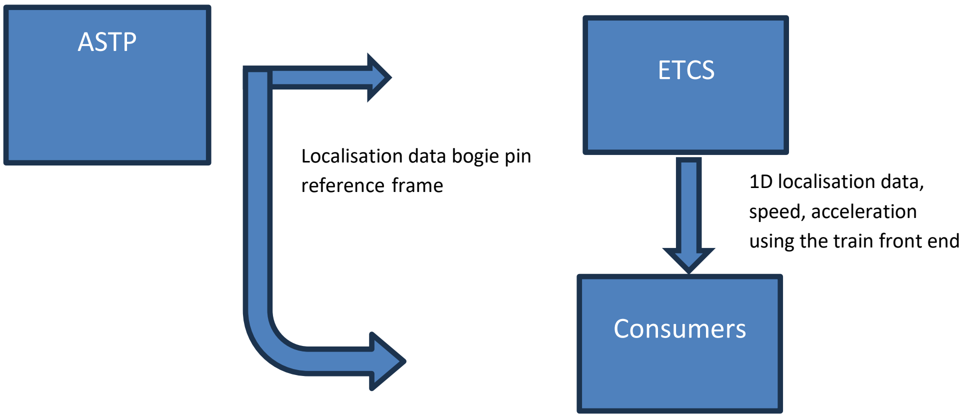


Figure 8 ASTP and ETCS are localisation service providers

From these 3 architectures that represent localisation data flows at the CCS system level, the role of the ASTP, ETCS or consumers, we can derive two cases from the ASTP prospective.

- Case 1: The ASTP is broadcasting localisation data using the train front end reference frame. It can be considered as the CCS on-board train front end localisation service provider.
- Case 2: The ASTP is broadcasting localisation data using a bogie reference frame. The service is called bogie pin reference localisation service provider.

The following chapters present first the process to transform data from a bogie pin reference to a train front end reference frame then the detailes of the two cases highlighting the pros and the cons.

3.7 Transformation of data

In the case the ASTP is providing data using the bogie reference frame, localisation consumers using train front end reference frame need to perform the following functions:

Function 1: Acquire the information determining the side of the train that shall be considered the train front end. This information can be provided by the ETCS.

Function 2: Acquire the length between the bogie pin of the ASTP carriage and the train front end which shall be dynamically computed based on the train configuration.

Function 3: Determine the train orientation using the balise data or the Digital Map data.

Function 4: Shift the localisation information from the bogie pin to the train front end (1D localisation data).

Function 5: Determine 1D data set using the train front end reference frame (train orientation, position qualifier from the LRBG…).

Function 6: Make the kinematic data consistent with the train orientation (sign of speed, acceleration, heading, attitude angles…).

Function 7: Determine the track-edge ID consistent with the localisation of the train front end. Access to the Digital map is required to perform this determination. ASTP is determining the track-edge ID using the origin of the bogie pin reference frame. When a train is passing a point, the 1D data can be determined. But since the train front end is in a forward location, determination of the track edge of the train front end needs to be done. If after the point there are several possibilities, either the track edge cannot be determined until ASTP passes the point or supporting information from the route needs to be used to determine the track edge of the train front end. The determination of the track-edge ID is required to update 3D data set.

Function 8: Update the 3D localisation data sets using the relevant track-edge ID. Note the attitude data set cannot be transformed. Attitude data set is relevant only for consumers installed in the same vehicle of the ASTP.

The Figure 9 depicts the general process to transform data expressed using the bogie pin reference frame to the train front end reference frame up to the localisation service provider.

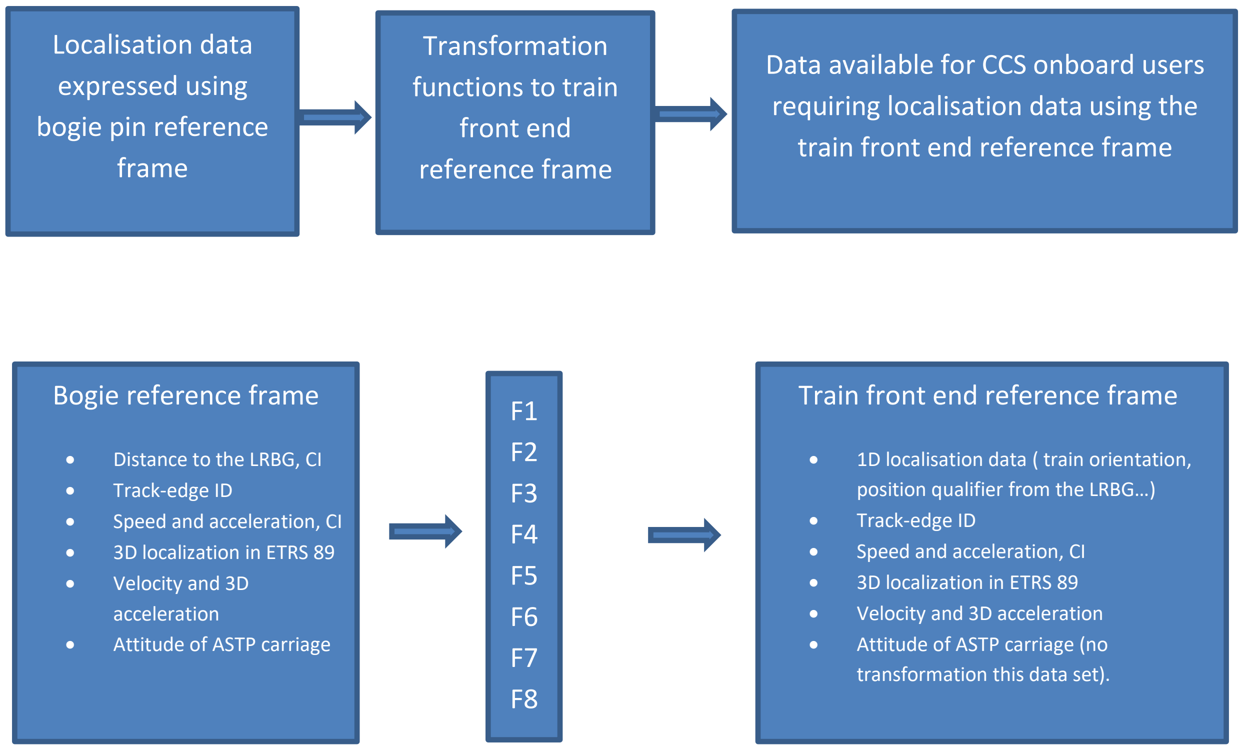


Figure 9: Process to transform data from bogie reference frame to train front end reference frame.

3.8 CASE 1: ASTP CCS ON-BOARD TRAIN FRONT END LOCALISATION SERVICE PROVIDER

In this architecture the ASTP provides outputs using the ASTP train front end reference frame. It is the localisation service provider, see Figure 6.

In this architecture Functions F1 and F2 are allocated to the ETCS, Function F3 to F8 to the ASTP.

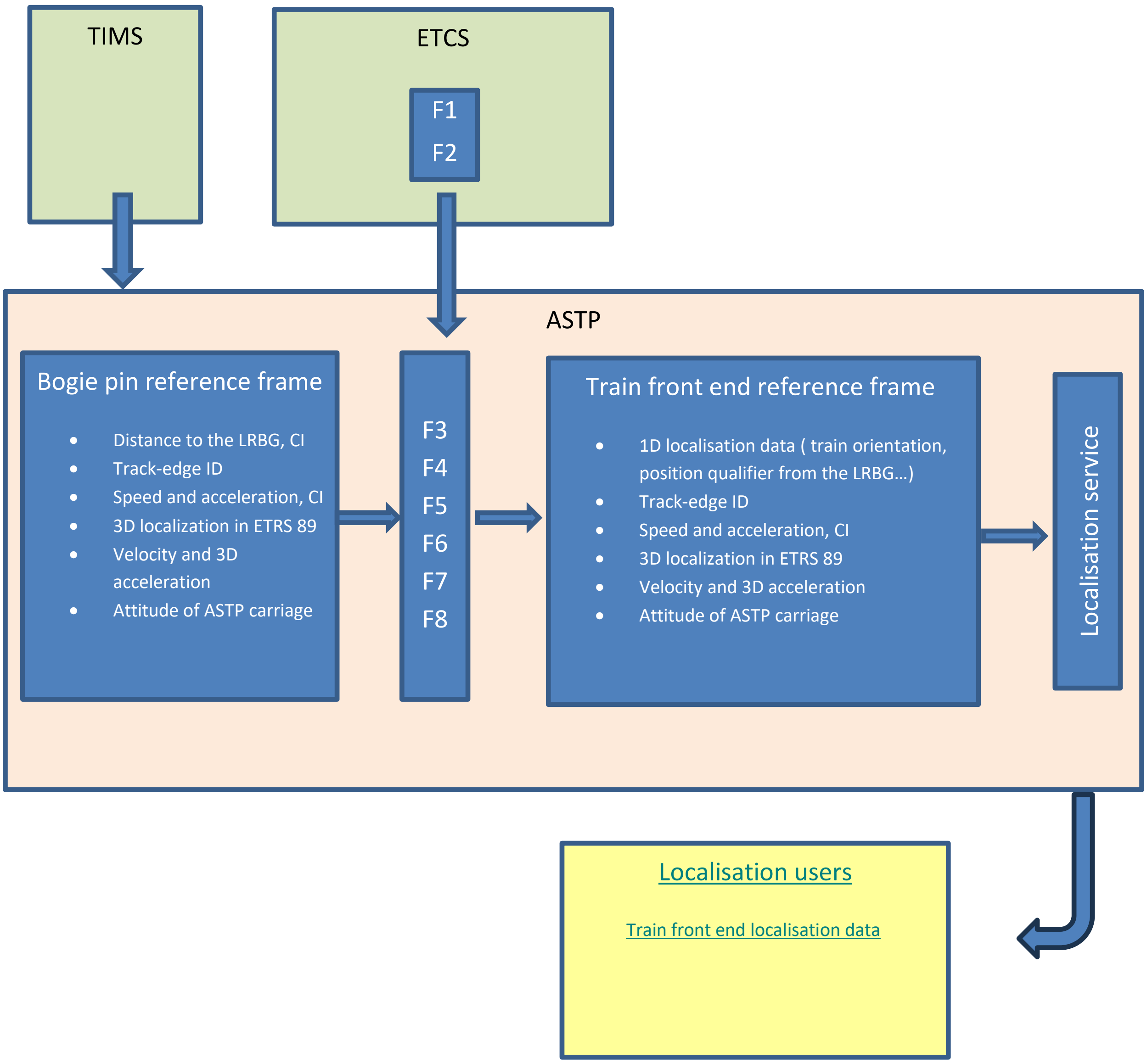


Figure 10: Function allocation with ASTP as the localisation service provider

ASTP requires additional input information:

- Only additional required inputs to make the transformation are listed. Required inputs to determine localisation data are not listed (e.g., balise data, digital map…). Please see D21.1 for all input information required by the ASTP.
- F1: ASTP needs to acquire the information about the side of the train to be considered as the train front end.
- F2: ASTP needs to acquire the length between the origin of the bogie reference frame and the train front end. This information can be static or dynamic depending on the train configuration and the position of the ASTP. This information can be provided by the ETCS or another building block of the CCS onboard
- TIMS: if the ASTP is not installed in the leading vehicle, TIMS information is required to achieve the safety requirement of the localisation of the train front end. For details see D21.1.

PROS:

1. Localisation service is centralised. Train front end localisation data sets are the same for all consumers.
2. Having one source of localisation makes system analysis easier. There is no need of realignment of data to make data comparison between consumers.
3. Meanwhile Localisation consumers can transform localisation data to any reference frame.
4. Safe information is made available without adding an additional safe cycle time to validate the integrity of the data.
5. The ASTP can adapt the refreshing cycle of the localisation data to the consumer' needs.
6. The localisation performance is the result of the ASTP only.

CONS:

1. The ASTP needs additional inputs (side of train considered as the train front end, length between bogie pin and train front end, TIMS if required).
2. The ASTP is linked to the ETCS localisation principle.
3. The ASTP has to be consistent with the train operational configuration.

3.9 CASE 2: ASTP BOGIE PIN REFERENCE FRAME LOCALISATION SERVICE PROVIDER.

In this architecture, see Figure 11, the ASTP provides data using the bogie pin reference frame to all consumers including the ETCS. The localisation data is broadcasted over the onboard CCS data network.

The ETCS is performing the transformation of 1D data sets to the train front end reference frame and can broadcast this information over the network. In this configuration, consumers can transform ASTP localisation data to their own reference frame. We have localisation data sets expressed using two or more localisation reference frames.

In this architecture Functions F1 to F7 are allocated to the ETCS.

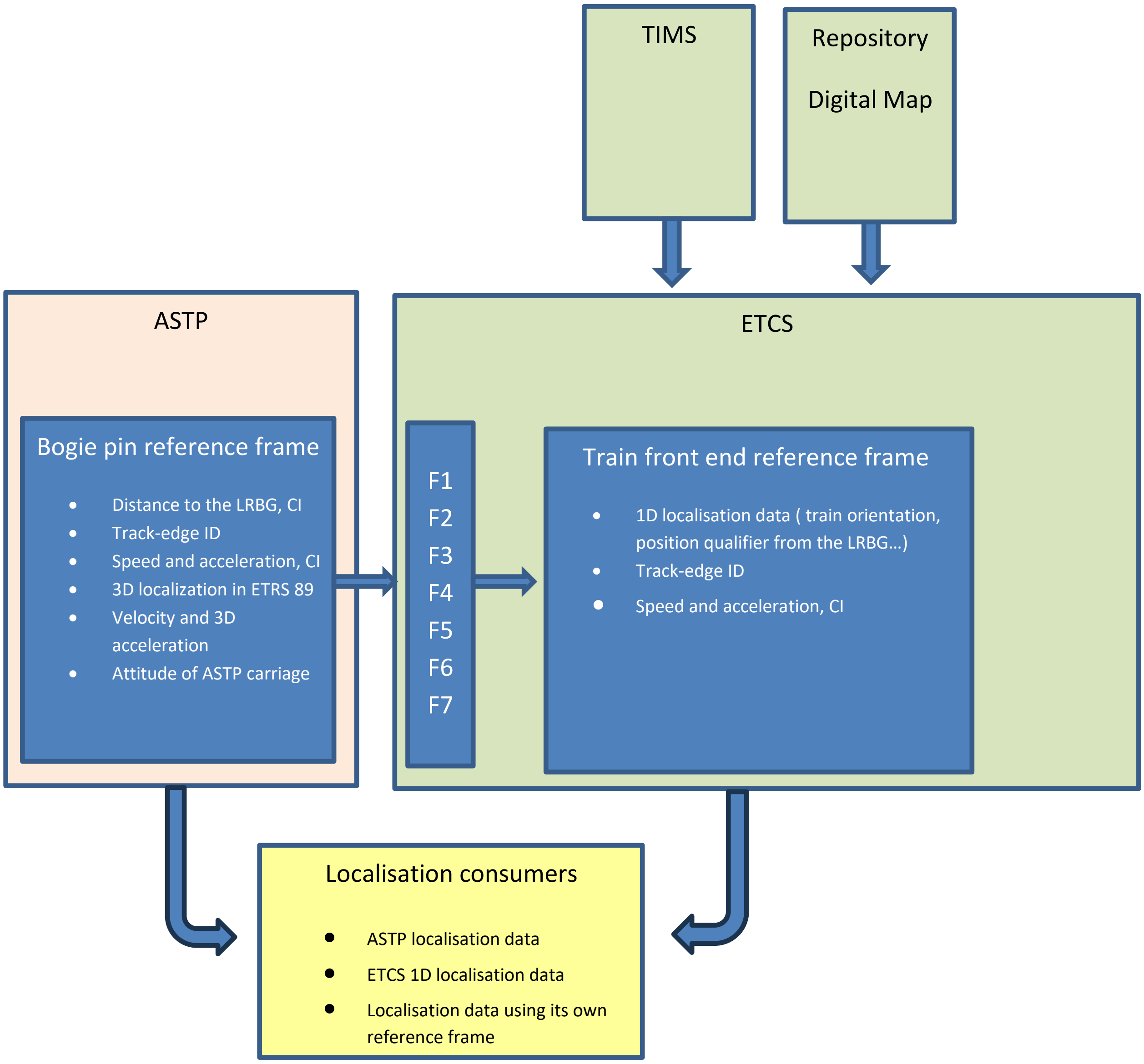


Figure 11: Functions allocation with the localisation service provider shared between the ASTP and the ETCS.

ETCS input information:

Only additional inputs required to make the transformation are listed:

- ETCS needs to access Digital Map data to determine the track-edge ID of the train front end.
- ETCS needs to get from the train the information about the active cab. This information is already available at the level of the ETCS.
- ETCS needs to determine the length between the bogie pin reference frame origin and the train front end reference frame. In the case the ASTP is not installed in the same vehicle of the ETCS, this information can be dynamic depending on the operational configuration of the train.

Consumers' input information:

- Depending on available information at the level of the consumer, and the specificities of the reference frame to be used, input information has to be defined specifically by each consumer to process the transformation of the localisation data.

PROS:

1. Localisation consumers access to bogie pin reference frame and train front end reference frame localisation data sets.
2. Localisation consumers can transform localisation data to any reference frame.
3. Data provided by the ASTP doesn't depend on the operational train configuration.
4. ASTP doesn't need additional input information.
5. ASTP can provide localisation data to all consumers without any specific interface.

CONS:

1. Having multiple localisation service providers and possibly different reference frames, it can make system analysis difficult. For system analysis, alignment of localisation data will be necessary to make easier comparison between data of subsystems.
2. The performance of localisation data, accuracy, quality of data can differ between consumers.

1. In the case consumers require safe localisation data from the ETCS, by adding one hop for delivering safe data to consumers, the increase of the latency due to ETCS safe processing time can be an issue. Depending on supplier safe processing time can vary from 200 ms to 1s (maximum defined in subset 041).
2. The determination of the track-edge ID of the train front end can be an issue and requires ETCS or consumers to access the Digital map.
3. Performance of the localisation is shared between the ASTP and consumers.

4. DECISION TO BE TAKEN

From case 1 and case 2 of ASTP architecture no consensus is found to select one architecture. Decision has to be made by the System Pillar.

The main advantage of architecture # 1 is to share the same train front end localisation data set to all onboard users.

The main advantage of architecture #2 is to make the ASTP independent of the train configuration.

Both cases allow consumers to adapt the localisation data to their own reference frame if needed.

The following table provides comparison between the two proposed architectures:

	Case 1 ASTP provides localisation data sets using Train front end reference frame	Case 2 ASTP provides localisation data sets using bogie pin reference frame
User can adapt localisation data to their own reference frame	Yes	Yes
Quality of the data	Train front end localisation data has the same data quality whatever is the user.	Train front end localisation data quality may differ between users.
Train configuration independency	No. ASTP shall acquire train configuration data in order to determine the train front end data sets.	Yes with regard to the ASTP. Warning: Nevertheless, each user has to acquire train configuration data to make the transformation of the localisation data to their own reference frame.
Determination of the track edge ID	Part of basic function of the ASTP	Need to add a specific function that requires users to access the Digital Map.
Possible additional latency for users with 1D safe localisation data	No	Yes

Table 1 Architecture comparison

5. OPINION OF THE SYSTEM PILLAR – TRAIN CS ON TECHNICAL NOTE N°1

n°	Issue	WP 21/22 opinion	ASTP team final opinion
1	Shall the ASTP provide overall localisation service (1D and 3D localisation information) to all onboard consumers using the train front end reference frame or shall the ASTP only provide absolute and relative data using a fixed reference frame.	The ASTP shall provide absolute and relative data using a fixed reference frame (bogie pin reference).	We have the two (a little bit contradictory) main concerns: - to not add more complexity in the ASTP. - to not have to add a "bogie pin --> train front end" converter in most of the consumers. **As a consensus, we would like to discuss with IP the following intermediate approach**: - to allow to split the ASTP functionalities in two internal subcomponent (provided by the same supplier): - the "Technical" ASTP part which will provide the bogie pin localisation output. - a "converter" which will translate the bogie pin localisation output into the Train Front End localisation output.

6. APPENDIX

6.1 VIEW FROM THE ASTP : HOW TO GENERATE A POSITION

6.1.1 Translations to the ASTP internal reference location

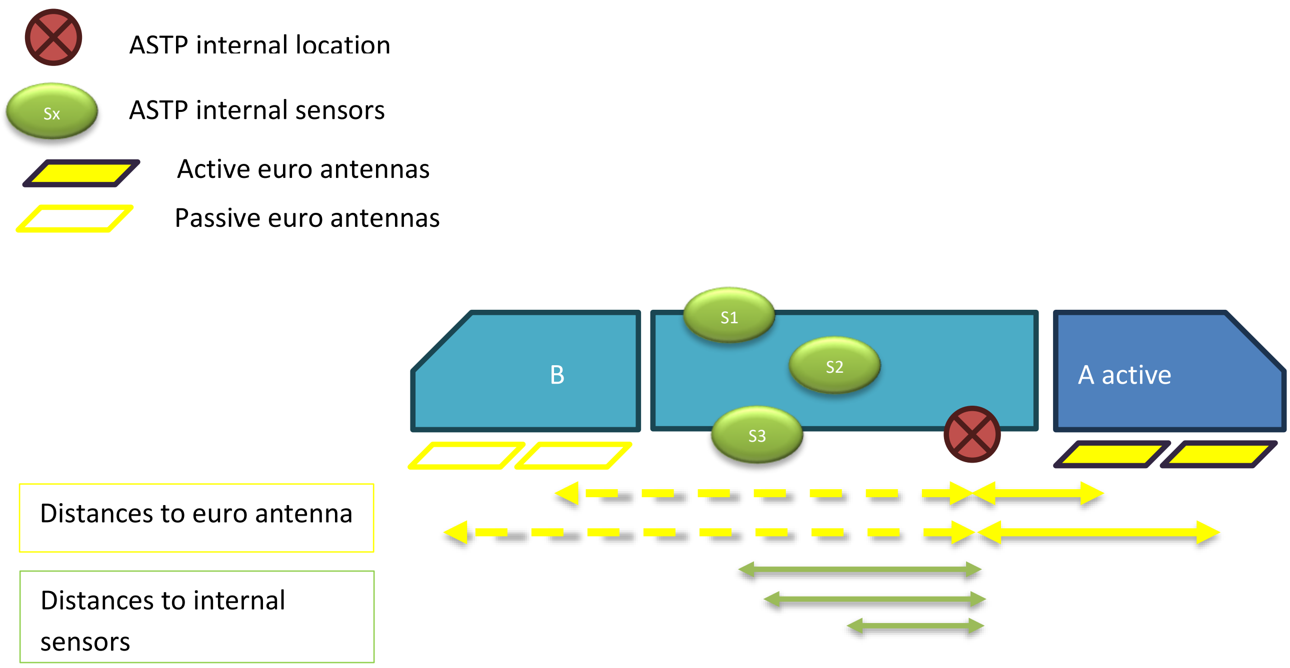


Figure 12 : illustration of the distances needed to derive the ASTP internal location

Specific internal sensors

ASTP uses several sensors to generate a position defined as the ASTP internal location. The use of ASTP internal sensors is specific and is in the scope of the supplier.

Case of the euro antennas

For the time being, it is agreed that the BTM and euro antennas are out of the scope of the ASTP.

As defined in subset 125/130 concerning the data transferred from ETCS to ATO, the euroantenna needs to be identified in the FFFIS.

Also, distances from the antennas to the ASTP internal location shall be known.

<u>In full ASTP mode (map + absolute position)</u>

ASTP will use the Balise telegram as an input to the fusion filter.

The fusion filter will need :

- The time stamped balise telegram
- The characteristics of the BTM (accuracy etc)
- Since the train will embed several antennas, the ID of the euro antenna.
- The distance from the euro antenna to the ASTP internal location.
- If the antenna is not in the same construct as ASTP, an accuracy of this distance will be needed related to the elasticity of the coupling.
- The orientation of the antenna relative to the ASTP internal location.

<u>In ETCS L2 mode (no map and relative distance)</u>

ASTP will use the Balise telegram to fulfill the requirements defined in subset 26 BL4.

ASTP will need:

- The time stamped balise telegram
- The characteristics of the BTM (accuracy etc)
- Since the train will embed several antennas, the ID of the euro antenna.
- The distance from the euro antenna to the ASTP internal location.
- If the antenna is not in the same construct as ASTP, an accuracy of this distance will be needed related to the elasticity of the coupling.
- The orientation of the antenna relative to the ASTP internal location.

6.1.2 Translations to the train front end location

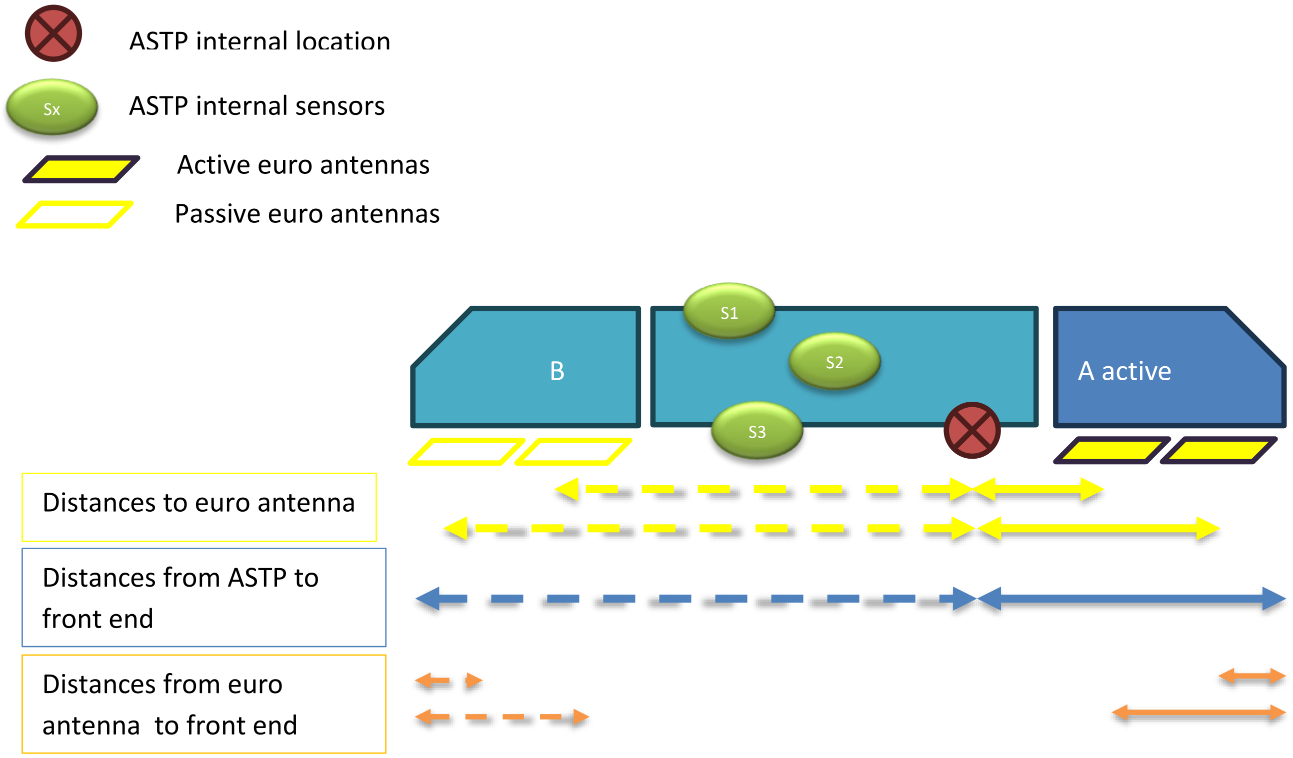


Figure 13 : illustration of the distances needed to derive the train front end

In full ASTP mode (map + absolute position)

In full ASTP mode, the ASTP will generate the ASTP internal location (as defined in §6.1.1). It is not foreseen to directly generate the train front end position by the fusion algorithm to avoid complexity.

A conversion will be done taking into account the distance to the active cab.

The fusion filter, to generate the ASTP internal location, will need:

- The time stamped balise telegram
- The characteristics of the BTM (accuracy etc)
- Since the train will embed several antennas, the ID of the euro antenna.
- The distance from the euro antenna to the ASTP internal location.
- If the antenna is not in the same construct as ASTP, an accuracy of this distance will be needed related to the elasticity of the coupling.
- The orientation of the antenna relative to the ASTP internal location.

The ASTP, to derive the train front end position, will need :

- The active cab
- The distance from the ASTP internal location to the front end and its accuracy

- The train orientation (determined by the ASTP and needed to generate the ASTP internal location.

Note: This conversion is only an addition since 1D position does not take into account curves or complex geometry.

Note: The distance from the ASTP internal location to the front end can include some uncertainty due to the train manufacture (is the ASTP internal location strictly identical for each train?) or to the elasticity of the coupling if the ASTP internal location and the front end are not in the same construct).

Note: This translation is mandatory to fulfil the subset 26 requirements, it can be done by ASTP or ETCS indifferently.

In ETCS L2 mode (no map and relative distance)

Two options are possible:

1) Generate the train front end position from the ASTP internal location as described before.
2) Generate the train front end position by calculating the travelled distance since the balise telegram was detected by an active antenna and adding the distance from the euro antenna to the front end as done today.

6.1.3 Need of the train orientation

Reminder of Subset 26

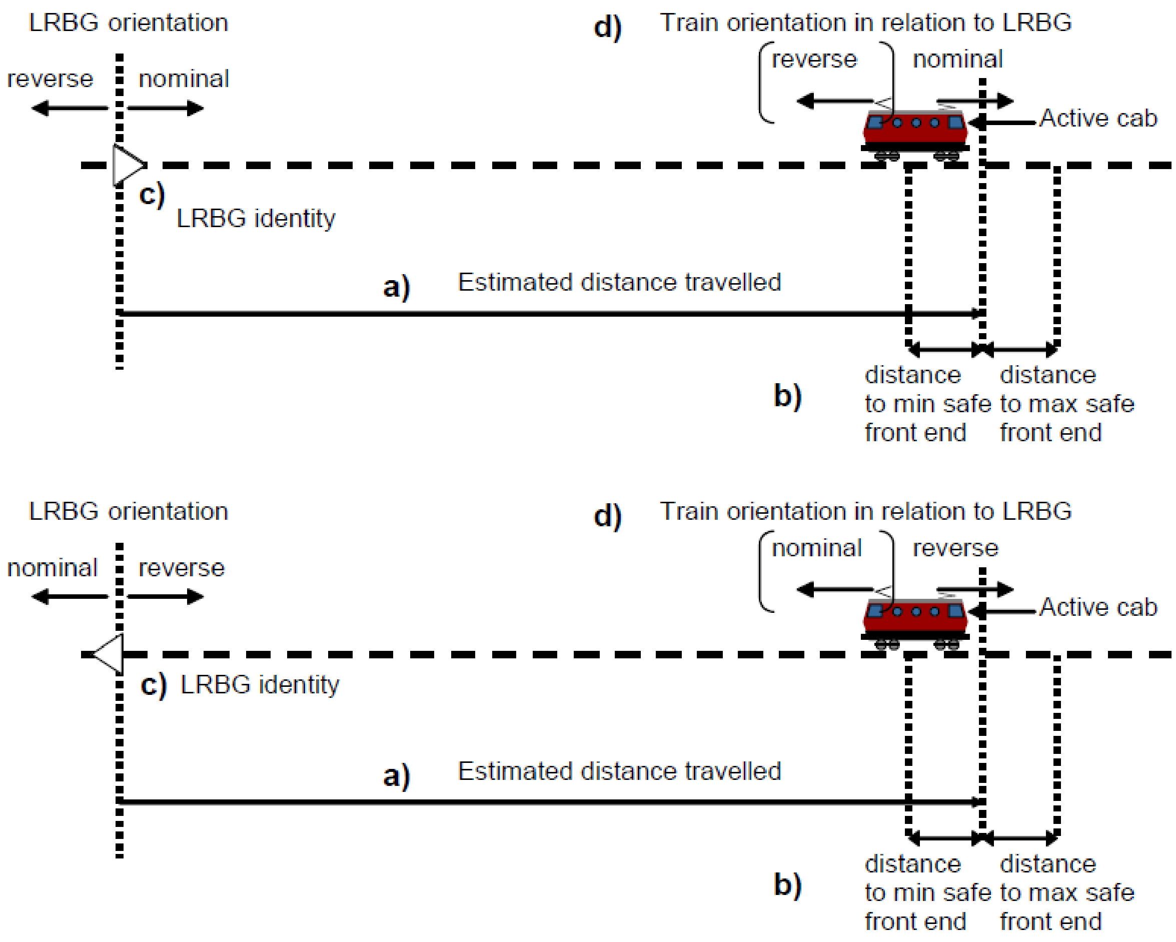


Figure 14 : extract of subset 26

1D position is represented by a travelled distance from an oriented LRBG referred to the train front end. The travelled distance is not signed, and the direction is represented by the attribute nominal / reverse.

Importance of orientation

Generalities

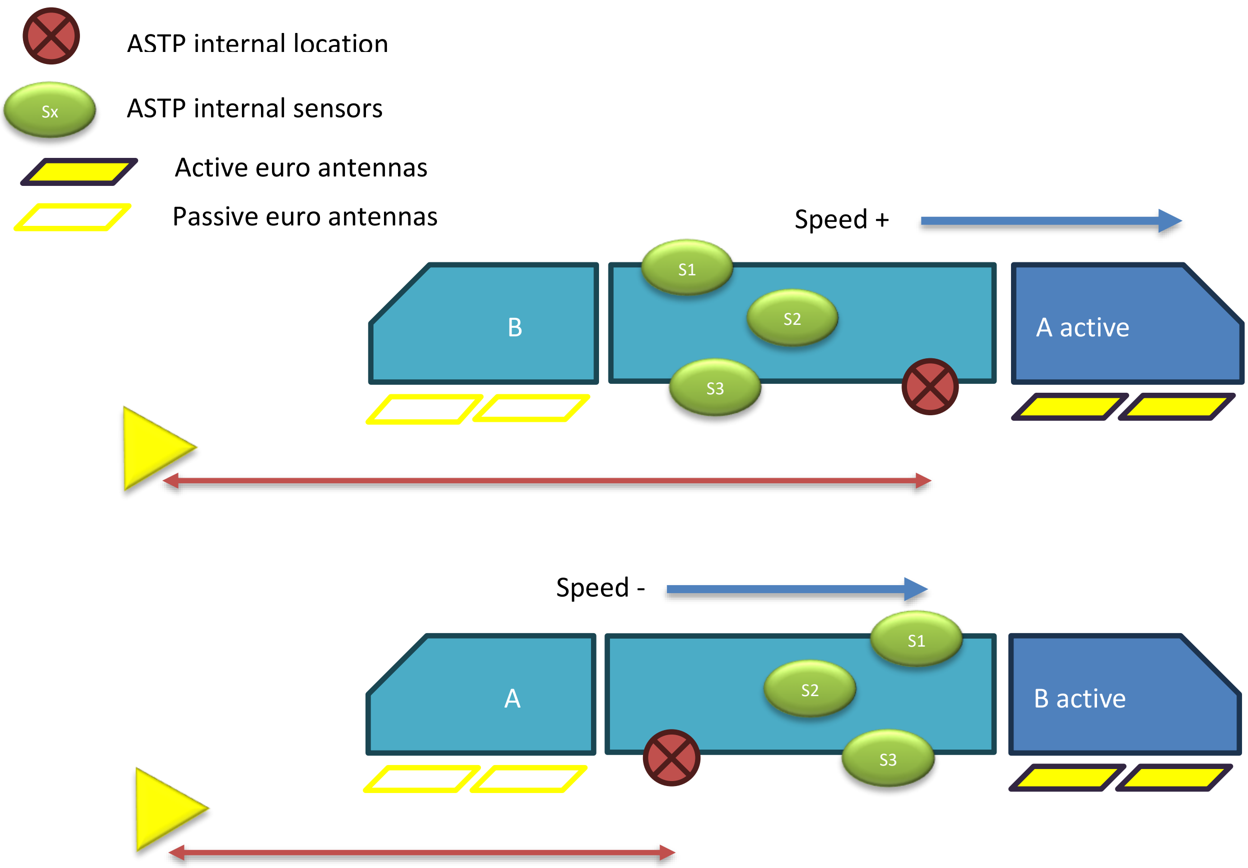


Figure 15 : effect of the train orientation

From the figure here before, we can identify that:

- The orientation of the train has an impact on the travelled distance from the reference location (LRBG) to the ASTP internal location.
- The orientation of the reference location needs to be known to explicitly define on which side of the reference location the train is.

Reference location orientation

<u>In full ASTP mode (map + absolute position)</u>

In this case, the orientation of the reference location is known in the map. ASTP will be able to generate a 1D position using it absolute position, pin it on the map and identify on which side of the reference location the train is.

<u>In ETCS L2 mode (no map and relative distance)</u>

In this case, the orientation of the LRBG is detected by the succession of balises ID in the balise group when detacted by the BTM.

This orientation deduction can be done by the ASTP or can be provided by the ETCS when defining the LRBG to be used.

Train orientation

In full ASTP mode (map + absolute position)

It is assumed that ASTP will need and will use IMUs to generate a safe and precise position in the railway environment. The IMU has the capacity to provide the train orientation in a reliable way and, thanks to the digital map, the fusion algorithm can match the digital map, the reference location position and orientation and the train orientation.

In ETCS L2 mode (no map and relative distance)

In ETCS L2 mode, the fusion algorithm does not have access to a digital map. The IMU can provide an absolute orientation, but the fusion algorithm cannot identify the train orientation in relation to the reference location.

the train orientation may be deducted from the signed speed of the train but certain cases can be complex (to be developed with parteners).

6.2 From the user perspective

6.2.1 Reminder of ETCS BL4

Today (BL4), most (all?) locations are referred to the train front end.

An example there after concerning the definition of powerless section where the pantograph shall be lowered. The position is referred to the train front end and not to the pantograph position.

2.4.2 Powerless section with pantograph to be lowered – Trackside orders

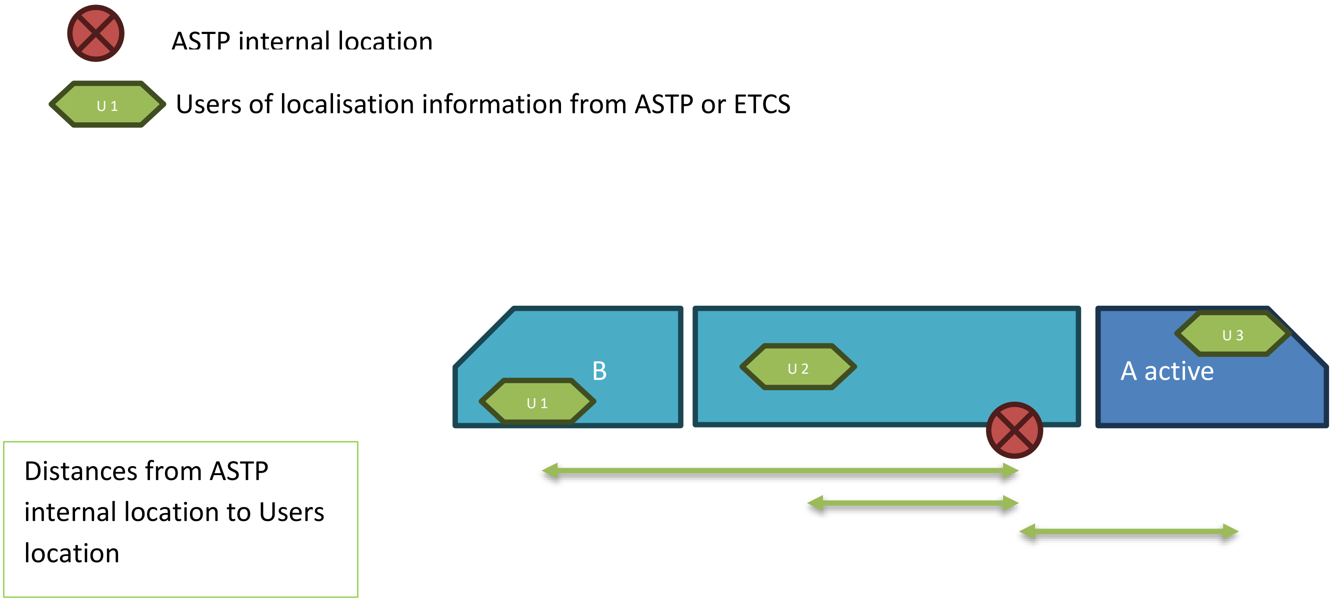
2.4.2.1 For each powerless section with pantograph to be lowered, the “Powerless section with pantograph to be lowered” information is an output that contains the following information:

- the remaining distance from the max safe front end of the train to the start location of this powerless section
- the remaining distance from the min safe front end of the train to the end location of this powerless section.

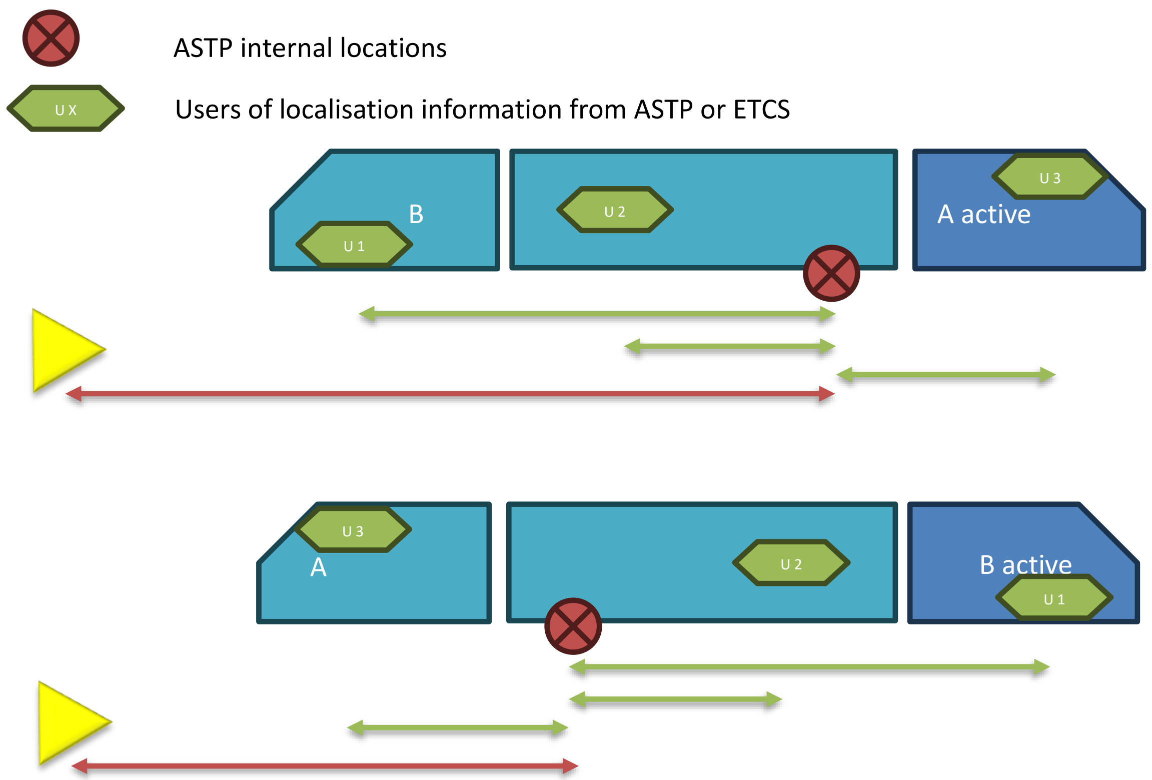
Figure 16 : extract of subset 32

Ref : https://www.era.europa.eu/system/files/2023-01/sos3_index007_-_subset-034_v320.pdf

6.2.2 The user uses the ASTP internal location



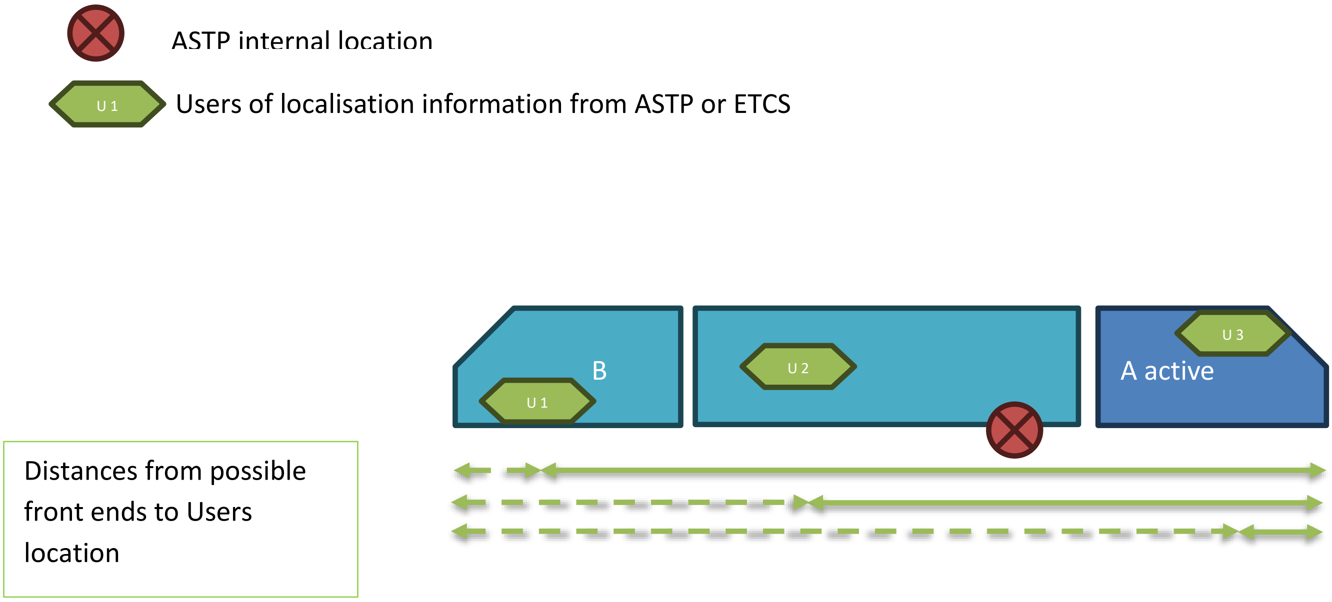
Users needs to know the distance from the ASTP internal location. Only one “signed” distance is needed.

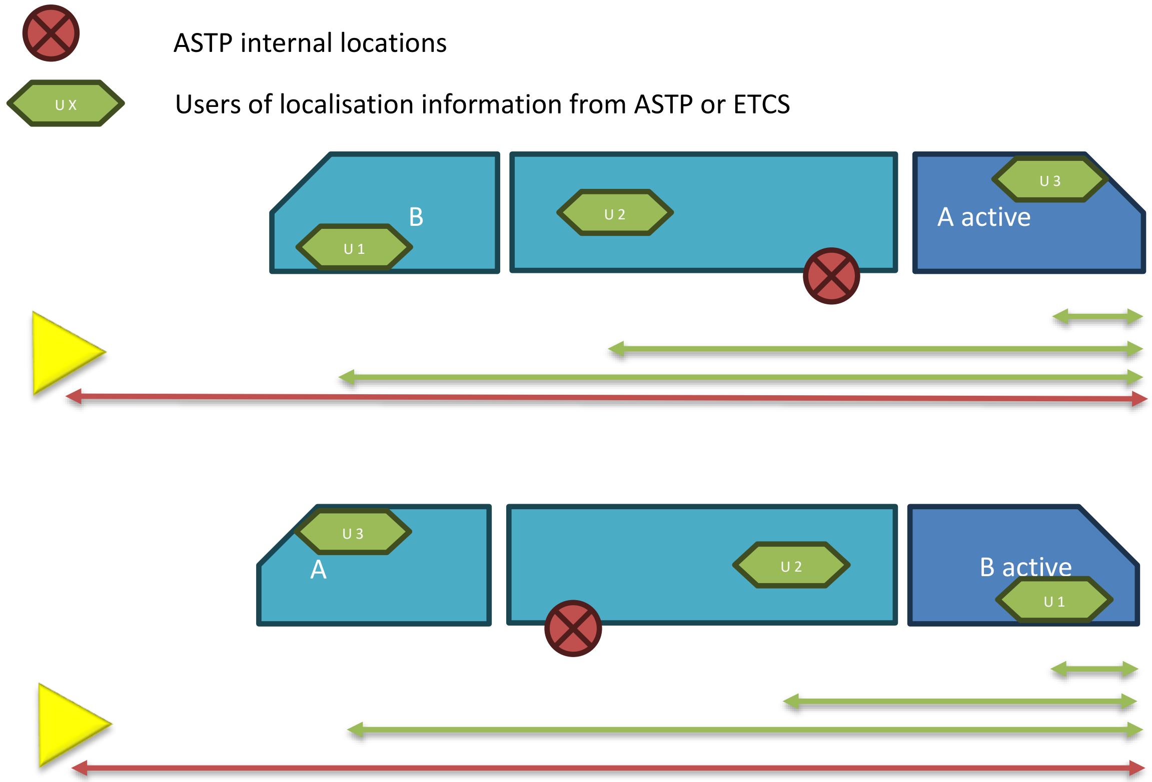


A user, depending on it needs, can use the ASTP internal location if enough or can derive it own position from the ASTP internal location considering:

- ASTP internal location
- The train orientation
- The reference location orientation
- The distance to the ASTP internal location

6.2.3 The users uses the train front end position


ASTP internal location
U 1
Users of localisation information from ASTP or ETCS
B
U 1
U 2
U 3
A active
Distances from possible front ends to Users location

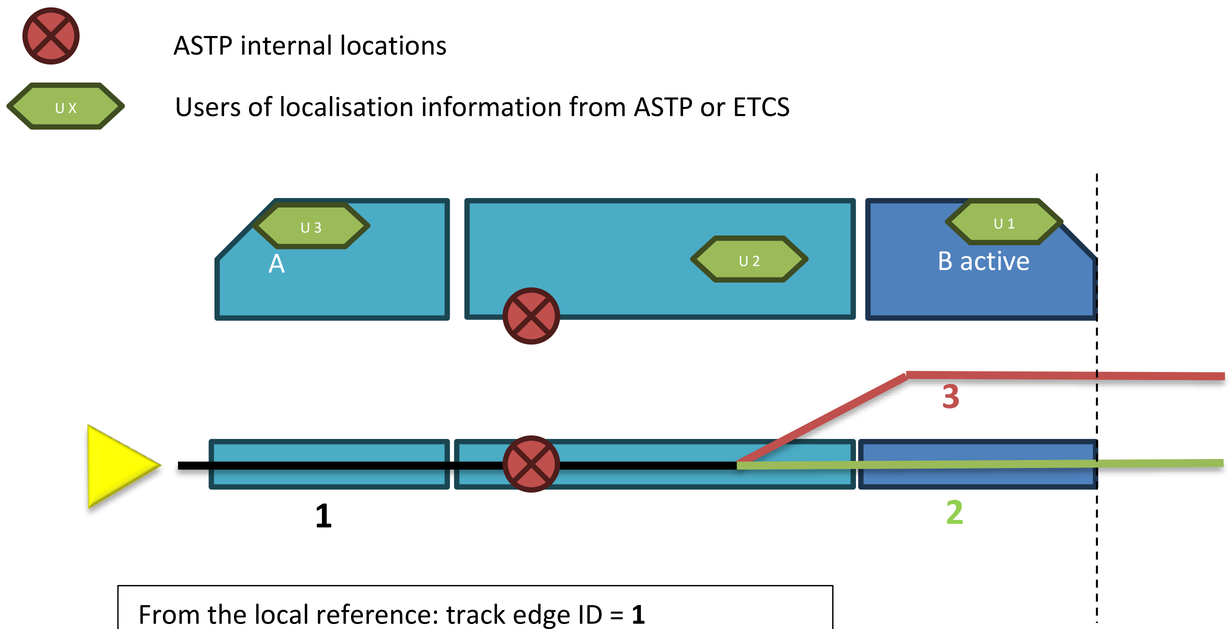


A user, depending on it needs, can use the train front end location, or can derive its own position from the train front end considering:

- The train front end location
- The active cab
- The distance to the train front end

6.2.4 Case of the track edge ID (or track selectivity)

The track edge ID is a new item used to identify on which track edge is the train location (front end of local reference). In ETCS Baseline 4, the onboard unit does not process or use this information. The onboard has only a 1D view of the tracks. Track selectivity in handled by the trackside using the MA, the TPR and the TTD.



From the local reference: track edge ID = **1**

From the train front end reference: track edge ID = **2**

Track edge ID referring to the ASTP internal location.

In this case, users will need to embed “complex” algorithm to derive its track edge position. For example, we assume that perception will need to know on which track it (to know which signal to read) is and cameras are installed on the front end. In this case, perception need to derive it track selectivity using the 1D position and it’s MA or JP.

Track edge ID referring to the train front end reference.

In this case, the ASTP need to anticipate the point status (using information from trackside as MA or directly the point status). The users will not need to derive this information.

6.3.1 One ASTP per cab

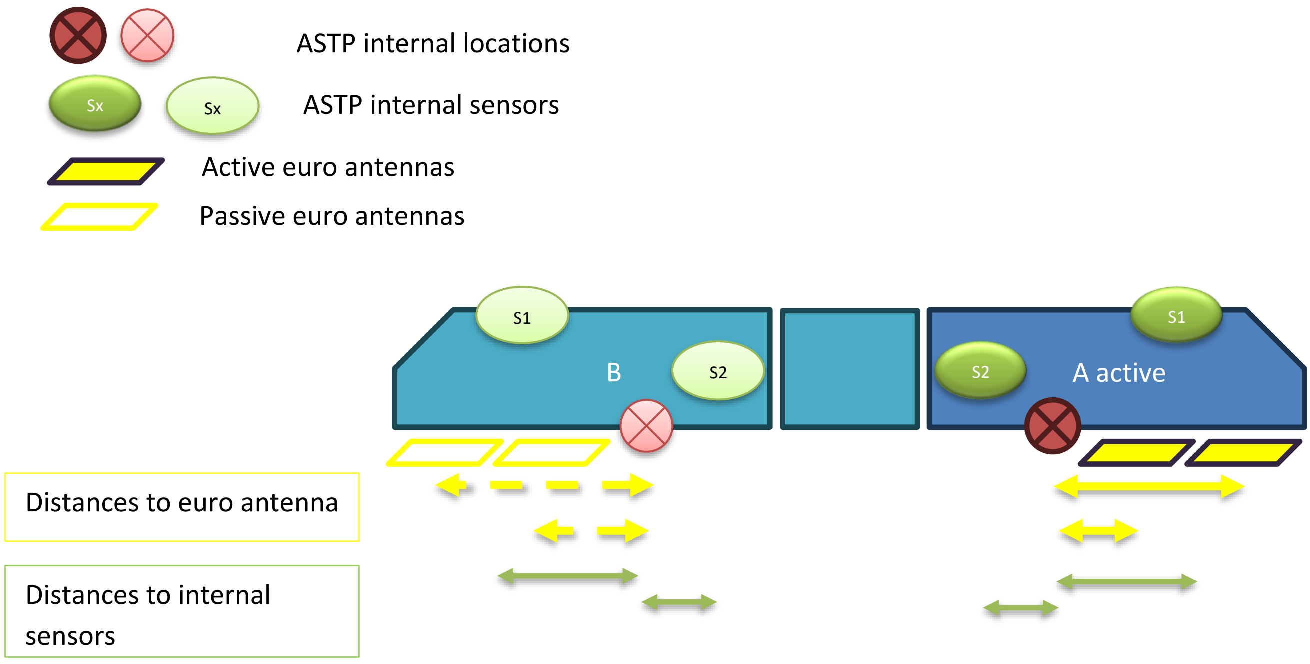


Figure 17 : case of 1 ASTP per cab

In this case, the trainset will have two ASTPs. The main question in this case is related to the way each ASTP is active and if the data is distributed on a common bus shared between the two cabs.

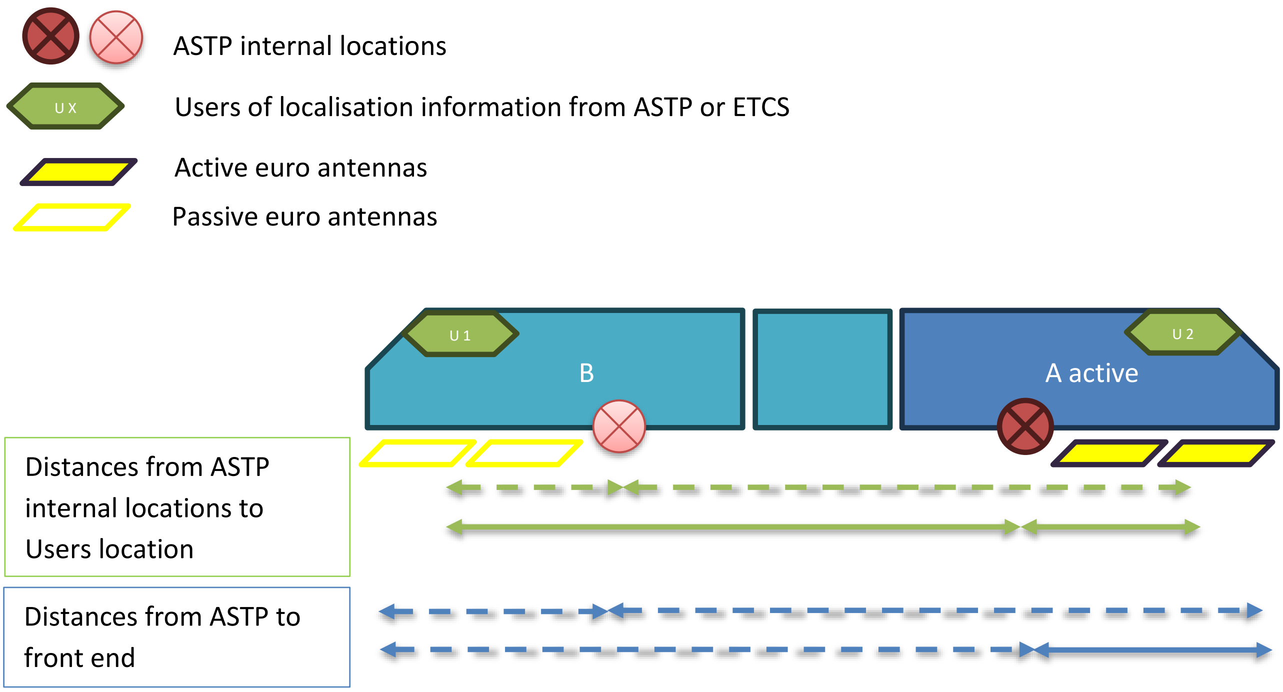


Figure 18 : Users with several ASTP internal location

If each ASTP povide it internal location, the user need to know wich ASTP is porviding the data. The users will devive it position depending on the identification of the ASTP. Since both ASTP are SIL4, the user can use the most relevant source (smalest CI etc).

If each ASTP povide the train front end postion, the user does not need to know wich ASTP is providing the data. Since both ASTP are SIL4, the user can use the most relevant source (smalest CI etc).

6.3.2 Availability redundancy

To be noticed that ASTP can be redonded for availability. This redondancy can be internal to the ASTP and then only one ASTP per cab will provide data or we can imagine that two ASTP are providing data per cab and then we may have 4 ASTP per train providing data on the CCN network.

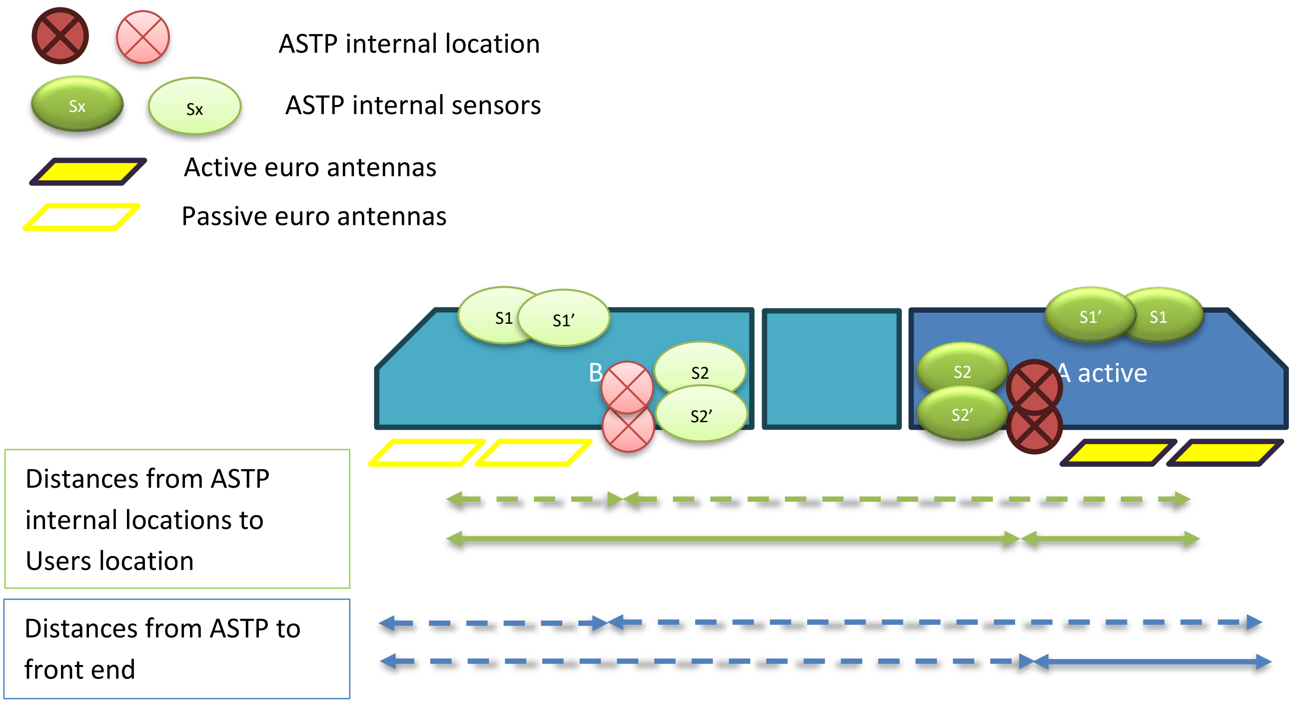


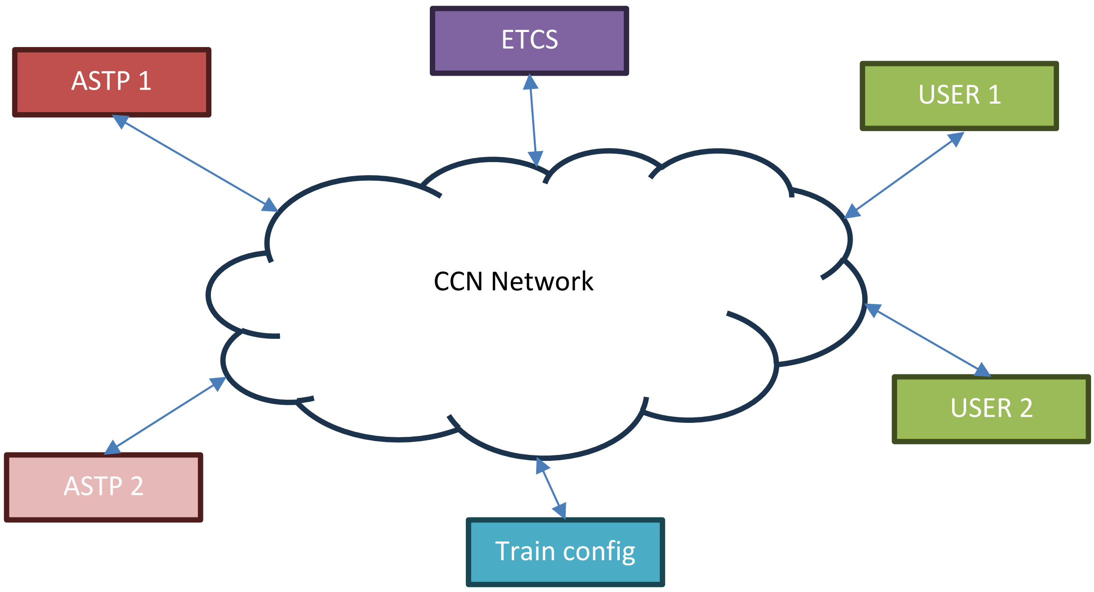
Figure 19 : ASTP redounded for availability purpose

6.4 DATA DISTRIBUTION

WARNING: this chapter is based on the assumption that the CCN network is available and a SIL4 protocol is available (SDTV4???).

From the previous chapters, we can point out that users will need several data to generate their own position. Some data are generated by the ASTP as the travelled distance to the reference location, but other are related to the static or active configuration of the train which are not directly handled by the ASTP.

All components are going to be interconnected by the CCN network.



3 options are possible.

1) The ASTP provide all the data to the USERS to generate its own position as active cab, orientation, static distances.
2) The ASTP does not provide all the needed data to the users, the user need to connect to other data provider as ETCS or some train components.
3) We totally make abstraction of which component is providing each data. We define a set standardised messages that can be sent on the network. Theses messages may be generated by the ASTP, the ETVS or others as done in the NMEA one net standard : https://www.nmea.org/nmea-onenet.html

APPENDIX E: TECHNICAL NOTE #2

Technical Note N°2
ASTP functions allocation

Author	Von Kaenel Andreas (SBB)
Partner	Marc Sarrat (SNCF) / Bernhard Stamm (SMO) / Iban Lopetegi (CAF)
Date	11/06/2025
Document Code	R2D-WP21-I-SNCF-TN2-04
Status	Final

Document status		
Revision	Date	Description
01	03/06/2024	First issue
02	06/06/2024	Update after first review session
03	24/07/2024	Final version
04	11/06/2025	Reference errors correction

TABLE OF CONTENTS

1. OBJECT OF THE TECHNICAL NOTE

The aim of this document is to show consequences of specific architectural decisions regarding the functional allocation of CCS functions. The document:

- does not propose decisions.
- is based on assumptions that are well described and identified as such.
- is a best guess regarding completeness of arguments.

If the modularity of the localisation function (in a future ASTP solution) is a priority, then a clear separation between ETCS functions and ASTP functions must be the aim of the system architecture. If this principle is not followed, the number of interfaces required will become very large, making an interoperable solution very complicated and ultimately very expensive. The consequences of system decisions that extract ETCS function from the ETCS onboard kernel are lined out in this technical note.

The document does not claim completeness of the consequences.

1.1 Reminder of the open issue

WP21 describes the different open issues in relation to architectural decisions. Open Issue 4 is described as:

[OI: FP2-ASTP-OPEN-ISSUE-4]: *ASTP functions allocation*

[Open Issue]: The list of functions not part of the ASTP needs to be confirmed.

[traceability]: D21.1 § 5.1.2

[Impact on ASTP]: Significant.

[Next step]: Decision to be taken with CCS onboard architects (System Pillar).

[END OI]

2. CONTEXT

To be noticed that the text or elements available in this chapter 2 are collected from other documents without any modifications or interpretation from the working group. The statements, facts or information present in this chapter may not reflect the ideas or point of view of the working group and are presented to help understanding and solving the issue considering all the available points of views.

2.1 Reminder of D21.1 v12

5.1.2.2 Functions not part of the ASTP

Among CCS-OB constituents some functions, some logical functional blocks, some devices could be part of the ASTP. The following assumptions are made on the ASTP boundaries and define functions that are not considered as part of the ASTP:

a) Generation and transmission of the Train Position Report (chapter 3.6.5.1.4 of SUBSET-026 [2],).

b) Determination of the train rear end position (chapter 3.6.4.4.1, 3.6.5.2 of SUBSET-026 [2]).

c) Determination of the train front end side (chapter 3.6.1.5 of SUBSET-026 [2]).

d) Determination of the train length (chapter 3.6.5.2 of SUBSET-026 [2]).

e) Determination of the train integrity status (TIMS-status).

f) Detection of cold movement (CMD).

g) Determination of standstill (chapter 3.14.4 of SUBSET-026 [2]).

h) Determination of track occupancy.

i) Current SUBSET-035 [3] odometer function information for STM system.

j) Determination of the LRBG.

k) Detection and transmission of Eurobalise telegram for the virtual balises.

l) Physical balises reader and forwarding Eurobalise telegram (BTM).

m) Management of the Map Data between the trackside and the on-board (On-board Digital Register management and functions see document [10]).

When required, data provided by those external functions or devices are considered as ASTP inputs.

The acquisition of those data will be defined as ASTP input functions.

OPEN ISSUE 4: The list of functions not part of the ASTP needs to be confirmed.

OPEN ISSUE 5: The detection of a train movement for the standstill supervision function, see chapter 3.14.4.2 of SUBSET-026 [2], is not part of the ASTP. This assumption needs to be confirmed.

OPEN ISSUE 6: Functions in charge of getting augmentation data or routing information from the trackside are part of the ASTP. This assumption needs to be confirmed.

2.2 Shift2Rail5

The following information is kept from X2R5-T5_3-D-MEC-XXX-XX_-Roadmap and Migration Strategy_0.0.21

6.3.1.1 Integration functional impact description

The current proposal requires an update on the functional architecture. In the following Figure 1, it is illustrated an updated architecture. Within the responsibility of the E_ODO-OB there are four main functional blocks:

- *Safe Fusion Algorithm* (SFA) functional block
- *Balise Telegram Reporter* functional block
- *Localisation Sensors* functional block
- *Data Client Manager* functional block

Notice that all internal interfaces within the E_ODO-OB are not expected to be standardised interfaces whereas the interfaces between E_ODO-OB subsystem and ETCS-OB and the interface between E_ODO-OB subsystem and E_ODO-TS shall be standardised.

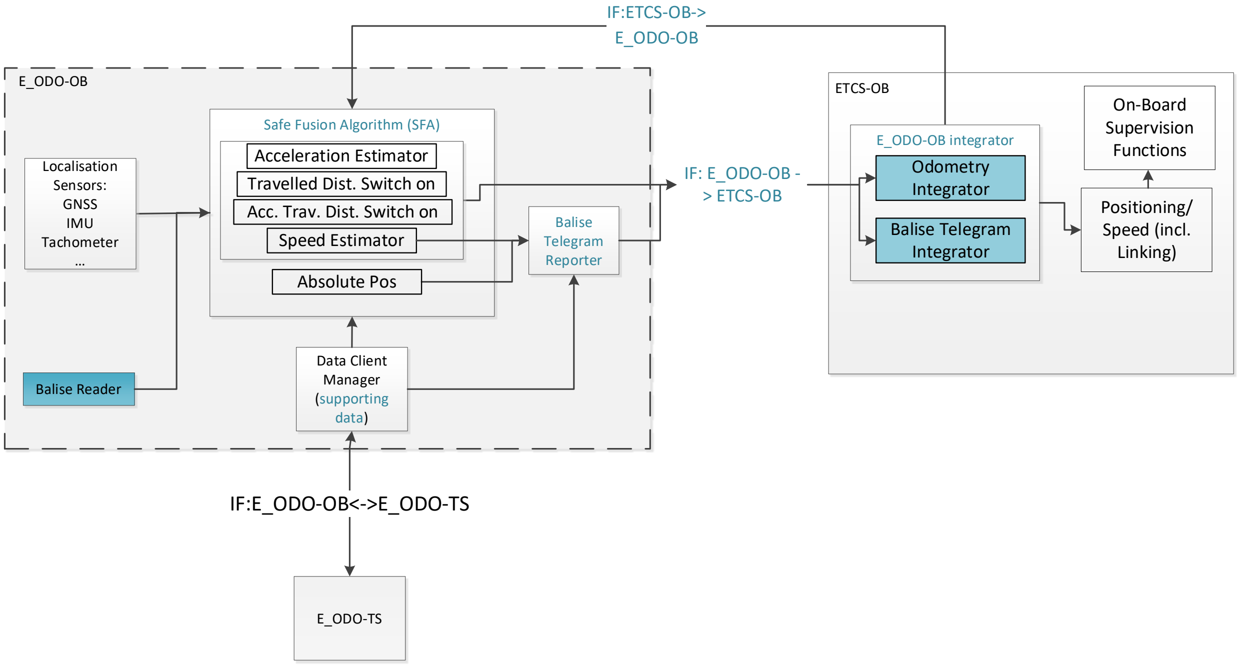


Figure 1: Architecture definition for Stream2 (upgrade in blue with respect to X2R2 defined architecture)

The *Safe Fusion Algorithm* (SFA) is the functional block that interfaces with the ETCS-OB. This functional block is divided into four main functions:

- Absolute Position Information Estimator
- Speed Estimator
- Travelled Distance since Switch On Estimator
- Accumulative Travelled Distance since Switch on Estimator
- Acceleration Estimator

The *absolute position information* from SFA is understood as the position that can be represented by a single-track edge and a distance from the start of that track edge.

For that purpose, the SFA uses data from *Sensors* functional block, *Data Client Manager* (for digital maps and augmentation information, if any) and E_ODO-OB inputs.

Since current state of the art technologies do not guarantee track discrimination with a SIL4 requirement, it is assumed that the read physical balise data is included as part of the input to the SFA. For this information there are two alternatives not decided at the stage of this proposal:

- On one hand, the physical balises read from ETCS are sent to the E_ODO-OB through the *IF: ETCS-OB->E_ODO-OB* interface.
- On the other hand, Balise reader itself is part of the E_ODO-OB sensor and thus every physically read balises shall be reported to ETCS-OB. This the option presented on Figure 1.

Notice that the described absolute position makes a reference to a fix point at the train vehicle in which the main sensors are installed. In other words, SFA is NOT responsible to calculate active cab's position, as this remains an ETCS-OB responsibility. However, the consumer of E_ODO-OB may require knowing this fixed point at the vehicle, which is considered a configuration information similar to the case of a tachometer sign known by ETCS-OB.

In addition, the absolute position information shall also be provided with a confidence interval which is based on the best effort of the algorithm. In other words, the CI provided by this information can shrink and grow without any restrictions.

The *speed estimator* function is responsible to estimate E_ODO-OB speed value and its confidence interval. It is expected that the estimation is used by the Balise Telegram Reporter function and by the ETCS-OB system as pure odometry information.

The *travelled distance since switch* on function is responsible to estimate travelled distance and its confidence interval since switch on. The confidence interval related to this function is a never shrinking confidence interval as it is for today's ETCS-OB odometry system. This is necessary to allow a seamless integration of this information within ETCS-OB. Notice that information is expected to be used by ETCS-OB to recalculate its confidence interval and to comply with STM requirements, see SUBSET-035 §8.3.

The *accumulative travelled distance since switch on* function is the travelled distance since switch on regardless of the direction of the travelled value, that is summing up absolute value of the travelled distance since switch on. The main purpose of this information is to facilitate the performance of the overall algorithms of E_ODO-OB.

The acceleration estimation function is responsible to estimate acceleration value. This information is necessary for ETCS-OB to comply with the A_traction value for the braking curves, SUBSET-026-3 §3.13.2.2.2.

The Balise Telegram Reporter functional block is responsible to possibly report a balise telegram whenever the E_ODO-OB crosses a reference location defined in the digital map. The functional block uses the absolute position and speed information from SFA to decide whether E_ODO-OB shall trigger a balise telegram report or not. This balise telegram report includes balise telegram bits stored in the digital map, the dynamic confidence interval calculated at the time the balise telegram is crossed and the corresponding time and odometer stamp information. Notice that the confidence interval provided by this function shall bound the position error of E_ODO-OB and the error defined in the digital map for theoretical localisation of balise telegram in the digital map.

With regards to *Data Client Manager* functional block, it is responsible to retrieve from track side all required supporting data. This includes managing safe communication channel with track side and to retrieve an updated digital map and augmentation information if any.

Finally, *Sensors* functional block refers to all required sensors by the SFA to estimate all defined functions previously in this section.

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

The *odometry integrator function* is responsible to manage the travelled distance since switch on and its confidence interval, speed estimator and its confidence interval and acceleration values. These values shall be received by the ETCS-OB timestamped and in a periodical manner, i.e. continuously.

Notice that the odometry integrator function receives information referred to a fixed position with a fixed orientation at the vehicle body frame. As such, travelled distance since switch on is expected to increment whenever the train moves in a fixed direction and decrease whenever it goes in the opposite direction. However, for the confidence interval related to the travelled distance, the value shall be always a non-shrinkable value. For the speed value the sign is also fixed to the vehicle body frame, and it is the responsibility of ETCS-OB to translate that to the appropriate sign based on active cab and train running direction. Recall that this fixed body frame translation is already a task performed by current ETCS-OB for tachometers where the sign value of the tachometer is typically a configuration parameter for ETCS-OB.

3. OPEN ISSUE ANALYSIS AND DECISIONS

ASSUMPTION = Assumption made by the working group based on the inputs provided in § 2 but may be contested due to the unavailability of reliable data or evolution of the input data.

3.1 OVERALL ANALYSIS

ASSUMPTION 1: ASTP does not embed ETCS functions such as:

a) preparing the train position report

b) defining a LRBG

These functions remain with the ETCS kernel. This to avoid the distribution of safety relevant ETCS function over several system.

ASSUMPTION 2: ASTP has two main functions which are:

1) providing the legacy ETCS odometry data

2) provide absolute position.

3.2 GENERATION AND TRANSMISSION OF THE TRAIN POSITION REPORT

3.2.1 Situation today

In current ETCS implementation, the train position report (Packet 0 described in TSI-SS-ETCS_B4-026-7) is generated within the ETCS onboard component. The ETCS onboard component integrates all interfaces that are needed to generate the TPR. This integration includes the sensor interfaces to the odometer sensors and the balise transmission module as well as the communication channel to ETCS trackside (Euroradio) (see Figure 1 in TSI-SS-ETCS_B4-026-2)

The TPR contains 16 individual variables.

7.4.3.1 Packet Number 0: Position Report

Description	This packet is used to report the train position and speed as well as some additional information (e.g. mode, level, etc.)		
Transmitted to	RBC, RIU		
Content	**Variable**	**Length**	**Comment**
	NID_PACKET	8	
	L_PACKET	13	
	Q_SCALE	2	
	NID_LRBG	10 + 14	
	D_LRBG	15	
	Q_DIRLRBG	2	
	Q_DLRBG	2	
	L_DOUBTOVER	15	
	L_DOUBTUNDER	15	
	Q_INTEGRITY	2	
	L_TRAININT	15	If Q_INTEGRITY = "Train integrity confirmed by external source" or "Train integrity confirmed by driver"
	V_TRAIN	7	
	Q_DIRTRAIN	2	
	M_MODE	5	
	M_LEVEL	3	
	NID_NTC	8	If M_LEVEL = NTC

Figure 2: Train position report - SS-026 § 7.4.3.1

3.2.2 Situation with ASTP

Part of the data that is compiled into the TPR will be provided by the ASTP. This raised the question whether it would make sense to generate and transmit the train position report from ASTP instead of transferring the recorded data to the ETCS onboard component and let him generate and transmit the TPR.

ASSUMPTION 3: BTM is not part of the ASTP. ASTP possibly receives BTM data but does not interpret it other than for localisation purposes. TPR Data, LRBG, L_DOUBTOVER, L_DOUBTUNDER are provided by ETCS onboard.

ASSUMPTION 4: the ETCS function is in charge of the interface with ETCS Trackside.

3.2.3 Consequences pro/cons

ETCS is in charge of compiling TPR Telegram, partly based on data provided by ASTP .

To be able to transmit the TPR to trackside, ASTP needs either a dedicated interface to the EURORADIO component - or - both, the ASTP and the EURORADIO must implement an FFFIS to the CCN

3.2.4 Recommendation from technical note working group

TPR should not be generated by ASTP because of two main reasons:

- it requires too much ETCS specific knowledge.
- At the system level, the ETCS on-board function is in charge of the interface with ETCS Trackside.

Implementing TPR in ASTP would require significant interface specification and development without added benefit.

3.3 Determination of the train rear end Position

3.3.1 Situation today

The train rear end is computed by the ETCS onboard unit by subtracting the train length from the min safe train front end. The Train length is either entered by the driver, read from preconfigured values or transferred via the Train interface prior to starting a mission (chapter 3.18.3 SS-26-3).

ASSUMPTION 5: The ETCS DMI will remain the only available DMI to enter train specific data

ASSUMPTION 6: ETCS onboard does compute and transmit data to the trackside

3.3.2 Situation with ASTP

If ASTP shall be able to compute the train rear end position, the train length needs to be transferred to the ASTP. Depending on the storage location of the train length this would require different interfaces.

3.3.3 Consequences of ASTP determining the train rear end position

If ASTP shall determine the train rear end, the safe train length needs to be transferred from either ETCS onboard or the train interface unit via an interoperable interface. The computed rear end position needs then to be retransmitted to the ETCS onboard, since ETCS needs it for further calculations such as Q_LGTLOC, L_TRAININT.

3.3.4 Recommendation from technical note working group

Train rear end should not be determined by ASTP since:

- ASTP does not need this information for itself. Train length is required only if the TPR has to be sent by the ASTP
- At the system level, the ETCS on-board function is in charge of the interface with ETCS Trackside.

Implementing rear end determination in ASTP would require significant interface specification and development without added benefit.

3.4 Determination of the train front end side (chapter 3.6.1.5 of SUBSET-026 [2])

3.4.1 Situation today

The active cab of the train defines the front-end side of the train. If no cab is active, the train orientation shall remain the same as it was when the last cab was active.

Train front end side definition as per today is an ETCS function, since it needs to know the active cab.

ASSUMPTION 6: ETCS onboard does compute and transmit values to the trackside

3.4.2 Situation with ASTP

ASTP does not have the necessary information to determine the front end side of the train. To be able to determine the front end ASTP would need:

- current active cab
- last active cab

3.4.3 Consequences of ASTP determining the train front end

This information mentioned in 3.4.2 must be transferred from ETCS to ASTP via an interface. The determined front end position needs then to be retransmitted to the ETCS onboard which needs it for further calculations. Train front end is a **very** important measure for safe train operation. A split of the logical allocation of the determination of input information to calculate the train front end has serious impact on the safety analysis of the overall system.

3.4.4 Recommendation from technical note working group

The determination of the side of the train front end is the result of a logic defined in SUBSET-026-3, currently part of the ETCS function. There is no added value to change this mechanism.

Implementing train front end side determination in ASTP would require significant interface specification and development without added benefit. We therefore propose to keep this function part of ETCS.

.

3.5 Determination of the confirmed train length (chapter 3.6.5.2 of SUBSET-026 [2])

3.5.1 Situation today

The physical train length is stored onboard as part of the Train Data. For CCS, the actual train length is determined by ETCS onboard, by taking into consideration the min safe rear end and the estimated train front end. This value is sent to the RBC as the confirmed train length.

ASSUMPTION 7: TPR is calculated by ETCS.

3.5.2 Situation with ASTP

If ASTP must be able to determine the confirmed train length it needs to know:

- the min safe rear end
- the estimated train front end

3.5.3 Consequences of ASTP determining the confirmed train length

ASTP needs to get the values mentioned in 3.5.2 in order to be able to determine the confirmed train length and send the calculated value back to the ETCS onboard which will use it for the L_TRAININT which itself is part of the TPR.

3.5.4 Recommendation from technical note working group

The working group recommends ASTP should not determine the confirmed train length. There are ongoing discussions if train length determination will be a function of the digital automated coupling DAC. In any case, train length and train integrity management System (TIMS) are in close relation. These two functions should be implemented in the same component.

Implementing train length in ASTP would require significant interface specification and development without added benefit.

3.6 Determination of the train integrity status (TIMS-status)

3.6.1 Situation today

Figure 3 shows the 4 different status Q_INTEGRITY has today

7.5.1.112 Q_INTEGRITY

Name	Qualifier for train integrity status		
Description	Qualifier, identifying the train integrity information. The related confirmed train length information is given by L_TRAININT		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
2 bits			
Special/Reserved Values	0	No train integrity information	
	1	Train integrity confirmed by external source	
	2	Train integrity confirmed by driver	
	3	Train integrity lost	

Figure 3: SS-026 § 7.5.1.112

ASSUMPTION 7: TPR is calculated by ETCS.

3.6.2 Situation with ASTP

Although Train integrity is a very important measure in relation to train position, ASTP does currently not foresee to provide train integrity information. To be able to generate this information, ASTP would need to be extended by such a functionality – or would need the information mentioned in Figure 3:

- External source confirming integrity.
- Driver confirming integrity.
- Integrity information from braking system.

3.6.3 Consequences of ASTP confirming train integrity

As the ASTP does not have the information mentioned in 3.6.2, the information must be made available to the ASTP via interfaces to the owning systems. Due to ASSUMPTION 1, the integrity must then be transmitted to ETCS onboard to be integrated to the TPR.

3.6.4 Recommendation from technical note working group

Train integrity management system as well as train length are part of the train configuration management. ASTP does not acquire any information contributing to the determination of train integrity. ASTP should therefore not integrate the TIMS function.

3.7 Detection of Cold Movement (CMD)

3.7.1 Situation today

Cold movement detection is today specified as a CCS onboard component, without further specifying where the function should be implemented. CMD must be battery powered for at least 72h if the train is cut from its main energy source.

3.7.2 Situation with ASTP

ASTP in its final step of development will eventually have all the necessary sensor inputs to implement a CMD.

3.7.3 Consequences of ASTP detect cold movements

ASTP or at least the part that is used to supervise the Cold Movement would require a Battery powered backup supply. If a segregation of the CMD within ASTP would not be possible, this Backup Power Supply would need to be able to supply the complete ASTP for at least 72h.

In addition, ASTP must be able to provide CMD information to ETCS onboard right at startup.

3.7.4 Recommendation from technical note working group

Although ASTP has all needed information available to provide a CMD function, the working group recommends not to integrate CMD into ASTP.

One main reason for this is the backup power requirement for 72h. The ASTP subsystem is not optimized to this requirement. The required backup power system would much bigger for ASTP than for a pure CMD component leading to a higher prices.

Another reason is that CMD will probably not be necessary for all EVU’s. There are countries that plan to configure their trains to be “always on, always connected” and there will not need the CMD component. An ASTP component that integrates CMD would simply be to expensive for such customers.

3.8 DETERMINATION OF STANDSTILL (CHAPTER 3.14.4 OF SUBSET-026 [2])

3.8.1 Situation today

ASSUMPTION 1: Odometry is implemented in ASTP.

Standstill is today sensed via the odometry sensors. If the train speed measured by the odometer sensors reaches zero threshold, the train is basically considered to be at standstill. The standstill supervision is based on a distance D_NVROLL (default value 2m).

3.8.2 Situation with ASTP

ASTP in its final step of development will eventually have all the necessary sensor inputs to detect standstill.

3.8.3 Consequences of ASTP determining standstill

If standstill shall be determined by ASTP, a standstill flag must be sent to ETCS in addition to the Train speed.

The ASTP information can be different depending on the use case: type of train, type of user (ETCS, ATO GoA2, ATO GoA4,…). In this case, several information need to be provided and adapted to each use case. The best solution seems that based on raw data provided by ASTP, each user determines its own standstill information.

3.8.4 Recommendation from technical note working group

In a first approach, it seems logical that ASTP provide standstill information, as it has all the sensors to detect it. But considering the different use case of modules needing this information, it seems reasonable that the standstill detection shall be a function part of each user.

3.9 Determination of track occupancy

3.9.1 Situation today

Track occupancy is nowadays determined by track circuits. The ETCS onboard equipment does not determine track occupancy in any case.

3.9.2 Situation with ASTP

For ASTP to be able to determine Track occupancy, ASTP has to be able to generate safe and track selective position reports under any operational situation and condition.

Technically ASTP in its final step of development will eventually have all the necessary sensor inputs to determine track occupancy.

3.9.3 Consequences of ASTP determining track occupancy

Even though ASTP shall be able to detect track occupancy in its final step, this is not an easy task, since it has a big impact to the overall CCS system track and train side. Safety logic that is today setup to receive track occupancy from trackside would have to implement interfaces to receive track occupancy from train onboard systems.

A question that arises from an operational point of view, is how trains without ASTP generating track occupancy reports can be operated with trains having this capability on the same tracks.

3.9.4 Recommendation from technical note working group

In best case, ASTP will be able to determine on which track it is currently running with a certain accuracy. To be able to determine track occupancy additional information such as train integrity and train length are necessary. From this point of view, it doesn't seem feasible for ASTP to determine track occupancy. The working group recommends not to determine track occupancy within ASTP

3.10 Current SUBSET-035 [3] odometer function information for STM system

3.10.1 Situation today

ASSUMPTION 8: Odometry is implemented in ASTP

SS-035 specifies STM odometer function. SS-035 § 5.2.3.1 says that "Odometry data & parameters shall be sent by the ERTMS/ETCS on-board to all STMs using multicast messages."

Obviously, this function is implemented in ETCS onboard, as this component has all the necessary information available.

3.10.2 Situation with ASTP

If ASTP implements Odometry, the information required for the STM Odometer function will no longer be native to ETCS onboard but will reside in the ASTP component.

3.10.3 Consequences of ASTP providing Odometer function for STM

No matter where the Odometer functions for STM will be implemented as soon as ASTP is available, a change in the data flow will be necessary. Either

- The data will be made available by ASTP **AND** ASTP implements an FFFIS to STM
- The data will be made available by ASTP **BUT** ETCS receives the data from ASTP and provides STM over the existing interface.

3.10.4 Recommendation from technical note working group.

If Assumption 1 is true in the final architecture, then STM will should be fed from ASTP.

3.11 Determination of the LRBG

ASSUMPTION 6: ETCS onboard does compute and transmit/receive values to the trackside

3.11.1 Situation today

LRBG is determined by ETCS onboard. The identification of an LRBG requires - besides the information stored in the balise - additional information that is sent from the RBC via the Movement Authority (packet 5).

3.11.2 Situation with ASTP

If LRBG is to be determined by ASTP, the Movement Authority (and any other Track to Train Telegram containing information regarding BG) must be forwarded to ASTP. This requires a FFFIS for this information between ETCS onboard and ASTP.

3.11.3 Consequences of ASTP determining the LRBG

A lot of the nowadays implemented functions on ETCS onboard would have to be transferred to ASTP.

3.11.4 Recommendation from technical note working group.

The working group recommends to not determine LRBG within ASTP:

- Determining LRBG needs information from trackside, that is not available in ASTP.
- LRBG is needed for further safety functions that are native to ETCS

Hint: If virtual reference points will be generated by ASTP, then ETCS kernel needs to be able to handle these and possibly use them as LRBG.

3.12 Detection and transmission of Eurobalise telegram for the virtual balises

3.12.1 Situation today

Nowadays no virtual balises are used on ETCS L2 tracks (by the way - virtual balise covers is something completely different. They are used during construction of a track to inhibit a balise telegram)

3.12.2 Situation with ASTP

Shift2Rail5 Stream 1 proposes to introduce a virtual balise generator that sends ordinary balise telegrams to ETCS onboard when a track reference point is identified by the ASTP. This idea is some been taken over by system pillar where ASTP shall be able to detect a trigger the passing of virtual reference points.

3.12.3 Consequences of ASTP detecting virtual balises

If ASTP shall detect and transmit virtual balises several additional interfaces and resources need to be available:

- A digital map containing the virtual balise positions
- A specific function to trig the telegram
- An interface from ASTP to the ETCS kernel for the (virtual) Balise information. This interface would extend the information coming from the physical balises.

3.12.4 Recommendation from technical note working group

Virtual reference points (not virtual balises) are likely to be detected and transmitted by the ASTP. However, for virtual balises this seems to be less realistic due to the additional BTM implementation effort.

Hint: As already mentioned in 3.11.4, ASTP will not decide whether or not a reference location becomes an LRBG or not. This will be done in the ETCS kernel.

3.13 Physical balises reader and forwarding Eurobalise telegram (BTM)

3.13.1 Situation today

The BTM (as well as the LTM) is an integral part of the ETCS onboard unit. No interface specification does exist for messages between the BTM and other onboard components.

3.13.2 Situation with ASTP

ASTP will most likely need balise information in order to be:

a) compatible with ETCS L2 lines

b) get reference information from track to be used in the fusion algorithm.

Balise telegram information can either be received from ETCS onboard via an FFFIS or by integrating the physical balise reader in the logical ASTP component. In the latter case, a FFFIS will still be necessary since ETCS needs balise information as well.

3.13.3 Consequences of ASTP implementing the balise reader

FFFIS to ETCS onboard unit.

Good system design to have low latency and / or very accurate timestamping on the balise telegrams.

3.13.4 Recommendation from technical note working group

The working group recommends the BTM to remain within the ETCS kernel. It is a stable interface that will not change significantly over time, and for most ETCS onboard manufacturers the BTM is deeply embedded into the ETCS kernel. A segregation of this function would be very costly without a significant benefit.

Since the BTM is very railway specific tech, it should be kept away from ASTP to not hinder non railway companies to develop ASTP solutions.

3.14 Management of the Map Data between the trackside and the on-board (On-board Digital Register management and functions see document [10]).

3.14.1 Situation today

Not applicable as there is no digital track map available onboard nowadays.

3.14.2 Situation with ASTP

ASTP will most likely need a digital map as input for the fusion algorithm. The digital map is provided by the Infrastructure Manager (IM) and must therefore be transferred from trackside to a digital onboard repository. Besides the ASTP, the digital map will be used by other onboard components. The digital register must be able to provide these consumers with the relevant map layers.

The map transfer and update mechanisms which will most likely be processed via the new FRMCS has to be implemented in the digital register as well.

3.14.3 Consequences of ASTP managing the map data between trackside and onboard

ASTP would need to implement a digital register onboard with the roughly described functionalities. The interfaces to other consumers would have to be implemented in ASTP as well, making later updates of the ASTP component more cumbersome and costly.

3.14.4 Recommendation from technical note working group.

In the overall CCS architecture digital register is nowadays foreseen as a separate component. Besides ASTP, systems like ATO, Passenger information, Perception, will need map information too. Since ASTP seems to be the only map customer requiring a SIL-4 implementation, a well-defined and safe interface between the digital register and ASTP is needed.

The working group recommends that ASTP should not be the system to implement the digital map, although the group cannot provide very strong arguments.

4. SUMMARY

Table 1 summarises the functional allocation recommendations from the working group. Note that the vast majority of the functions shall remain the ETCS kernel, and only the functions that are closely tied to information that is available within ASTP shall be implemented there.

Issue	Recommended allocation	Note
Generation and transmission of train position report	ETCS onboard	See TN1
Determination of train rear end position	ETCS onboard	
Determination of train front end side	ETCS onboard	
Determination of train length	ETCS onboard or digital automated coupling	
Determination of train integrity status	ETCS onboard or digital automated coupling	
Detection of cold movement	Separate component	
Determination of standstill	Part of each user	
Determination of track occupancy	ETCS onboard / trackside	
Odometer function	ASTP	
Determination of LRBG	ETCS onboard	
Detection and transmission of Eurobalise telegram for the virtual balises	ASTP	There will be no virtual balises but virtual reference points. Therefore no balise telegrams will be generated by ASTP, just reference locations
Physical balise reader and forwarding the balise telegram	ETCS onboard (BTM)	
Management of the map data between onboard and trackside	Digital register	See results of WP27

Table 1: Recommended functional allocation overview

5. SUMMARY OF ASSUMPTIONS MADE

1	ASTP does not embed ETCS functions such as: a) preparing the train position report b) defining a LRBG These functions remain with the ETCS kernel. This to avoid the distribution of safety relevant ETCS function over several system.
2	ASTP has two main functions which are: 1) providing the legacy ETCS odometry data 2) provide absolute position.
3	BTM is not part of the ASTP. ASTP possibly receives BTM data but does not interpret it other than for localisation purposes. TPR Data, LRBG, L_DOUBTOVER, L_DOUBTUNDER are provided by ETCS onboard.
4	the ETCS function is in charge of the interface with ETCS Trackside.
5	The ETCS DMI will remain the only available DMI to enter train specific data
6	ETCS onboard does compute and transmit data to the trackside
7	TPR is calculated by ETCS
8	Odometry is implemented in ASTP.

Table 2: Table of assumptions

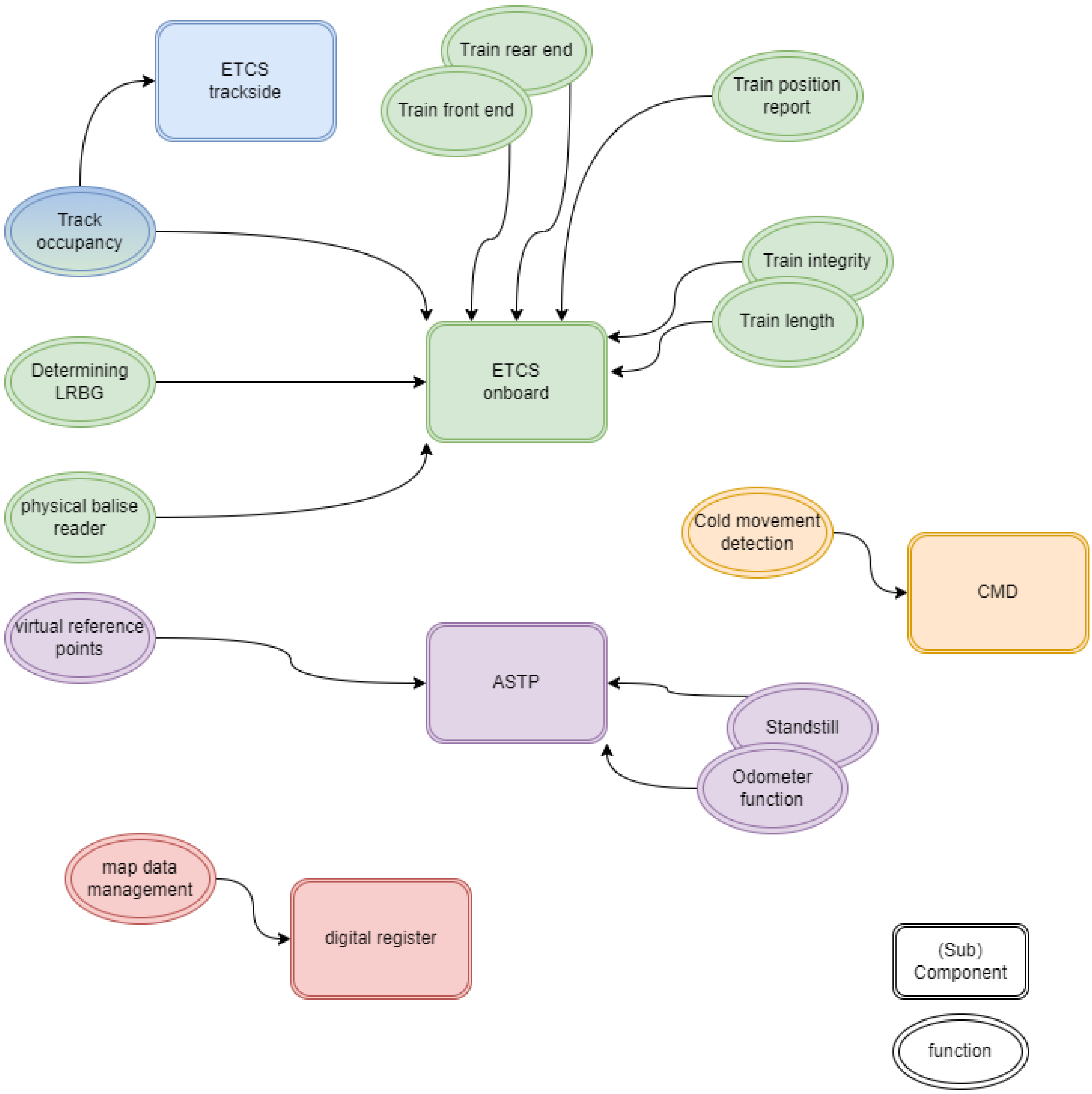


Figure 4: Schematic overview of functional allocation

6. OPINION OF THE SYSTEM PILLAR – TRAIN CS ON TECHNICAL NOTE N°2

n°	Assumption	ASTP team final opinion
1	ASTP does not embed ETCS functions such as: a) preparing the train position report b) defining a LRBG These functions remain with the ETCS kernel. This to avoid the distribution of safety relevant ETCS function over several system.	Agreed
2	ASTP has two main functions which are: 1) providing the legacy ETCS odometry data 2) provide absolute position.	Agreed
3	BTM is not part of the ASTP. ASTP possibly receives BTM data but does not interpret it other than for localisation purposes. TPR Data, LRBG, L_DOUBTOVER, L_DOUBTUNDER are provided by ETCS onboard.	This assumption shall be removed because already covered and evaluated but the following open issue "Physical balise reader and forwarding the balise telegram".
4	the ETCS function is in charge of the interface with ETCS Trackside.	Agreed
5	The ETCS DMI will remain the only available DMI to enter train specific data	Agreed but small rewording: "[...] to enter **CCS** train data"
6	ETCS onboard does compute and transmit data to the trackside	Agreed with the following comment: seems overlap with Assumption 4.
7	TPR is calculated by ETCS	Agreed but with the following comment: seems overlap with Assumption 1 and 4, and redundant with the first open issue.
8	Odometry is implemented in ASTP.	Agreed but seems redundant with assumption 2.

Open points

N°	Issue	WP21 opinion	ASTP team final opinion
1	Generation and transmission of train position report	ETCS onboard	Agreed
2	Determination of train rear end position	ETCS onboard	Agreed
3	Determination of train front end side	ETCS onboard	Agreed
4	Determination of train length	ETCS onboard or digital automated coupling	Agreed
5	Determination of train integrity status	ETCS onboard or digital automated coupling	Agreed
6	Detection of cold movement	Separate component	ASTP team assumption to be confirmed: CMD function should be included in a new dedicated logical component (mainly because of the need being powered independently from the other CCS-OB components (when CCS-OB is switch off)) and leave more evolution/modularity for the future.
7	Determination of standstill	Part of each user	Agreed, but consequently new additional information from ASTP to ETCS-OB could be necessary to let the ETCS to determine itself the safe standstill information (e.g. raw data from OPG)
8	Determination of track occupancy	ETCS onboard / trackside	Agreed
9	Odometer function	ASTP	The ASTP shall be able to do both options: send odometry to ETCS for backward compatibility) and to the STM for future evolution
10	Determination of LRBG	ETCS onboard	Agreed
11	Detection and transmission of	ASTP	The recommendation is not clear and we have no definition of what is a "virtual reference point".

	Eurobalise telegram for the virtual balises		In our opinion there are 3 different open point: - how and who have to detect when a virtual balise is crossed. - who should determine if a virtual balise can be used as "LRBG" - who have to transmit the virtual balise telegram. First assumption: the Digital map shall contain the localisation of the virtual balise in the map but also at least the header of the virtual balise (NID_C, NID_BG, ...) and eventually attached fixed telegram. Disclaimer: the new virtual balise function has not yet be investigated within Train CS, and to ensure this new functionality there are too many different possibilities. Here are just a first feeling: to ensure this new functionality we can imagine the need to introduce a new component (Virtual ETCS Transponder Service as introduce by OCORA) the main functions of this new component could be to detect when a virtual balise is crossed (via a the combination of the 1D localisation + trackedge ID information) and send to the ETCS the corresponding virtual telegram. And then up to the ETCS to inform the ASTP if this virtual balise has to be used as a new LRBG. After investigation, it could be decided to introduce this new component in the ASTP.
12	Physical balise reader and forwarding the balise telegram	ETCS onboard (BTM)	Disclaimer: The scope of this Recommendation is part of the remit for SC2.4 for TrainCS on ASTP, so it's difficult to already state today the results. But, without this deep dive analysis, we would continue to rely on our current Train CS logical architecture: to keep the BTM function within the ETCS.
13	Management of the map data between onboard and trackside	Digital register	The distribution of the data should not be in the responsibility of the ASTP, it should be a transversal function. The best candidate today to do that is the REPository as specified in the Train CS logical architecture.

APPENDIX F: TECHNICAL NOTE #4

TECHNICAL NOTE 4

Routing information for ASTP

Author	Zoltan Abram (DB)
Partner	Saïd El-Fassi (SNCF), Bernhard Stamm (SMO)
Date	19/08/2024
Document Code	R2D-WP2-I-GTSD-TN4-03
Status	Final

Document status		
Revision	Date	Description
01	17/06/2024	First issue
02	09/07/2024	Updated based on the review comments
03	19/08/2024	Minor corrections

TABLE OF CONTENTS

1. OBJECT OF THE WHITE PAPER

1.1 Reminder of the open issue

[OI: FP2-ASTP-OPEN-ISSUE-08]: *Linking and route information*

[Open Issue]: Linking information from ETCS or route information map repository can also be used. The solution and the provider needs to be confirmed.

[traceability]: D21.1 § 5.1.3.3

[Impact on ASTP]: Significant.

[Next step]: Decision to be taken with CCS onboard architects (System Pillar).

[END OI]

1.2 Issues to be resolved

Issue:

Routing information together with Digital Map data could be used as a supportive information for enabling the ASTP to reduce position inaccuracies and to determine the track edge ID when a train passes a point. Because there are different types of routing information which could be provided, like the balise linking information, point status or route, it needs to be analysed which could be potentially the best input for the ASTP.

2. CONTEXT

To be noticed that the texts or elements available in this chapter 2 are collected from other documents without any modifications or interpretation from the working group. The statements, facts or information present in this chapter may not reflect the ideas or point of view of the working group and are presented to help understanding and resolving the issue considering all the available points of view.

2.1 Reminder of D21.1 v12

According to the [2] the "Routing information" that is assumed to be needed for the ASTP is defined as follows:

> **5.1.3.3 Routing information**
>
> An interlock list of point status according to the (safe) train path uniquely assigned to a train/vehicle and mapped against the Map data commonly shared by onboard and trackside. This information is seen useful to fetch the required map data for the train path ahead and to validate the determined position by the ASTP against track selectivity, e.g., at start-up after vehicle has moved during power-off mode (degraded mode). It might also be used to determine track selectivity, e.g., if the vehicle position is known prior to passing a switch point and to decide whether it turned left or right.

Please note that whether the "Routing information" as supportive information for the ASTP is needed or not is out of scope of the technical analysis. In this document the focus is on analyzing which routing information could potentially be used.

In the [2] there is a system function defined for acquiring the route information, but the definition still needs to be specified, as it is shown below:

7.1.11 ASTP_SF-102: Acquire Route

Rationale: The point status of the train path uniquely assigned to a train/vehicle. This information is seen useful to fetch the required map data for the train path ahead and to validate the determined position by the ASTP against track selectivity. It might also be used to determine track selectivity, e.g., if the vehicle position is known prior to passing a switch point and to decide whether it turned left or right.

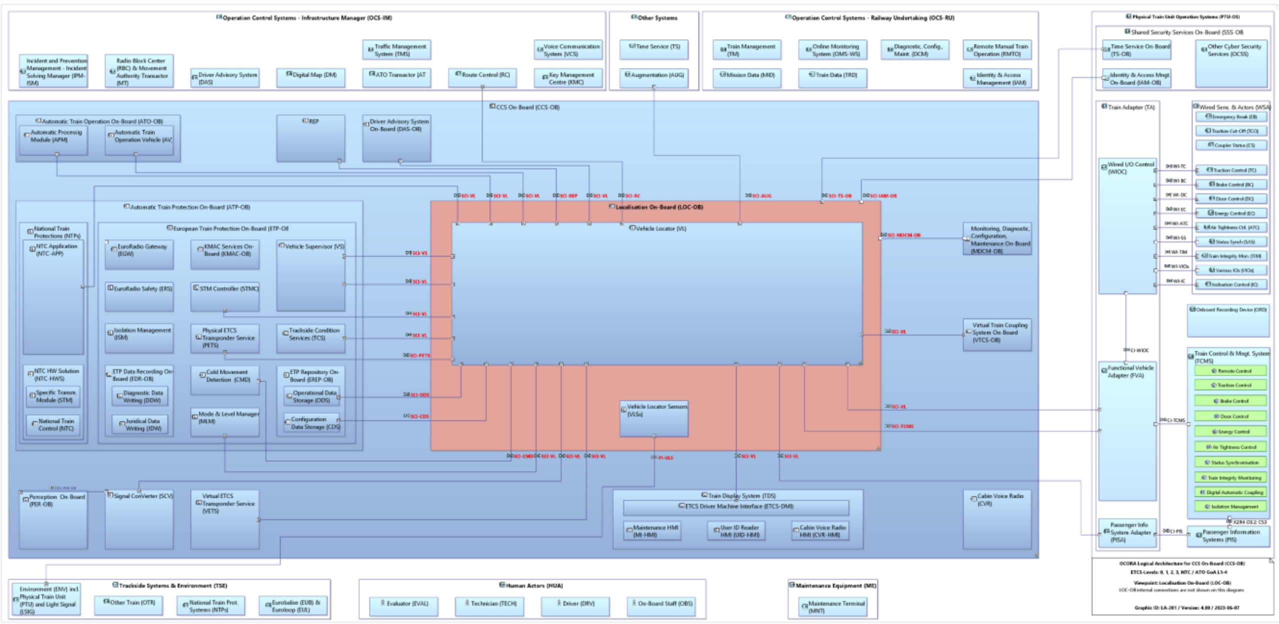
7.1.11.1.1 Data properties

Following a list of identified data properties that are seen useful as part of the function's output.

Route information: to be defined.

2.2 OCORA ONBOARD ARCHITECTURE

At the CCS-onboard system level document [4] the interface SCI-RC was introduced between the Route Control and CCS on-board. This interface is used to send the route information to the LOC-OB as it is also illustrated in the figure below:



Repository On-Board (REP-OB) and Route Control (RC)	The Repository On-Board provides - beside other information - digital maps. together with Routing Information they can be used as supporting information by the sensor fusion logic of the LOC-OB to reduce positioning errors arising in GNSS/INS sensors (e.g., due to the gradient and curve of the tracks) and in general to improve the LOC-OB positioning performance when using GNSS/INS sensors. In addition, digital maps are considered as critical inputs needed by LOC-OB for safe absolute train positioning. Further details on rationale see "LOC-OB_SF-101: Acquire Digital Map" and "LOC-OB_SF-102: Acquire Route" in [10].	Reference locations used for safe absolute train positioning are limited to physically installed objects detected by the train such as balises in the track bed. Solutions depending on absolute GNSS positions and/or track geometry signatures are not feasible for safe train front end 1D position as required by ETCS. Especially, the usage of 3D information in the sensor fusion logic to map match GNSS and balises to reference locations on track edges is not feasible.

In addition to that also a system function is defined for acquiring the route information, the definition can be found below:

5.2.11 LOC-OB_SF-102: Acquire Route

5.2.11.1 Rationale: An interlocked (safe) train path uniquely assigned to a train/vehicle. This information is seen useful to fetch the required map data for the train path ahead and to validate the determined position by the LOC-OB against track selectivity, e.g., at startup after vehicle has moved during power-off mode (degraded mode). It might also be used to determine track selectivity, e.g., if the vehicle position is known prior to passing a switch point and to decide whether it turned left or right.

In RCA terminology, a route is defined as a "Movement Permission (MP)" that is an authorisation for a particular Trackbound Movable Object to move in a defined direction, with a defined speed, along a defined path (a contiguous stretch of Track Edge Sections) on the track network [RCA.Doc.14].

5.2.11.2 Data properties: Following a list of identified data properties that are seen useful as part of the function's output.

In OCORA also a system requirement can be found which is defined as follows:

OCORA-983, D-Level - Provide Train Routing Information (SCI-RC)

An interlocked (safe) train path shall be uniquely assigned to a train/vehicle if the LOC-OB is not able to provide by itself track selectivity everywhere on the network.

Status	✓ Approved
Classification	Requirement
Rationale	This information is seen useful to fetch the required map data for the train path ahead and to validate the determined position by the LOC-OB against track selectivity, e.g., at startup after vehicle has moved during power-off mode (degraded mode). It might also be used to determine track selectivity, e.g., if the vehicle position is known prior to passing a switch point and to decide whether it turned left or right.
Remark	Today's ETCS Movement Authority (MA) specifies a distance (in meters) from a fixed, unique reference location(= balise group ID) up to which distance can be driven from this reference location. However, it does not specify a track-selective, unique route, for example, providing relevant track edge sections (see RCA domain knowledge [RCA.Doc.18, BL0 R2]) describing the interlocked train path. An ETCS MA (message 3) along with linking information (packet 5) provides the list of balise groups that the train is expected to pass on its route. Since the positions of all physical and virtual balise groups (each identified by a unique balise group id) are known by the digital map, the LOC-OB can use this information to determine the tracks that will be occupied by the train. Though, this is only a valid scenario as long as balise groups are defined consequently at the leg parts of each switch point to identify whether the left or right leg will be used and the selected mode of ETCS requires a MA. Another solution is to receive the position of each point (switch stand) as part of the interlocked train path (not covered yet by ETCS) that indicates a safe direction of travel (e.g., straight track, diverging track). Whether routing information can be used to actually determine track selectivity (not only for validation purposes) needs to be further analysed with respect to safety. In either case, the LOC-OB logic needs to avoid position jumps to other tracks if train routing information is suddenly interrupted.

2.3 RCA

In the RCA it is suggested to introduce the Movement Permission (MP) exchange between the trackside and LOC-OB. The MP is defined in the RCA concept paper [5] as follows:

The scope for the Movement Permission is defined by:

- Ensuring the safeguard of movement after switchable Field Elements are in correct state;
- Providing the basis for enabling the issue of a Movement Authority (MA) to a train such that the on-board control functions can supervise the train

The Movement Permission sets the outer limits for the operational movement of the train, given as MA from trackside to on-board, and also includes risk areas secured around the MA to assure safe train operation. The MA is to be implemented by a driver, assisted by an Automatic Train Operation (ATO) system, if present. The concept of the Movement Permission covers an approach by getting rid of the historical split between route and train control. Further information on the present philosphies can be found in the section *Problem description*.

The MP can be considered as an MA with additional extensions. The MP route covers the running path of the train and it‘s represented as a linear contiguous track area, it includes the speed profile, and optionally the risk buffer and risk path.

3. OPEN ISSUE ANALYSIS AND DECISIONS

3.1 OVERALL ANALYSIS

ASSUMPTION = Assumption made by the working group based on the inputs provided in § 2 but may be contested due to the unavailability of reliable data or evolution of the input data.

As it is stated in the [2] the routing information is needed to fetch the required map data for the train path ahead and to validate the determined position by the ASTP against track selectivity. This information is also needed to determine track selectivity i.e. the position of the train unit is known before passing a point and track selectivity enables to decide if the train unit travelled to the left of right leg of the point.

Most of the references in the previous chapters also suggest using the route information as input for the future localisation on-board system.

But there are also major concerns regarding the usage of the route information for determining a track selective position. These concerns are the following:

- A safety related concern is that the trackside is using the train location provided by the ASTP to assign and lock the train route, and this information is then used by the ASTP to determine its track selective position. This is considered as a circular reference of the train location between the interlocking and the ASTP.
- The availability of the route information depends on the trackside system i.e. the trackside system should be able to provide the route information to the train and the data should always be available, which is not always the case, because we can have degraded situations where a route can't be set by the interlocking.
- There is a dependency on the availability and performance of the transmission system. Trackside could revoke or update a reserved route. Any such updates must be promptly communicated to the ASTP.

ASSUMPTION 1: The route information will be highly available to the ASTP so that it can provide a track selective position.

In the next chapters the possible options for route information are analysed and described.

3.2 MOVEMENT AUTHORITY AND BALISE LINKING INFORMATION

In ETCS Level 2 there is a continuous radio-based communication between the Train Units onboard unit and the Radio Block Center (RBC). The Train Unit reports its current position and direction relative to a reference balise group to the RBC which calculates and transmits the Movement Authority (MA) to the Train Unit.

The track layout is unknown by the OBU it only knows about the distance from the last relevant balise group and distance to the End of Authority (EoA). The MA is updated or extended by the RBC based on certain events. According to the [3] chapter 8 the MA is sent with the Message 3. This message includes the Packet 15 that contains the details of the MA and can contain the optional packet 5 which is for the balise linking information. This linking information provides details about subsequent balises that the train is expected to encounter on its path defined by the MA. The information is essential for the ETCS on-board to detect any discrepancies between the train location known on the OBU and the real train location known on the trackside.

According to the remark of the *OCORA-983* system requirement, the linking information can be used by the ASTP when the balise groups are defined consequently at the leg parts of each point, to decide if the left or right leg will be used.

The process and the method of sending the MA to a train is closely linked to the ETCS mode in use. For example, in case of Staff Responsible the ETCS system does not receive the MA automatically, the driver is in charge and follows direct instructions from the railway staff. In case of the Shunting mode the MA may not be continuously communicated via the RBC but instead managed by local control within the shunting area. In case of the On-Sight mode the MA is granted for short distances, requiring the driver to proceed with caution and visual inspection. In case of Limited Supervision, the sending of MA may not be continuous and can depend on specific trackside equipment, requiring the train to interpret both ETCS data and traditional signals.

***Conclusion*:** Using the balise linking information to determine the train running path is not possible in all cases. There are no general engineering rules for placing balises onto the tracks, the balise linking information is optional for the Movement Authority, and the process and method of sending movement authority to a train is closely linked to the ETCS mode in use.

3.3 POINT STATUS

According to the OCORA system requirements the point status would be an information as part of the interlocked train path. This is currently not covered by the ETCS.

Trackside constituents should be able to transmit the status of the points to the ASTP based on the current position of the train. It also must be guaranteed that the point status information is always updated by the trackside before the ASTP intends to use it.

Technically the point information could be used to select the next track segment from the digital map, when passing a point in facing point movement. It is difficult to determine the point position with SIL4 when passing a point, using only data from the onboard sensors.

Although the trackside signalling could provide the point status with a proprietary formatted message, the EULYNX standard message “Point Status” gives an example for such a message as depicted in the next figures extracted from [6] message 0x0042.

Eu.SCI-RBC.PDI.168	Head	**3.5.12 Message "Point Status"**
Eu.SCI-RBC.PDI.411	Info	With this telegram, the Subsystem - Electronic Interlocking informs the RBC about the status change of a point. This telegram refines the InformationFlow "Msg_Point_Status" specified in the requirements specification (ID Eu.RBC.6066).
Eu.SCI-RBC.PDI.169	Info	Telegram definition for message "Point Status"

Byte-Nr.	Content
00	Protocol Type: 0x50 (1 Byte binary)
01..02	Message Type: 0x0042 (2 Bytes binary)
03..22	Sender Identifier (20 Bytes ISO IEC 8859-1:1998)
23..42	Receiver Identifier (20 Bytes ISO IEC 8859-1:1998)
43..62	Point ID (20 Bytes ISO IEC 8859-1:1998)
63..64	Group number (2 Bytes binary)
65..66	Subgroup number (2 Bytes binary)
67	ESI (1 Byte binary)
68	Position (1 Byte binary)
69	Requested Position (1 Byte binary)

Eu.SCI-RBC.PDI.170	Req	Permitted values for message "Point Status":
Eu.SCI-RBC.PDI.171	Req	**Message Type** The message bytes 1 - 2 shall be set to 0x0042.
Eu.SCI-RBC.PDI.172	Req	**Sender Identifier** The message bytes 3 - 22 shall contain the technical identifier of the Subsystem - Electronic Interlocking according to section 3.2.
Eu.SCI-RBC.PDI.173	Req	**Receiver Identifier** The message bytes 23 - 42 shall contain the technical identifier of the Radio Block Centre according to section 3.2.
Eu.SCI-RBC.PDI.249	Req	**Point ID** Bytes 43 to 62 shall contain a unique point identity according to section 3.3.
Eu.SCI-RBC.PDI.174	Req	**Group number** The message bytes 63 - 64 shall contain the number of an element group. Permitted values are: value meaning ----------------- ----------------
Eu.SCI-RBC.PDI.903	Req	0x0001..0x7FFF Group number
Eu.SCI-RBC.PDI.904	Req	0xFFFF Group number not applicable
Eu.SCI-RBC.PDI.175	Req	**Subgroup number** The message bytes 65 - 66 shall contain the number of an element group. Permitted values are: value meaning ----------------- ----------------
Eu.SCI-RBC.PDI.905	Req	0x0001..0x7FFF Subgroup number
Eu.SCI-RBC.PDI.906	Req	0xFFFF Subgroup number not applicable

ID	Type	Requirement
Eu.SCI-RBC.PDI.522	Req	**ESI** The message byte 67 shall contain the extended status information. Permitted values are: value meaning ----------------- ----------------
Eu.SCI-RBC.PDI.523	Req	0x01 Current status data available
Eu.SCI-RBC.PDI.524	Req	0x02 Current status data not available (telegram data not reliable)
Eu.SCI-RBC.PDI.389	Req	**Position** The message byte 68 shall contain the point position. Permitted values are: value meaning ----------------- ----------------
Eu.SCI-RBC.PDI.517	Req	0x01 Detected at left end position (proceed to the left as viewed from the front)
Eu.SCI-RBC.PDI.518	Req	0x02 Detected at right end position (proceed to the right as viewed from the front)
Eu.SCI-RBC.PDI.652	Req	0x03 Not detected at either of the end positions
Eu.SCI-RBC.PDI.551	Req	0xFE Unknown
Eu.SCI-RBC.PDI.647	Req	**Requested Position** The message byte 69 shall contain the requested point position in a route that is currently initiated. This information allows the RBC to prepare the related MA simultaneously. Permitted values are: value meaning ----------------- ----------------
Eu.SCI-RBC.PDI.648	Req	0x01 Left position requested in initiated route (proceed to the left as viewed from the front)
Eu.SCI-RBC.PDI.649	Req	0x02 Right position requested in initiated route (proceed to the right as viewed from the front)
Eu.SCI-RBC.PDI.651	Req	0x03 No position requested / no route initiated
Eu.SCI-RBC.PDI.650	Req	0xFF Requested Position not applicable

ASSUMPTION 2: The point status is available for the ETCS equipped lines. The RBC can provide the point information such as in the EULYNX message 0x0042.

ASSUMPTION 3: There is a message structure defined for providing the relevant points status to the train.

For determining which point status is of interest for a train, the train position should be known, so that the status of the points in the area where the train is can be provided. There are also cases where the point status provided for a train is not valid anymore since the status has changed meanwhile, it must be made sure that the train has the most recent status of the points which it is passing, before using the information.

In addition, point status doesn't depend on the position of the train, the status of them would come from the safe design of the interlocking.

There are lines with mechanical or electrical interlocking, where the point information can't be provided. There are also points where manual operation is used like in shunting yards or depot areas. In these cases, it's also not required to have a track selective position, because usually in case of a shunting mode an area is assigned for the train where it can perform the shunting operation, this area is limited by balises. In case the train detects a balise which is delimiting its assigned area then it will stop.

Conclusion: The usage of the point status seems to be the most straight forward routing information to be used. When the data is available i.e., the point status is known and there is no failure then the information could be provided to the train. The point status is not depending on the current position of the train nor has any links to the ETCS mode, if the information is available, it can always be provided.

3.4 Route

An interlocking is a safety-critical control system which ensures that all actions regarding movable elements are performed in a safe manner. Interlocking takes requests for setting a route, and then moves track elements, provides information if a specific route is set and safe.

This route information could potentially be provided for the ASTP for determining its track selective position. But setting a route also depends on the position of the Train Unit. This already indicates a circular reference which occurs when two systems correct their data based on the outputs of each other. In this case the trackside would use the position information provided by the ASTP to localize the train and assign and lock a safe route and then this information is then used by the ASTP to determine its track selective position.

Route is also not always available, for example in case of degraded situation where there is a failing point, no route can be assigned. In this case the driver could get the authorization from the Operation Center to pass the point even if there is no route. Route might also not be available because it can get cancelled, in case some of the sections were assigned to another upcoming train.

***Conclusion**:* The route information is not always available, and it also depends on the current position of the train unit which is causing a circular reference as stated above. These are clear indicators that the route itself might not be the most feasible solution for the ASTP to provide a track selective position.

3.5 Synthesis, PROS and CONS TABLE

	Pros	Cons
Balise Linking information	- The information is already sent as an optional packet together with the MA, no new interfaces changes are required	- MA receival is linked to the ETCS modes - There are no harmonized rules in Europe for placing the balises. - The packet of balise linking information is optional
Point status	- The status of the point doesn't depend on the train position or on the ETCS mode. If the information for a specific point is available, it can always be provided for the train unit. - Track selectivity safety requirements can be achieved.	- In case the point status detection fails, no information will be available for that point.
Dynamic route	- The dynamic route is already determined and could be provided by the RBC. For each train a specific route is assigned.	- Depends on the current position of the train, because of this it can cause a circular reference - Routes can be cancelled so there is a risk that the train uses an outdated route - It's not always available for example in case a point is broken

4. DECISIONS TO BE TAKEN

Issue: Routing information together with Digital Map data could be used as a supportive information for enabling the ASTP to reduce position inaccuracies and to determine the track edge ID when a train passes a point. Because there are different types of routing information which could be provided, like the balise linking information, point status or route, it needs to be analysed which could be potentially the best input for the ASTP.

Decision: WP21 proposal is to provide the point status to the ASTP as per analysis and conclusions stated in the sections above, in case it will be considered that the route information is needed for the ASTP as supportive information.

5. ACTIONS

1) The open issue shall be deleted from WP21 since the issue is solved.
2) For the route information the point status shall be specified as information provided for the ASTP if the route information is needed as additional information for the ASTP.

6. OPINION OF THE SYSTEM PILLAR – TRAIN CS ON TECHNICAL NOTE N°4

n°	Decisions to be taken	ASTP team final opinion
1	Because there are different types of routing information which could be provided, like: • the balise linking information, • or, point status • or route It needs to be analysed which could be potentially the best input for the ASTP	The opinion on this Technical Note can't only be a Train CS opinion due to huge dependency with trackside. The following should be analysed/answered by, at least, Traffic CS: - Do you require CCS-OB to be able to fully ensure the "Track Train Detection" function? - Which type of route information could you safely send to the on-board: list of track edge, Switch Status, ...? And through which interface? Assumption: to ensure the Train Track Detection function on-board is not a SERA need, so we propose to take the assumption that ASTP shall not be used to contribute to Train Track Detection function. Train CS opinion: - if a route is set, we would like to receive the status of the switches for the route set. - if no route, ASTP shall acquire the switches' status around the train (e.g. 1 or 2 km around the train).

7. REFERENCES

[1] SUBSET-023 ERTMS/ETCS Glossary of Terms and Abbreviations issue 3.3.0 Baseline 3 R2

[2] Operational needs and system capabilities of and ASTP system, D21.1 version 12, R2DATO

[3] SUBSET-026 ERTMS/ETCS System Requirements Specification issue 3.6.0 Baseline 3 R2

[4] OCORA-TWS01-100 Localisation On-Board (LOC-OB) Introduction, R5

[5] APS Concept Movement Permission RCA.Doc.63, v1.0

[6] Interface_specification_SCI-RBC_Eu.Doc.48, v4.0 A

APPENDIX G: TECHNICAL NOTE #5

Technical note #5

Model of accuracy and constrained areas

Author	Adrien GHARIOS (SNCF)
Partner	Arnault SFEIR (ADS), Iban LOPETEGI ZINKUNEGI (CAF), Javier LOPEZ RUIZ (ADIF)
Date	23/07/2024
Document Code	R2D-WP21-I-SNCF-TN5-01
Status	Final

Document status		
Revision	Date	Description
01	23/07/2024	First issue

TABLE OF CONTENTS

1. OBJECT OF THE WHITE PAPER

In the context of D21.1 v12 section 6 is defined an accuracy model for absolute positioning systems that applies to the ETCS/ERTMS. Two types of models are presented in this document: on one hand the speed dependent model and on the other hand the fixed value model. It is within the latter that some open issues are arise which are further developed here below.

To be noticed that this technical note only focuses on position dues to the fact that no technical lock is identified concerning speed or acceleration.

To be noticed that the core group decided to provide an analysis on two other topics which are related to performance objectives:

- Tolerance and availability objectives toward the confidence interval.
- Allocation of the performance requirements.

1.1 REMINDER OF THE OPEN ISSUE

[OI: FP2-ASTP-OPEN-ISSUE-10]: *Number of constrained area types*

[Open Issue]: The number of area types can be extended to more than 2 values to be more flexible in regard on the optimisation of the performance of the line. In this case, the areas where the values shall apply need to be defined in a specific tier of the Map Data.

[traceability]: D21.1 § 6.3.3

[Impact on ASTP]: Significant.

[Next step]: Decision to be taken with CCS onboard architects (System Pillar).

[END OI]

[OI: FP2-ASTP-OPEN-ISSUE-11]: C*onstrained area selection*

[Open Issue]: The way to select one of the two areas need to be defined with other WP. At this stage, two methods are identified:
- Getting the distance to the EoA from routing information provided by the ETCS. The area with constraint has a length of +- x meter (e.g., 900m) around the stopping point of the EoA.
- Getting the definition of areas from the Map Data.

[traceability]: D21.1 § 6.3.3

[Impact on ASTP]: Significant.

[Next step]: Decision to be taken with CCS onboard architects (System Pillar).

[END OI]

[OI: FP2-ASTP-OPEN-ISSUE-13]: Confidence interval model and backward compatibility

[Open Issue]: Confidence interval model and backward compatibility:
The proposed confidence interval models needs to be analysed and tested during the prototype / Proof of concept phases to measure the real impact of such models on the legacy lines.

[traceability]: D21.1 § 6.3.4

[Impact on ASTP]: Significant.

[Next step]: Decision to be taken with the ASTP designers with the results of ASTP experimentation.

[END OI]

1.2 QUESTIONS TO BE ANSWERED

Question 1: How to define the area with constraints.

Question 2: Shall we define intermediate area in addition to the area with constraints and the area without constraints.

Question 3: what the consequences are if the objectives on the confidence interval or the accuracy of the estimated position are not achieved.

Question 4: How to handle the differences with the subset 26 BaseLine4 that identify an accuracy objective based on increasing over/under estimation.

2. CONTEXT

To be noticed that the texts or elements available in this chapter 0 are collected from other documents without any modifications or interpretation from the working group. The statements, facts or information present in this chapter may not reflect the ideas or point of view of the working group and are presented to help understanding and resolving the issue considering all the available points of view.

2.1 Reminder of D21.1 v12

D21.1 v12 provides an analysis of all identified model of accuracy including the subset 26 Baseline 4 model of accuracy, the speed related model of accuracy and the fixed value model on accuracy.

§6_WP21.1_V12_Final.pdf

D21.1 V12 concludes :

"*Simulations have been performed with the two proposed models. They show some improvement on the capacity of the line. The main issue with regards the capacity is to achieve a small confidence interval when trains are arriving/leaving to/from stations. For the performance requirement, the speed dependent model has a major issue in achieving the performance anywhere on the network. The fixed value dependent model is closer to the real operational needs and seems to be achievable. Nevertheless, a way for the ASTP to identify on which type of area the train is running needs to be more analysed in details.*

In a first approach the fixed values model is recommended.

OPEN ISSUE 13: Confidence interval model and backward compatibility:
The proposed confidence interval models needs to be analysed and tested during the prototype / Proof of concept phases to measure the real impact of such models on the existing ETCS lines. "

2.2 X2R2 REFERENCES

X2R2 (WP3) recommend using a speed related model of accuracy that may be compatible with the 2 fixed value model. To be reminded that X2R2 is focussing on the design of prototypes (equivalent to WP22) and WP21 is focussing on the railway need with no assumption on technology.

Extract from X2R2 WP3

"The fail-safe train positioning shall calculate the forward position of the train with a maximum confidence interval of +/-10 metres within speed ranges from zero to 40km/h, 40km/h included. For speeds higher than 40 km/h and less than or equal to 500 km/h, the confidence interval shall be equivalent to a distance travelled in one second"

2.3 X2R5 REFERENCES

X2R5 (D5.2) refer to the same model of accuracy defined in X2R2 concerning the Absolute Position Information Estimator without concluding if the +/-10 metres objective within speed ranges from zero to 40km/h is valid.

To be noticed that X2R5 (especially D5.5) focuses on the Travelled Distance since Switch On Estimator with an objective to limit the CI to 2% of the travelled distance. The travelled distance from power on is not in the scope of this technical note and is defined in D21.1 as part of ASTP_SF-008: Provide Odometer information.

2.4 EXTRACTS FROM SUBSET 26 BL4

Subset 26 § 3.6.4 define the Train Position Confidence Interval and Relocation behavior.

2.4.1 Reminder of subset 26 related to the train position (SUBSET-026-3 v4.0.0.0):

The figure there after (extracted from subset 26) explicit how the train position is defined, using a location reference (LRBG), a travelled distance of the train front end from this location reference and a confidence interval related to safety and defined by two values: L_DOUBTOVER and L_DOUBTUNDER.

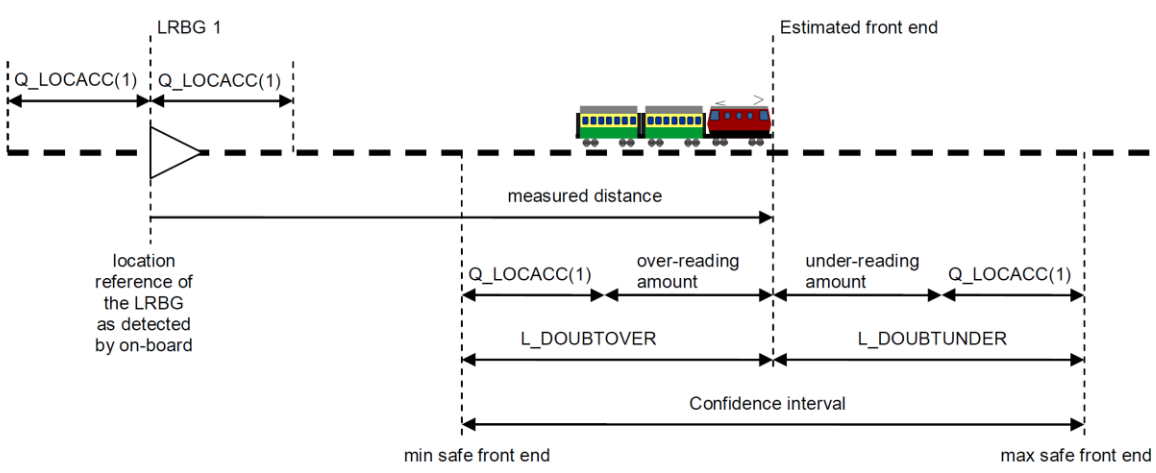


Figure 13a: Train confidence interval and train front end position in reference to LRBG

2.4.2 Sources of inaccuracy identified in the subset 26

To be noticed that the subsets does not define any requirements focusing on the performances of the estimated position (front end) error (for example a two sigma objective) and only define performances toward the confidence interval that is safety related (SIL4).

Inaccuracy of the location reference

The inaccuracy of the reference location is expressed by the Q_LOCACC parameter.

The Q_LOCACC is defined in the subset 26 as:

7.5.1.115 Q_LOCACC

Name	Accuracy of the balise location		
Description	This Qualifier defines the absolute value of the accuracy of the Balise location (i.e., the value 63m identifies a location accuracy of +/- 63m)		
Length of variable	***Minimum Value***	***Maximum Value***	***Resolution/formula***
6 bits	0 m	63 m	1 m

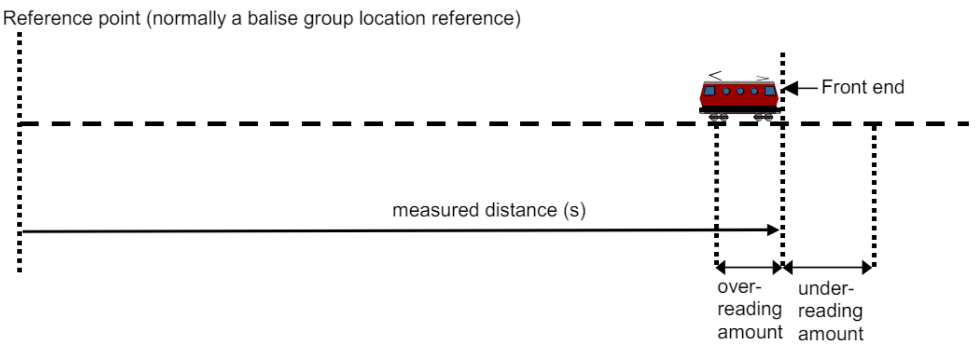
Q_LOCACC is a static value provided by the balise via the balise telegram or by using the default value (Q_NVLOCACC). There are no real performance requirements toward the Q_LOCACC values and are related to the trackside engineering rules.

Inaccuracy related to the over-reading amount or under-reading amount of the travelled distance

The accuracy related to the over-reading amount or under-reading amount of the travelled distance is defined in the subset 41 as:

5.3 Accuracy

5.3.1.1 Accuracy of distances measured on-board

Description	Accuracy of distances measured on-board
Start Event	not applicable
Stop Event	not applicable
Value	for every measured distance s the accuracy shall be better or equal to ± (5m + 5% s), i.e. the over reading amount and the under reading amount shall be equal to or lower than (5m + 5% s). 
Notes	This performance requirement includes the error for the detection of a balise location, as defined in the Eurobalise specifications. Also in case of malfunctioning the on-board equipment shall evaluate a safe confidence interval.

This over/under reading amount is including a static part (5m) related to the detection of the balise and a dynamic part (5% of the travelled distance) related to the cumulative error of the wheel sensor.

2.4.3 Balise engineering rules and impact on the train position.

Generalities

The subset 26 does not provide an explicit objective on the overall train positioning performance which is the combination of trackside and on-board behaviour and performance.

Dimensioning and Engineering rules toward balises are defined in the subset SUBSET-040 v400.

The subset 40 does not explicitly define the distances between balises and some specific points (as EoA) which is left to the infrastructure manager.

The Subset-088 Part 3 Annex A 6.6.1.2 defines :

10.2.1.14	Maximum distances between Balise groups	2.5 km	2.5 km

Swiss example

The specific Swiss engineering rules available publicly:
https://www.bav.admin.ch/dam/bav/fr/dokumente/themen/zugbeeinflussung/102_etcsl2kgb_projektierungsregelnv15.pdf.download.pdf/_102_etcsl2kgb_projektierungsregelnv15.pdf

The engineering rules give constraints on where a balise group needs to be placed in chapter 5.3. Especially rule 5.3.1.6 restricts how far apart balise groups can be placed and what their distance to the next ETCS marker should be.

The maximal distances before an ETCS marker should always be smaller than 100m, therefore, with a Confidence Interval better than 5m+5% of 100m the Confidence Interval should always be smaller than 10m (without considering the balise inaccuracy Q_LOC_ACC).

The same reasoning is applied to the maximal allowed distance between balise groups (not close to an ETCS marker) of 1500m, therefore, with a Confidence Interval of 5m + 5% of 1500m, the Confidence Interval should always be smaller than 80 m. (without considering the balise inaccuracy Q_LOC_ACC).

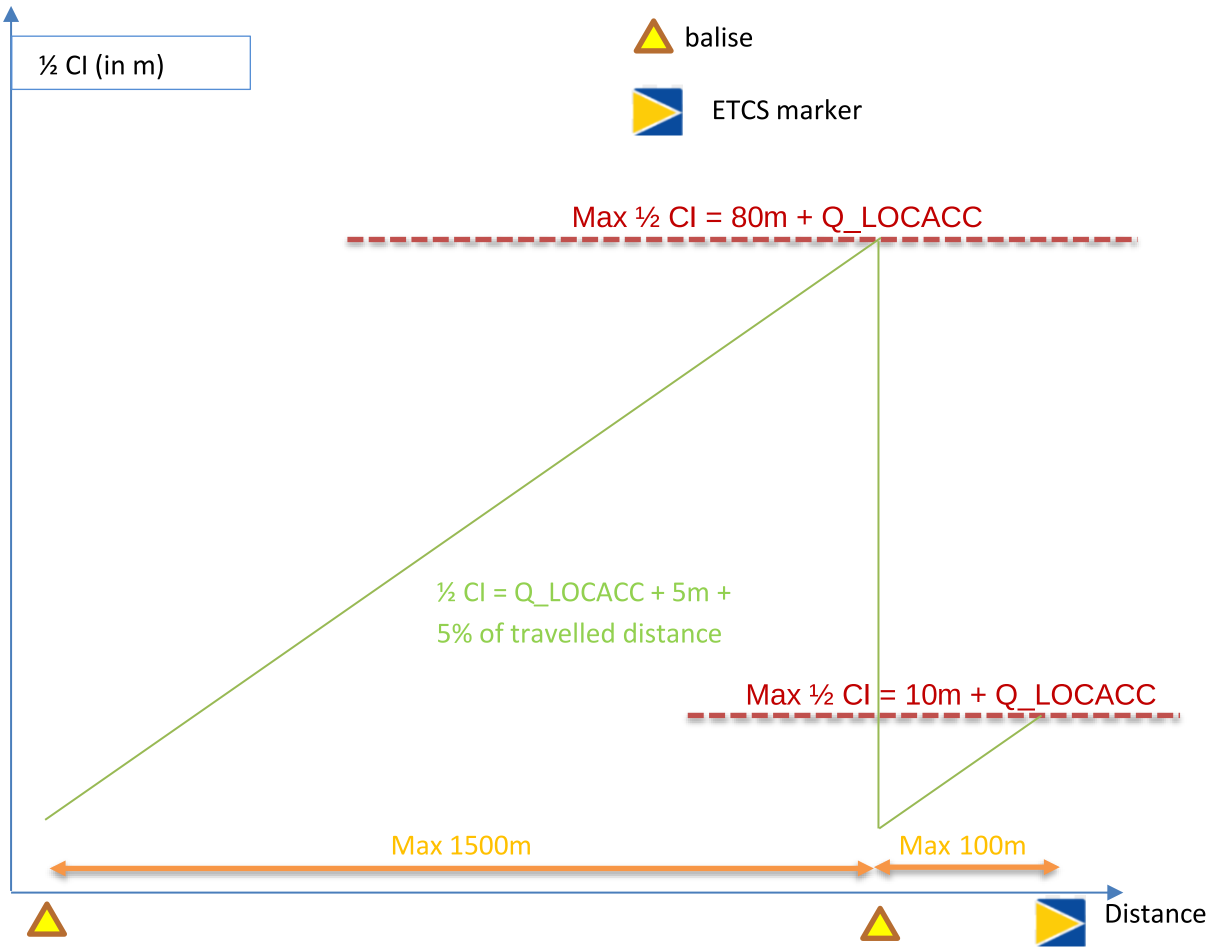


Figure 1 : Swiss illustration, Odometry + engineering rules

To be noticed that the values, without considering the Q_LOCACC, are close to the ones defined in WP21 (§2.1).

2.4.4 Implicit behaviour of the odometry

Even if not explicitly defined in the subset, the train estimated position can only be incremented if the train is not moving backwards. This fact only applies to the estimated position. The overestimation and underestimation can decrease and increase with no restrictions.

Using wheel sensor as a main sensor prevent an oscillation on the train travelled distance. For illustration purpose only, using GNSS as a main positioning sensor may generate some erroneous movement at standstill that shall be handled and filtered

2.4.5 Monitoring of odometer accuracy in Subset 26 baseline 4

Since the model of accuracy is different between subset 41 and WP21 proposal, it is interesting to highlight how localisation accuracy the is monitored.

3.6.8 Monitoring of odometer accuracy

3.6.8.1 The ERTMS/ETCS on-board equipment monitors the odometer accuracy based on the separate accumulation of underestimation and overestimation in measuring the movement of the train over a fixed distance.

3.6.8.1.1 Note: The accumulation of the underestimation/overestimation in measuring the movements considers that for both the forward and the backwards movements the absolute value contributes separately to the accumulation.

3.6.8.2 The ERTMS/ETCS on-board equipment shall store the accumulated underestimation/overestimation in measuring the movements over a defined total distance (as defined in A.3.1).

3.6.8.3 The check of the odometer accuracy shall be performed periodically at fixed distance intervals (see 3.6.8.5 and 3.6.8.7).

3.6.8.4 The distance of the intervals shall be less than or equal to a defined maximum distance interval (as defined in A.3.1).

3.6.8.5 When performing the check at fixed distance intervals, if any of the accumulated underestimation/overestimation in measuring the movements over the defined total distance travelled (see 3.6.8.2) exceeds the impairment threshold (as defined in A.3.1), the ERTMS/ETCS on-board equipment shall consider the odometer performance impaired, and the driver shall be informed.

3.6.8.5.1 Note: Exceeding the impairment threshold may indicate that the odometer accuracy exceeds the performance requirement as defined in SUBSET-041 §5.3.1.1.

3.6.8.6 Once the odometer performance is impaired, the ERTMS/ETCS on-board equipment shall continue to consider the odometer performance as impaired until the train has travelled the defined total distance (as defined in A.3.1 see 3.6.8.2) with both the accumulated underestimation and overestimation in measuring the movements being continuously below the "accuracy of distances measured on-board".

3.6.8.6.1 Note: This means that once the odometer performance is impaired, the odometer performance will continue to be displayed as being impaired until the train has travelled at least again the defined total distance (see 3.6.8.2).

3.6.8.6.2 As long as the odometer performance is considered as impaired the on-board shall inform the driver.

3.6.8.7 When performing the check at fixed distance intervals, if any of the accumulated underestimation/overestimation in measuring the movements over the defined total distance travelled (see 3.6.8.2) exceeds the safety threshold (as defined in A.3.1), the ERTMS/ETCS on-board equipment shall switch to mode System Failure.

3.6.8.7.1 Note: The train must not be stopped due to exceeding this safety threshold while operating in Level 0 or Level NTC. The ERTMS/ETCS on-board equipment should therefore handle this when entering Level 1 or 2.

3.6.8.8 If any of the accumulated underestimation/overestimation in measuring the movements exceeds the defined values (see 3.6.8.5 and 3.6.8.7) the ERTMS/ETCS on-board equipment shall apply the related reactions even if the on-board has not travelled the whole total distance (see 3.6.8.2).

Values identified in S26 Appendix A3.1 :

Monitoring of odometer accuracy: Total distance of accumulated movements	5000 m	
Monitoring of odometer accuracy: Maximum distance interval	100 m	

Monitoring of odometer accuracy: Impairment threshold	250 m (derived from 5% of 5000m)	
Monitoring of odometer accuracy: Safety threshold	1500 m (derived from 30% of 5000m)	

2.4.6 Reminder of braking curves and the impact of the estimated position accuracy defined in subset 26.

Subset 41 only propose accuracy objectives related the confidence interval (5m + 5% of travelled distance) in opposition to WP21 which propose accuracy objectives on the estimated position (absolute error) and performance objectives on the confidence interval.

It is then interesting to analyse the braking curves mechanisms defined in subset 26 to highlight the impacts of the estimated position and the impacts of the confidence interval associated.

3.13.9.3 Braking to target supervision limits

3.13.9.3.1 Overview

3.13.9.3.1.1 The braking to target supervision limits are derived from the EBD, SBD and GUI curves.

3.13.9.3.1.2 From an EBD curve, the Emergency brake intervention (EBI), Service brake intervention (SBI2), Warning (W), Permitted speed (P) and Indication (I) supervision limits, valid for the estimated speed, are defined as follows(see Figure 45):

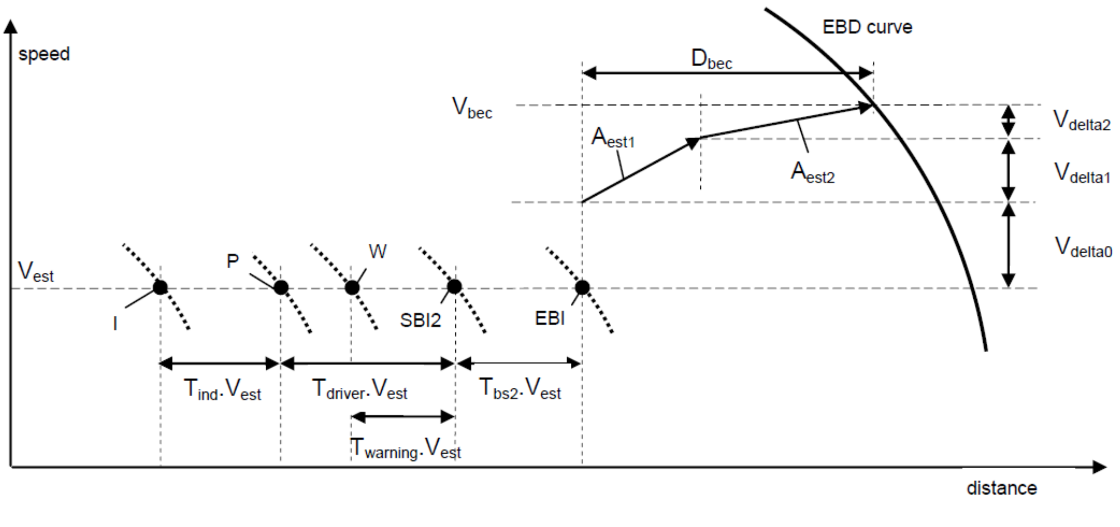
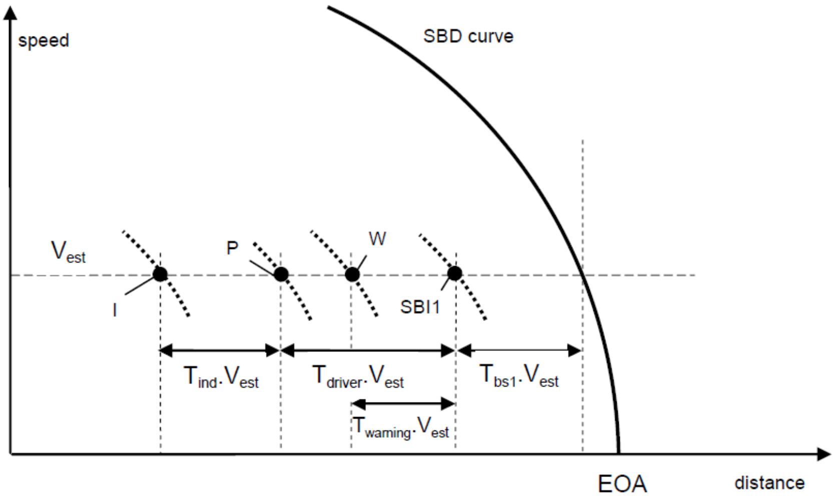


Figure 45: Braking to target supervision limits from EBD curve

3.13.9.3.1.3 From the SBD curve, Service brake intervention (SBI1), Warning (W), Permitted speed (P) and Indication (I) supervision limits, valid for the estimated speed, are defined as follows (see Figure 46):



Comment: the EBI is triggered taking into account the max safe front end. The EBI curve does protect a danger point or a supervision limit shall never be over passed with a SIL4 objective.

The end of authority is “protected” by the SBI curve. Even if overpassing a EoA forbidden, it is not considered as a dangerous situation (not taking into account the specific case of release speed) .

An operational stopping point is not linked to an end of authority.

Also, based on the experience from other projects, trackside manufacturers have also implemented three operational solutions for a stopping point (station):

- The operational stopping point can have an EoA associated to the station exit signal (in proceed aspect)

- The operational stopping point can have an EoA associated to the station exit signal (in danger aspect)

- The operational stop point does not have an EoA associated with the station exit signal.

2.4.7 Interpretation of the subset 26 braking curve mechanism

If the figure here after is valid, when the Movement Authority is updated regularly, the Safe Confidence Interval has no real impact on the capacity in opposition to the estimated position (which is not safe) since the EoA (and then the Danger point) is updated regularly and then the distance between the train and the EoA or Danger point is kept significantly large.

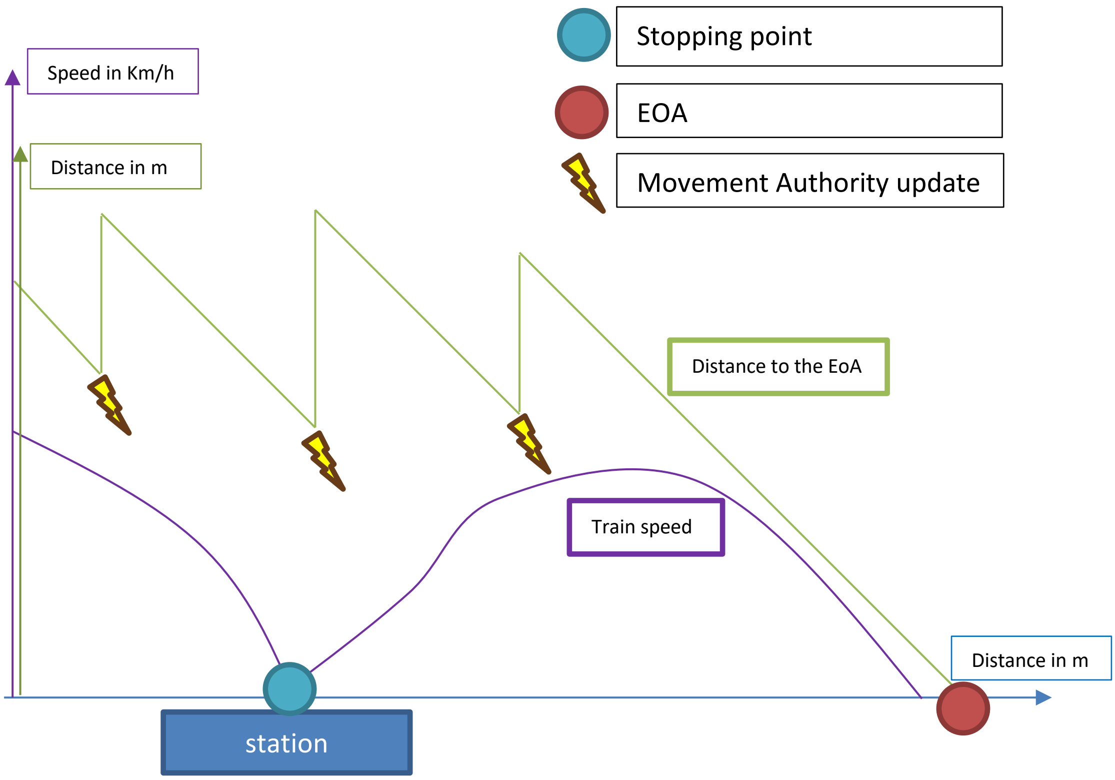


Figure 2 : stopping point vs EoA

2.4.8 Interpretation of relation between the Emergency Braking Deceleration, the Service Braking Deceleration, the estimated position, and the max safe position

The train operation stopping pattern that may have an impact on capacity can be represented by the following profiles:

The stopping point target, which represent an operational stop in a station for example,

The End of Authority, which represent the end of the supervised (by ETCS) movement. This point shall not be crossed but is not related to safety. (crossing the EoA is acceptable in a safety point of view). The service brake is triggered to avoid overpassing this point. To be noticed that we do not consider the release speed mechanism in this case.

The Danger Point (SvL), which represent a position that shall not be overpassed for safety reasons. The emergency brake is triggered to guarantee not to overpass this point.

To try to illustrate the impact of the localisation items, especially the estimated position and the associated confidence interval, some deep simplifications of the subset 26 breaking curves principle (refer to §0) are done thereafter for illustration purposes only.

As defined before:

A stopping point is an operational stopping point that is not supervised by the ETCS. It can be a stop in a station for example. Usually, only the estimated position/speed is used to control the train in order to stop as close as possible to the stopping point.

An End of Authority (EoA) is a stopping point that is supervised by the ETCS. ETCS generate a breaking curve controlled by the train estimated position / speed (Service Brake Intervention or SBI) in order to stop as close as possible to the EoA using the service brake. To be reminded that overpassing an EoA is not considered as a dangerous event and is not related to safety. To be noticed that we do not consider the release speed mechanism in this case.

A Danger Point or a Supervision Limit (SvL) is the border of the authorized movement authority that protect train movements. The ETCS has to guarantee that the train can't over-pass it. ETCS generate a breaking curve controlled by the train max safe position / max safe speed (Emergency Brake Intervention or EBI) in order not to exceed the SvL using the emergency brake. To be reminded that overpassing a danger point or an SvL is considered as a dangerous event and is related to safety (SIL4).

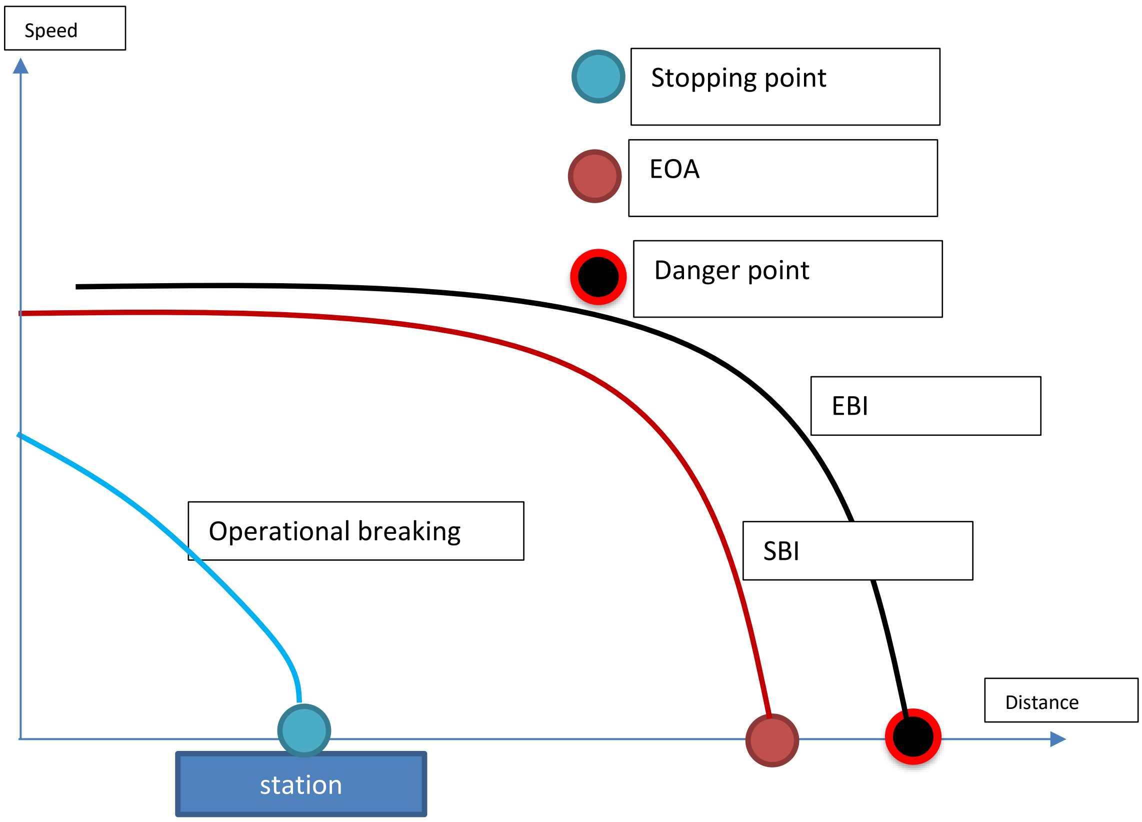


Figure 3 : EBI vs SBI vs operational braking curves illustration

Impossible case since safety related: The train real position overpass the danger point

In the following case, the train real position overpass the Danger Point without being detected by ETCS. ***This is an unccaptable feared event and shall never happen (at a THR of 10E-9 ev/h).***

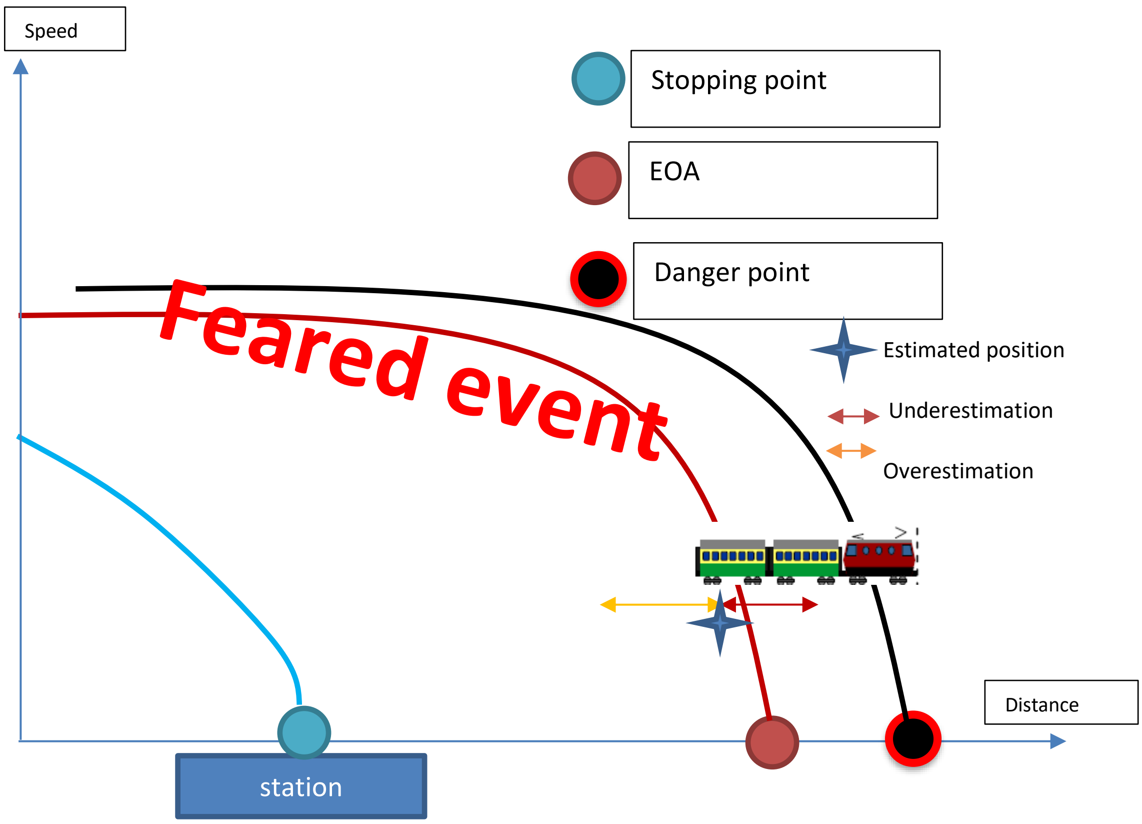


Figure 4 : The train real position overpass the danger point

Case 1 : train position is not interfering with the ETCS braking curves.

In the following case, the train is not overpassing any limit defined by ETCS and ETCS does not interfear .

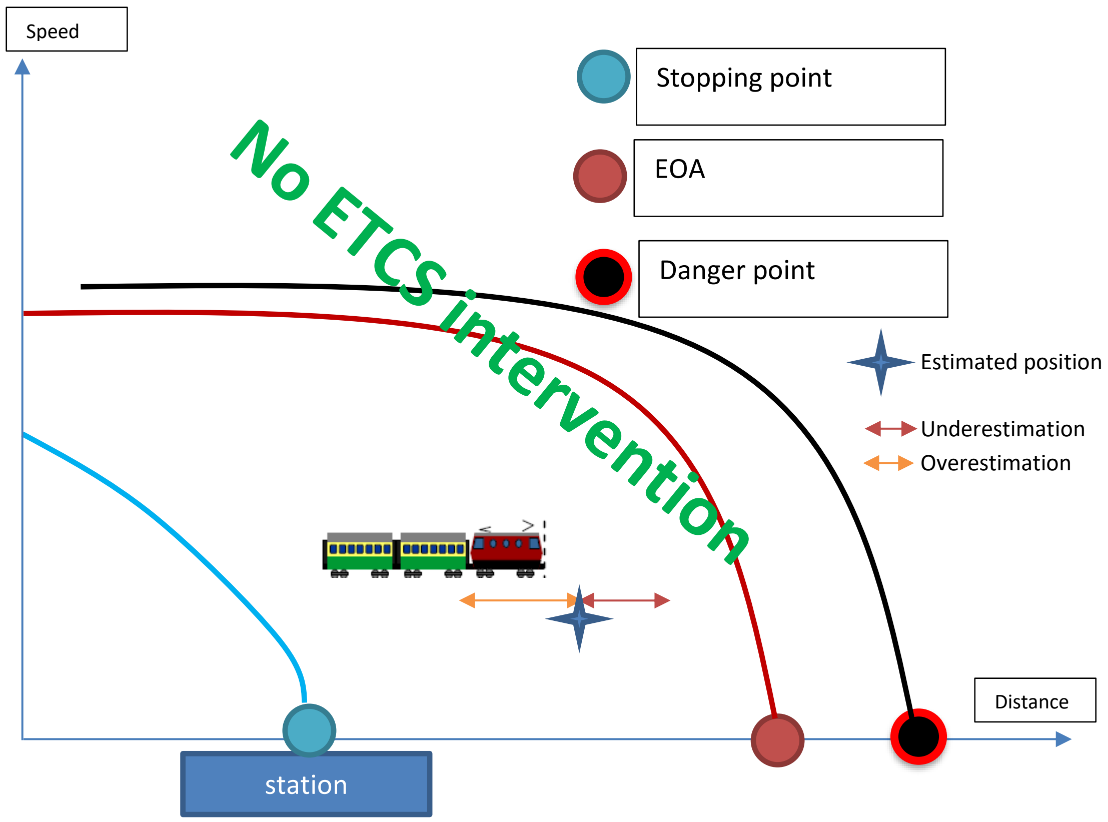


Figure 5: train position is not interfering with the ETCS braking curves.

Case 2 : The max safe position overpass the SBI

In the following case, the train max safe position overpass the SBI related to the EoA. there is a probability that the train can overpass the EoA but no risk to overpass the Danger Point. ETCS does not interfear.

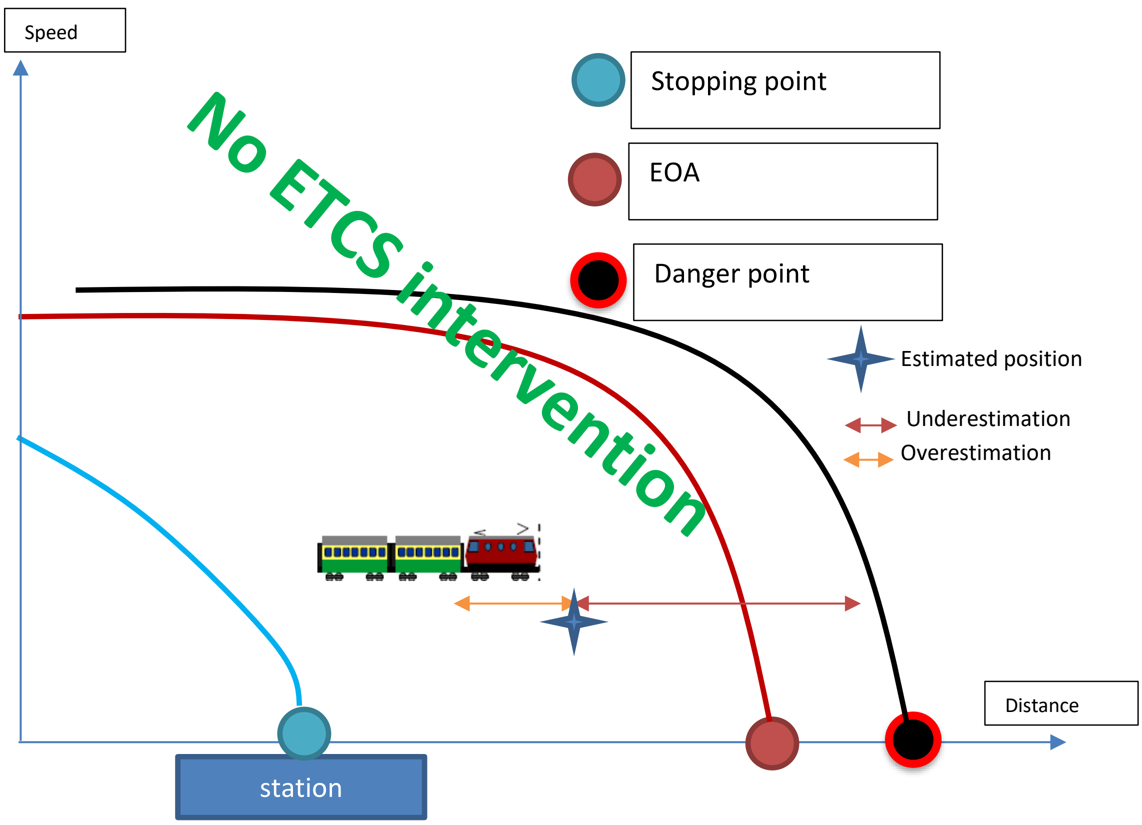


Figure 6 : The max safe position overpass the SBI

Case 3 : The max safe position hit the EBI

In the following case, the train max safe position hit the Emergency Brake Intervention curve related to the Danger Point . The ETCS trigs the emergency break to guarantee that the train will not overpass the emergency brake Intervention curve at the end the Danger point.

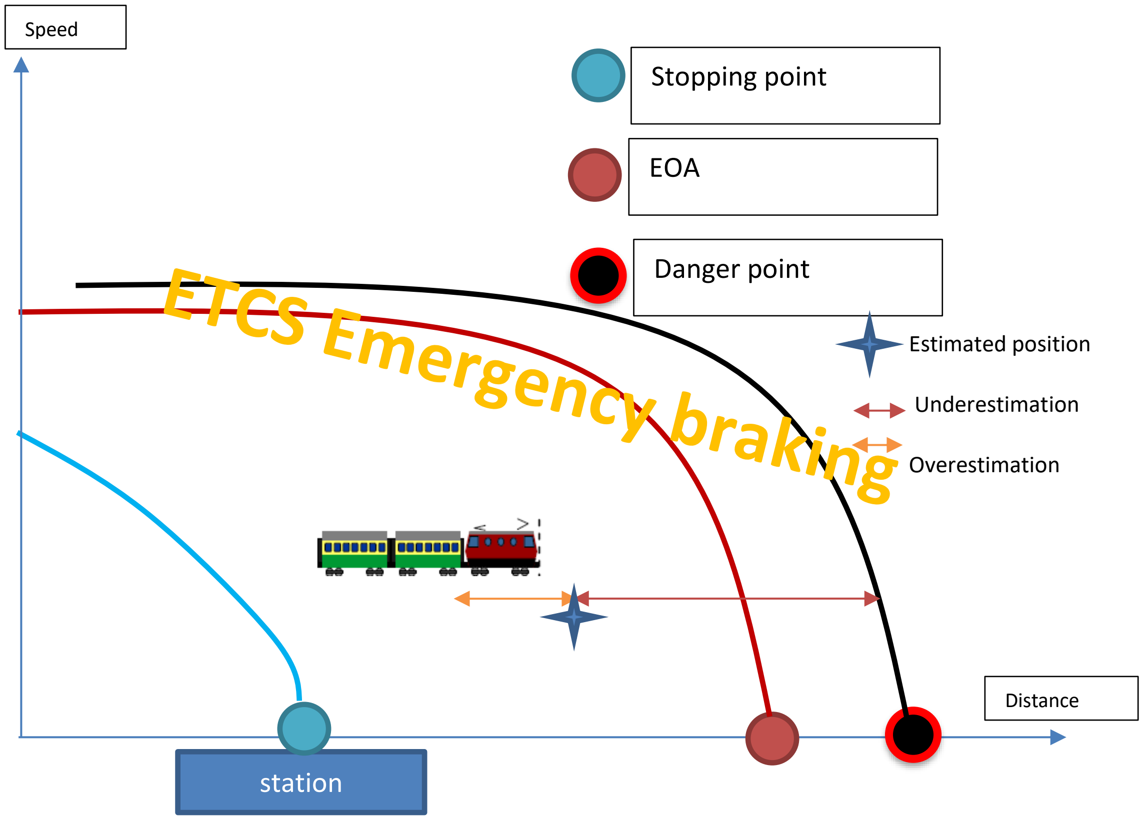


Figure 7 : The max safe position hit the EBI

Case 4 : The estimated position hit the SBI

In the following case, the train estimated postion hit the Service Brake Intervention curve related to the EoA. To keep the train under the service brake deceleration curve, the ETCS intervenes by trigging the service brake. There is a high probability that the train will not pass the EoA but it is not safety guaranteed.

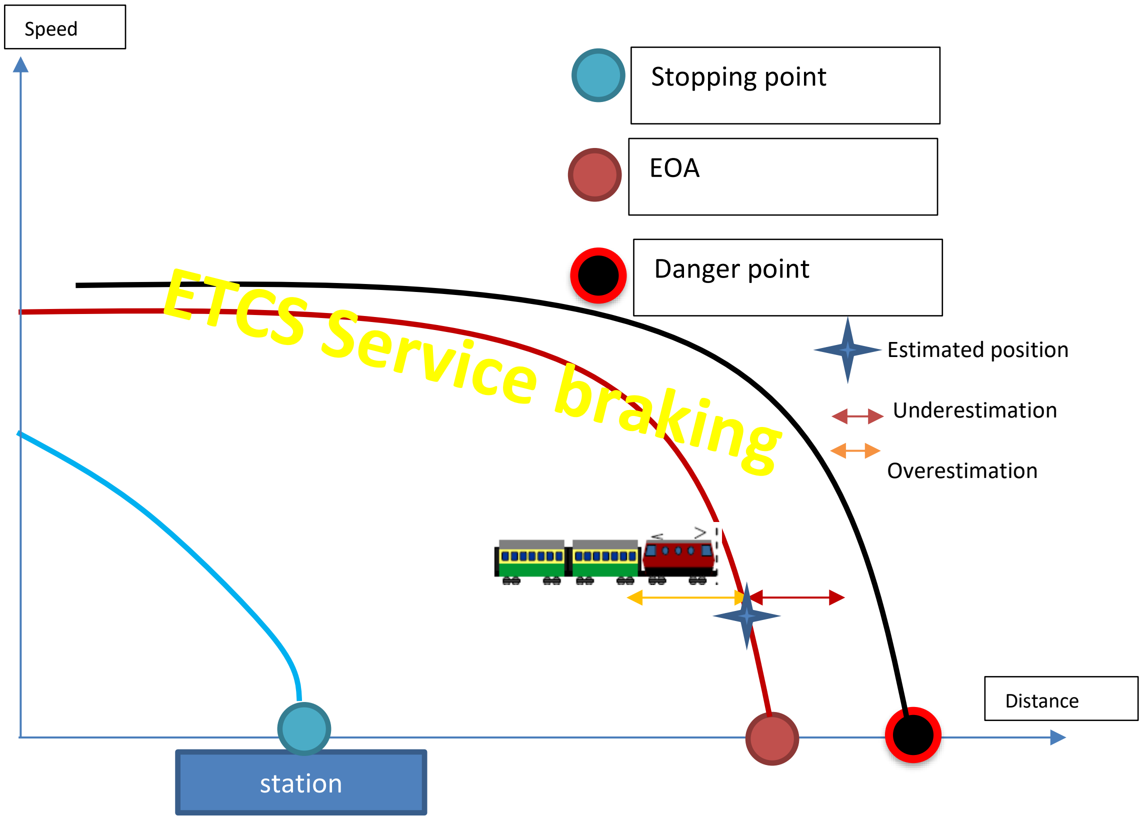


Figure 8 : The estimated position hit the SBI

2.4.9 Impact of the localisation items in term on capacity and performances of the railway.

From § 2.4.8, we can state that the impact of the confidence interval of the estimated position can be various.

If the Movement authority is updated regularly and the distance to the danger point kept large enough, we can state that in this case the confidence interval can have a slight impact on the running time. In opposition, an accurate estimated position can improve train control in terms of speed and position.

If EoA or SvL are close to the operational stopping points as stations, the confidence interval can have a significant impact on operation especially if release speed is fixed to 0km/h by the infrastructure manager.

We can also state that in addition to the required performances on the safe Confidence interval (defined in subset41), it is necessary to add requirements focussing on the performances of the estimated position of the train (no define in the Baseline 4)

3. OPEN ISSUE ANALYSIS AND DECISIONS

3.1 Analysis done by SNCF using NExTEO simulator

In the scope of WP21, in opposition of today ETCS where the train position is related to the balise engineering rules (subset 40) and the odometry performance (subset 41), the ASTP shall handle the train positioning not relying only on the balises.

To try to identify what would be the real need toward an absolute positioning system, and without considering the behaviour of the potential sensor set, SNCF provided an analysis based on NExTEO Simulator (NExTEO is a new CCS developed by SNCF for suburban mass transit).

NT_Impact_localisation_v1.4.pdf NT_Impact_localisation_v1.4_eng.pdf

This analysis state that a good accuracy is really needed when the train stops in a station. In all other cases, an Under/Over estimation lower than 80m is not impacting the capacity of the railway.

To be noticed that the results are close to the Swiss example provided in§ 2.4.3

3.2 WP21 proposal and comparison with other initiatives

3.2.1 Accuracy definition in the scope of WP21

In opposition to baseline 4 where only performances toward the Confidence Interval is defined and called accuracy, WP21 define performance objectives on the Confidence Interval and on the accuracy of the estimated position.

In the scope on WP21, accuracy is defined as: The difference between true and estimated values with a defined probability.

The confidence interval is defined as: The position, speed, acceleration interval within which the ASTP guarantees the true train position, speed, acceleration is, with a defined probability (THR).

WP21 does not use the term accuracy to define the Confidence Internal performance objectives.

Type of areas	MAPO, MAPU (1/2 MAPCI)
Area with negligible constraints	60m
Area with constraints	10 m

Table 5: Confidence interval model

Type of areas	Estimated position accuracy along the track with a defined probability of p=95.4%
Area with negligible constraints	+/- 4 m
Area with constraints	+/- 1.25 m

Table 6: Estimated position accuracy performance

Figure 9 : extract of D21.1

3.2.2 Two fixed value model and comparison with other models

WP21 two fixed value model is defining two objectives to be fulfilled without considering the accuracy model or behaviour of the sensors but based on operational needs. This model is also proposed by OCORA and CLUG2.0.

Some projects (CLUG(1) or X2R5 for example) proposed a speed related model of accuracy where the 1/2CI objective is related to the speed. (refer to 2.3)

The Subset 26 propose a travelled distance related model of accuracy and is deeply linked to the behaviour of wheel sensors.

it is interesting to superimpose the three proposals models to identify the common behaviour and differences.

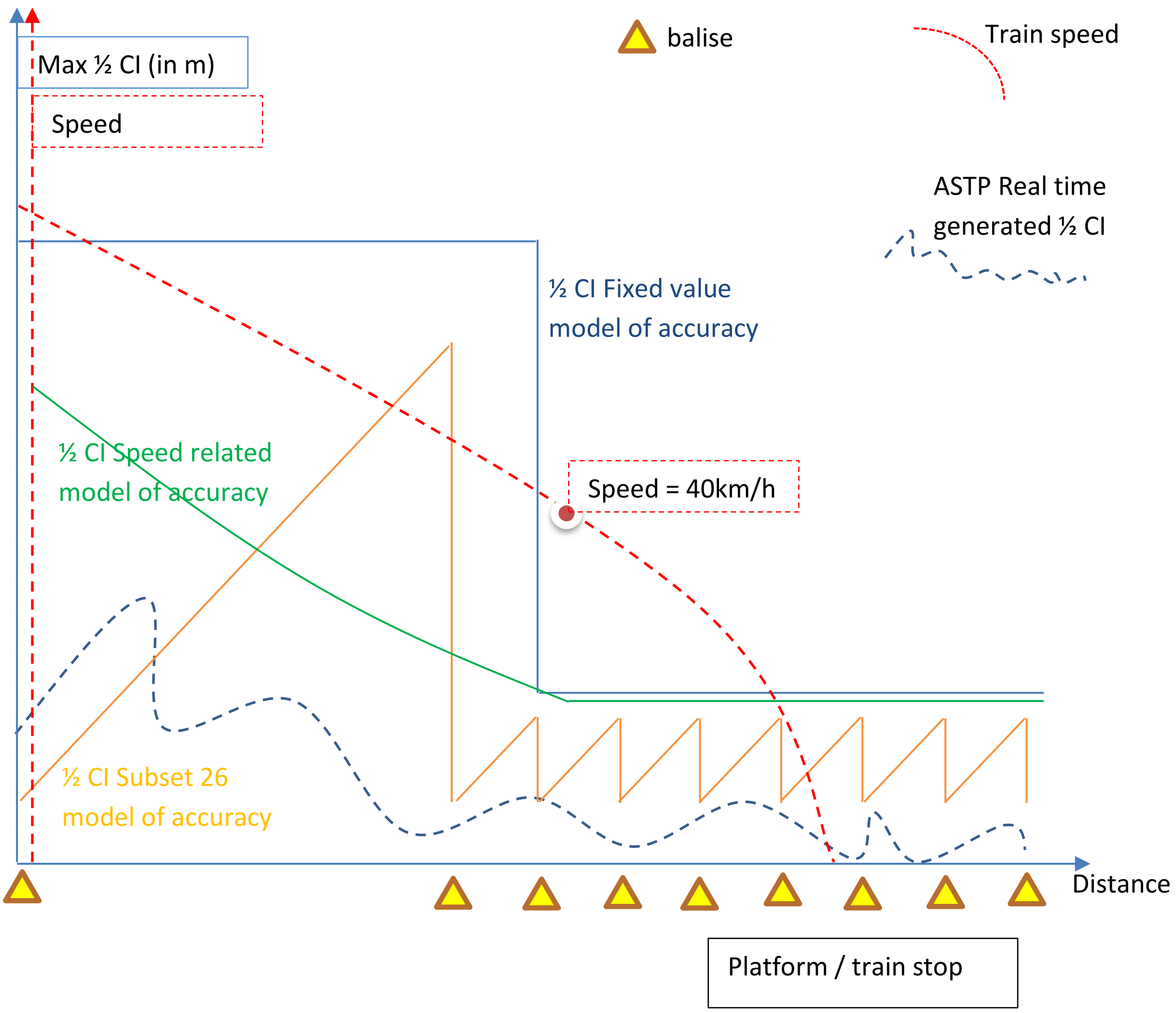


Figure 10 : superimposition of the three models

From Figure 10, we can see that the present-day model of confidence interval or the speed related model of confidence interval can fulfil the two fixed value model depending on the balise engineering rules or on the speed.

To be noticed that, in the scope of WP21, the same principle is applied to the accuracy of the estimated position.

To be noticed that, In the case of the speed dependent model, the ASTP, sicne we can't guarantee the train speed during operation, Therfore, to cope with train running at low speed, the ASTP has to achieve anywhere on the line the best performance, which seems to be a constraint difficult to achieve.

3.2.3 Number of areas

WP21 identified an open issue concerning the number of areas to be defined.

[OI: FP2-ASTP-OPEN-ISSUE-10]: *Number of constrained area types*

[Open Issue]: The number of area types can be extended to more than 2 values to be more flexible in regard on the optimisation of the performance of the line. In this case, the areas where the values shall apply need to be defined in a specific tier of the Map Data.

[traceability]: D21.1 § 6.3.3

[Impact on ASTP]: Significant.

[Next step]: Decision to be taken with CCS onboard architects (System Pillar).

[END OI]

From the NExTEO simulation (refer to §3.1) and considering the Swiss example when combining the engineering rules and the odometry performance, we can state that only two areas are mandatory to achieve operational needs and adding more areas will add complexity with unclear added value.

Number areas	Advantages	Disadvantages	Comment
1	-Simplification of the engineering rules when designing the ETCS line.	-Adds severe performance constraints on ASTP	Can only be implemented if ASTP can achieve the most constraining performance on the whole line. Seems impossible at the time this TN is written and is not considered.
2	-Cover the present-day operational needs. -Does not add complexity to the ETCS engineering rules. -	-some exported constraints may appear depending on the sensor set used by the ASTP.	Seems to be the best compromise
>2	- Can help to refine the operational need taking into account a large number of scenarios	-Add complexity to the ETCS engineering rules. -Does not match present day needs and future needs are unclear. -May add complexity to the ASTP design	the constraints seems more important than the benefits

3.3 DEFINING THE TWO TYPE OF AREA

Question : are the 2 zones defined as static zones (related to geographic zones) or dynamic zones (related to operation or EOA)

[OI: FP2-ASTP-OPEN-ISSUE-11]: C*onstrained area selection*

[Open Issue]: The way to select one of the two areas need to be defined with other WP. At this stage, two methods are identified:
- Getting the distance to the EoA from routing information provided by the ETCS. The area with constraint has a length of +- x meter (e.g., 900m) around the stopping point of the EoA.
- Getting the definition of areas from the Map Data.

[traceability]: D21.1 § 6.3.3

[Impact on ASTP]: Significant.

[Next step]: Decision to be taken with CCS onboard architects (System Pillar).

[END OI]

3.3.1 Geographically related area definition:

In this case, the ASTP shall respect the high accuracy objectives when the train is entering a high constraint area (or area with constraints) whatever is the train operation (stopping in a station or cruising at high speed). In this proposal, there are cases where the ASTP is required greater performance values than it is really required as it is in the example of cruising on a station.

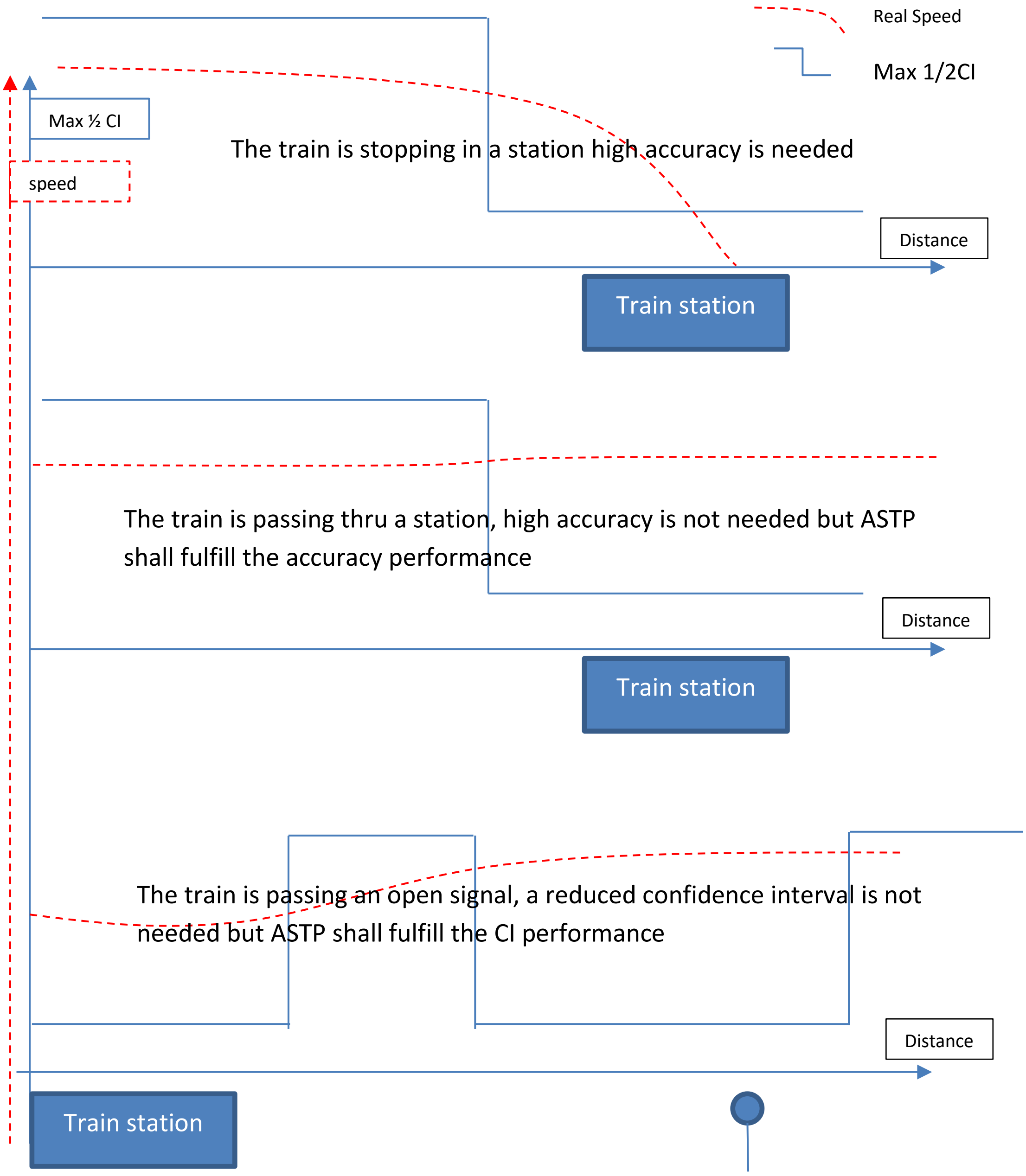


Figure 11 : Illustration of a geographical related zones

3.3.2 Dynamic area definition (related to EOA or a stopping point):

In this case, the ASTP shall respect the high accuracy objectives when the train is approaching a stopping point or an EoA wherever it is needed. If the zones where the train may stop in advance are not identified in advance, some cases may be problematic. For example, in an underground station without an open sky is GNSS is used the ASTP may fulfill the requirements for areas without constraints with no balise but not for areas with constraints.

Also, ASTP will need to acquire the train Movement Authority or other route information which cannot always be available depending on train operation.

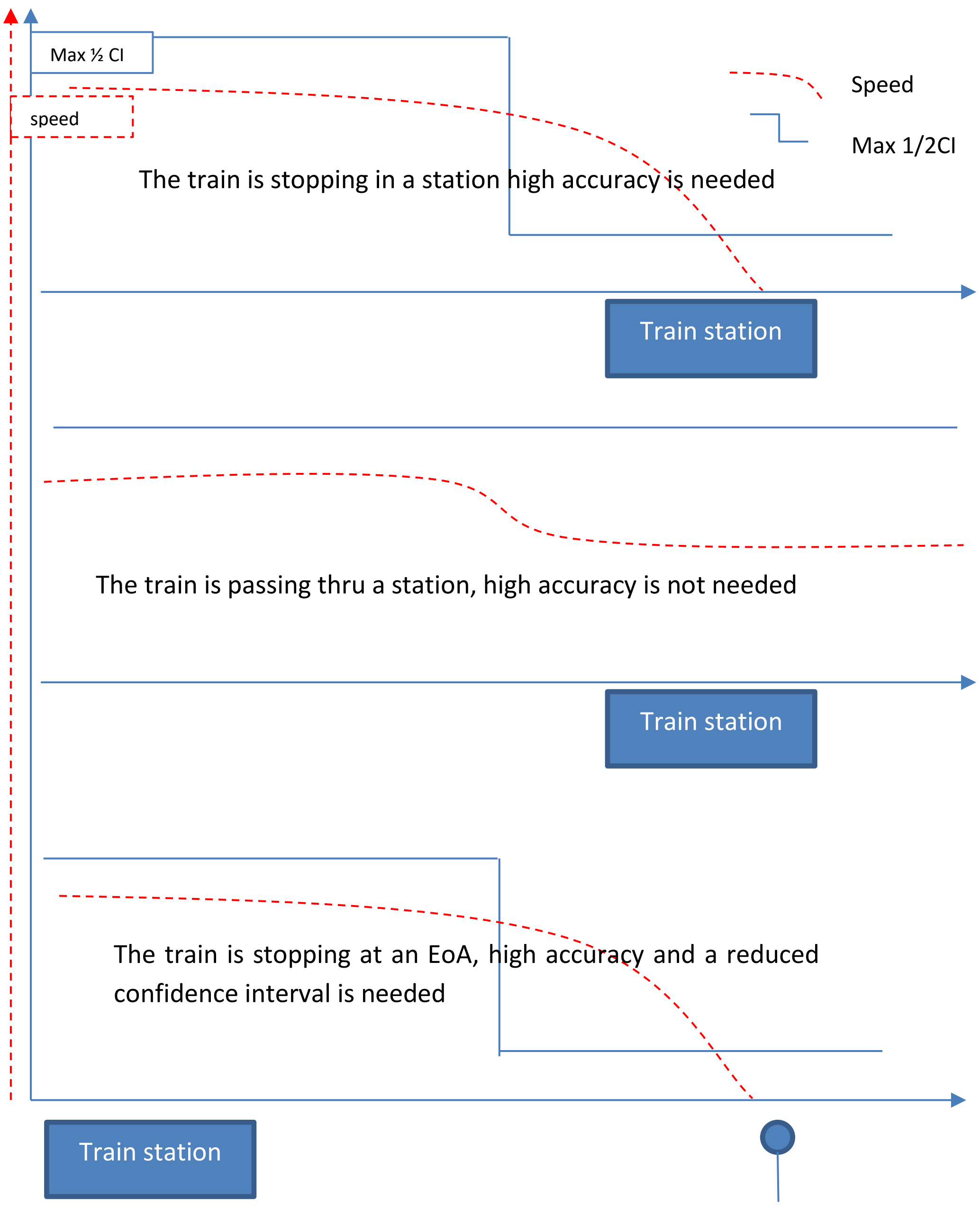


Figure 12 Illustration of a dynamic area definition

3.3.3 Geographic definition of the areas with constraints and applying theses constraints when the train stops

In this case, we may define the geographically the area with constraints, where accuracy may be needed (in stations, surrounding signals) but apply the constrained performances (max ½ CI <10 m) if, for example, the speed is lower than 40Km/h or if a deceleration is detected (identifying a stop). The advantage of this principle is that areas with potential constraints can be identify and a verification of the achievement can be done (access to open sky for ex if GNSS is used) and counter measures can be taken if needed (installation of balises in places where the conditions may be difficult). Also, a balise may be placed to surround area with constraints to be compatible with a potential Advanced Odometry mechanism.

TO BE NOTICED : that the same mechanism shall apply to the accuracy objectives defined toward the estimate position.

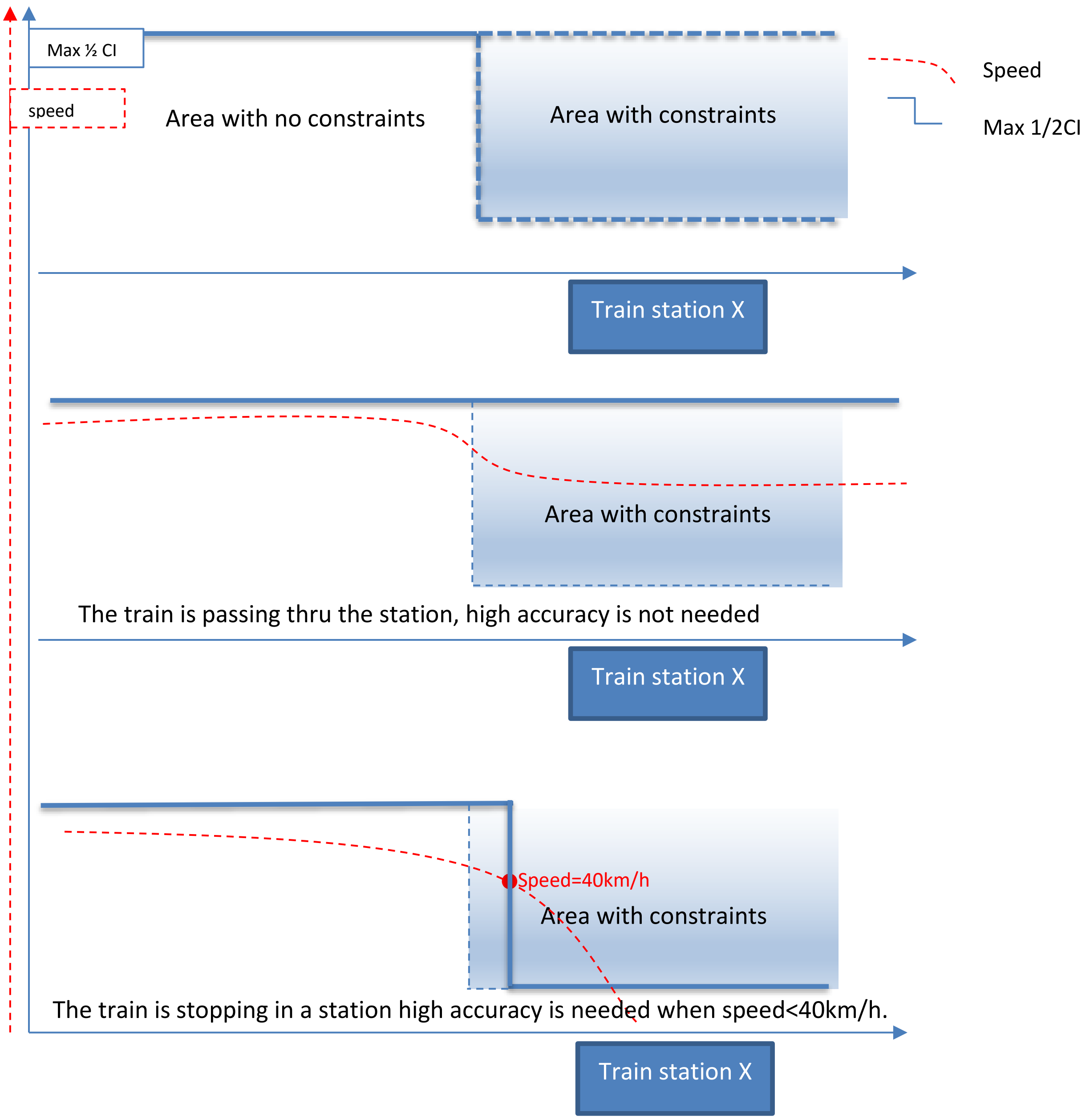


Figure 13 : Geographic definition of the areas with constraints and applying theses constraints when the train stop

3.3.4 Comparison of the area definition

Area definition	Advantages	Disadvantages	Comment
Areas are defined only geographically	-Areas are known in advance and the achievability of the requirements can be verified prior to operation.	-ASTP shall fulfil the high accuracy and reduced CI constraints depending on the train position without considering the train operation	
Areas are related to the operation or speed of the train (Distance to stopping point or EoA or the speed)	- ASTP fulfil the high accuracy and reduced CI constraints depending on the train operation and then only when needed.	-ASTP need to acquire the Movement Authority or equivalent data that is not always available. - If only speed is used, ASTP will need to fulfil the high accuracy and reduced CI constraints even when not needed (slow freight train).	
Areas are defined geographically but the accuracy and reduced CI constraints are applied if the train is at low speed AND is on an area with constraints	- Areas are known in advance and the achievability of the requirements can be verified prior to operation. -ASTP fulfil the high accuracy and reduced CI constraints under a defined speed (comparable to the speed related model) but only specific area.		

3.4 Specific cases

To be noticed that some ETCS modes may take benefit of high accuracy anywhere.

For example, in Onsight mode, the train can enter an occupied track circuit at low speed to get close to the previous train. Today, the driver shall prevent train collision and ETCS supervise speed. In the case ASTP can provide high accuracy and reduced Confidence Interval at low speed, Onsight may also provide a position supervision.

3.5 Tolerance and "availability objectives" toward the Confidence interval

TO BE REMINDED that providing a confidence interval larger than the maximal values(Max Acceptable Position Underestimation / Max Acceptable Position Overestimation) is not a safety issue and can only affect performance by slowing down or stopping a train.

TO BE NOTICED that, taking into account what is defined in § 2.4.7, the effect of reasonable (in value and/or time) excess of the 1/2CI objectives may have no impact depending on the distance to the SvL (Supervision Limit) or the Danger Point.

For these two reasons, a compromise shall be agreed to define a tolerance to overpass the performances objectives when the performances objectives toggle from an area with no constraints (1/2CI<60m, Accuracy < 4m) to an area with constraints (1/2CI<10m, Accuracy < 1,25m)

Since the Subset26 BaseLine4 define an explicit behaviour in case the performance objectives are not fulfilled on a 5000m "frame", we may get inspiration from this by defining, for example,

Proposal 1 : The average computed 1/2 CI shall not grow more than 10m in the area with constraints (assuming that they will not be longer than 5000m) and 60 m on the last 5000m in the other areas.

Proposal 2 : The computed 1/2CI shall decrease from relaxed to constraint area and become lower than Max 1/2 CI (10m) before X meters and before Y seconds after entering a constraint zone. (both distance / time conditions to comply). The values will be defined taking into account the results of the demonstration.

Proposal 3 : an alternative in case the under/over estimation exceeds the MAX ½ CI : we may consider the integration of the overriding (meter x meter or meter x second) to define an acceptable behaviour.

We may also consider the % of overriding. Considering the % of the overriding is interesting since it does take into consideration the two values (an 10% overriding = 6m for a 60m objective = 1m for a 10m objective).

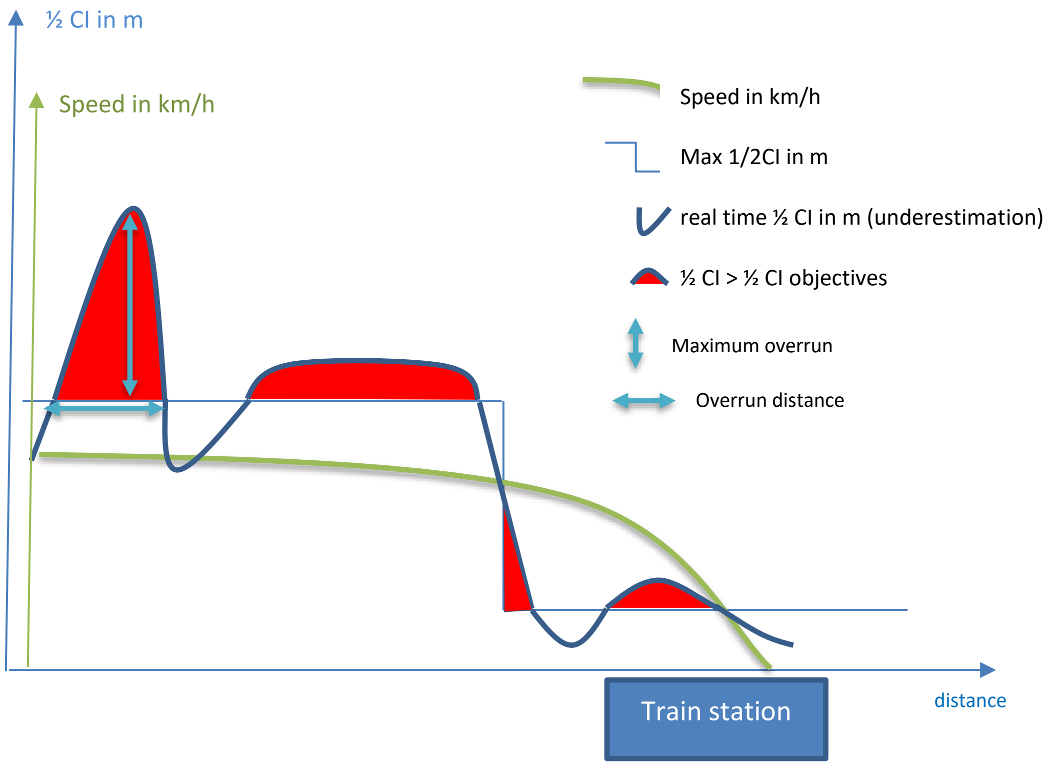


Figure 14 : illustration of unrespected objectives toward underestimation

Availability objectives definition	Advantages	Disadvantages	Comment
The average computed 1/2 CI shall not grow more than 10m in the area with constraints (assuming that they will not be longer than 5000m) and 60 m on the last 5000m in the other areas.	- Equivalent of the definition of subset 26 Baseline 4	- an averaged objective can hide problematic behaviour	
The computed 1/2CI shall decrease from relaxed to constraint area and become lower than Max 1/2 CI (10m) before X meters and before Y seconds after entering a constraint zone. (both distance / time conditions to comply). The values will be defined taking into account the results of the demonstration	- Overrun is considered acceptable only during the transition which is a good compromise between the RU/IM needs and the complexity of the ASTP design.	- No overrun is considered acceptable when the train is running in an area without constraint which may impact the ASTP complexity.	

Areas are defined geographically but the accuracy and reduced CI constraints are applied if the train is at low speed AND is on an area with constraints	- Areas are known in advance and the achievability of the requirements can be verified prior to operation. -ASTP fulfil the high accuracy and reduced CI constraints depending on the train operation and then only when needed.		
Considering the integration of the absolute overriding (meter x meter or meter x second) to define an acceptable behaviour.	-In this case, the overrun impact is represented in a better way (a small overrun will not be sanctioned in opposition to a significant overrun)	-since the absolute overrun is considered, it will have the same sanction on the area with and without constraints	
Considering the integration of the relative overriding (% x meter or % x second) to define an acceptable behaviour.	-In this case, the overrun impact is represented in the best way (a small overrun will not be sanctioned in opposition to a significant overrun taking into account the area with and without constraints)		

4. ALLOCATION OF THE PERFORMANCE REQUIERMENTS:

4.1 Reminder of subset 26 (SUBSET-026-3 v4.0.0.0) :

Refer to § 2.4.1 of this document.

4.2 Allocation of the inaccuracy budget in the scope of WP21

4.2.1 Reminder of WP21

WP21 reused the definitions of subset 26 concerning the data provided by the ASTP:

The requirement defined in D21.2 refering to the position dataset and the performance requirements are reminded there after :

[REQ: FP2-ASTP-SRS-002]: *1D localisation dataset provided by ASTP*

[category]: FR.

[Requirement]: ASTP shall provide the following data concerning the 1D train front end position:

Data	Unit / resolution	Range	Safety assumption	default invalid value
Reference location id	N/A	[0;16777214]	Safety related	16777215
Train orientation	N/A	0 Reverse 1 Nominal 2 Unknown	Safety related	Unknown
Position qualifier	N/A	0 Reverse 1 Nominal 2 Unknown	Safety related	Unknown
Estimated distance	Cm (0.01m) / 1 cm	[0;4 294 967 294]	Safety related (used to define the max/min train safe front end)	4 294 967 2945
Underestimation of the estimated distance	Cm (0.01m) / 1 cm	[0;4 294 967 294]	Safety related	4 294 967 2945
Overestimation of the estimated distance	Cm (0.01m) / 1 cm	[0;4 294 967 294]	Safety related	4 294 967 2945
Track edge id	N/A	[0;16777214]	Safety related if no trackside train detection is available	16777215

Map reference data	Exported constraint from the Digital Register (TBD by WP27)	Exported constraint from the Digital Register (TBD by WP27)	Exported constraint from the Digital Register (TBD by WP27)	Exported constraint from the Digital Register (TBD by WP27)
Train front end safety property	N/A	0 Safe 1 Not safe	Safety related	Non-safe
Validity timestamp	Depending on the selected technique	Depending on the selected technique	Safety related (safe time management)	Depending on the selected technique
Function status	N/A	0 Non-available 1 Available	Not safety related	Non-available

Table 1 : 1D localisation dataset

[Rationale]: Definitions of the dataset are defined in D21.1 § 7.1.2 as:

"Reference location id. Unique identifier of the element from which an estimated distance is given. Comparable to NID_LRBG but not limited to balise technology (SUBSET-026), i.e., could be any point on the track edge. The reference location id is determined by either of the two options:

a) Reference balise group id is received through function ASTP_SF-108: Acquire Last Relevant Balise Group (LRBG) and passed through this function.

b) ASTP determines the reference location by supporting information of the Map Data.

Train orientation. Orientation of the train in relation to the direction of the reference location. Comparable to Q_DIRLRBG but not limited to balise technology (SUBSET-026).

Position qualifier. It tells on which side of the reference location the estimated train front end position is. Comparable to Q_DLRBG but not limited to balise technology (SUBSET-026).

Estimated distance. Distance along the track between the last relevant reference location and the estimated train front end position. Comparable to D_LRBG but not limited to balise technology (SUBSET-026).

Underestimation of the estimated distance. The safe distance along the track the train may have travelled further than the estimated train front end position. Comparable to L_DOUBTUNDER but not limited to balise technology (SUBSET-026).

Overestimation of the estimated distance. The safe distance along the track the train may have travelled shorter than the estimated train front end position. Comparable to L_DOUBTOVER but not limited to balise technology (SUBSET-026).

Track edge id. Identifier of the track edge on which the estimated train front end position is located. By using a Map Data, the parameters "train orientation" and "position qualifier" can be derived based on the "reference location id" and the "track edge id". Only populated if system is using a Map Data based on a node/edge-model.

<u>Map reference data.</u> Map parts validated by ASTP that cover the area between the min safe train front end position and the max safe train front end position. Map reference data is defined in RCA.Doc.59. Only populated if system is using Map Data.

<u>Train front end safety property.</u> This output, considering the train integrity and the ASTP location onboard, will determine if the localisation information can be considered safe or non-safe. The ASTP can be installed anywhere on the train. Depending on its location, installed or not in the first vehicle of the train, the use of the TIMS is required or not.

<u>Validity timestamp.</u> Time stamping of the output, i.e., the time when the localisation information was valid. Rationale: needs to be safe to help users to decide on freshness of information.

<u>Function status.</u> Health of the system function and its output information."

[V&V method]: Verification.

[Safety assumptions]: Assumptions on the safety relation for each data of the dataset are provided in the dataset definition.

[traceability]: ASTP_SF-001.

[END REQ]

D21.2 (v0.5) defined the following requirements concerning performance objectives:

[REQ: FP2-ASTP-SRS-036]: *ASTP computed confidence interval toward the estimated train front end position performance*

[category]: NFR-PERFO.

[Requirement]: The computed ½ confidence interval (Underestimation of the estimated distance and Overestimation of the estimated distance) toward the estimated train front end position provided by ASTP shall not exceed:

- 60m in areas with negligible constraints.
- 10m in areas with constraints

[Rationale]: refer to D21.1 § 6.3.3.

[V&V method]: Lab test.

[Safety assumptions]: Not related to safety.

[traceability]: D21.1 § 6.3.3 / §4.1.1.4.1 / §4.1.1.4.2 / §4.1.1.4.5 / §4.1.2.4.1 /

[END REQ]

[REQ: FP2-ASTP-SRS-038]: *ASTP computed estimated position accuracy*

[category]: NFR-PERFO.

[Requirement]: The two-sigma accuracy toward the estimated train front end position provided by ASTP shall not exceed:

- +- 4m in areas with negligible constraints.

- +- 1.25m in areas with constraints.

[Rationale]: Refer to D21.1 § 6.3.3.

[V&V method]: Lab test.

[Safety assumptions]: Not related to safety.

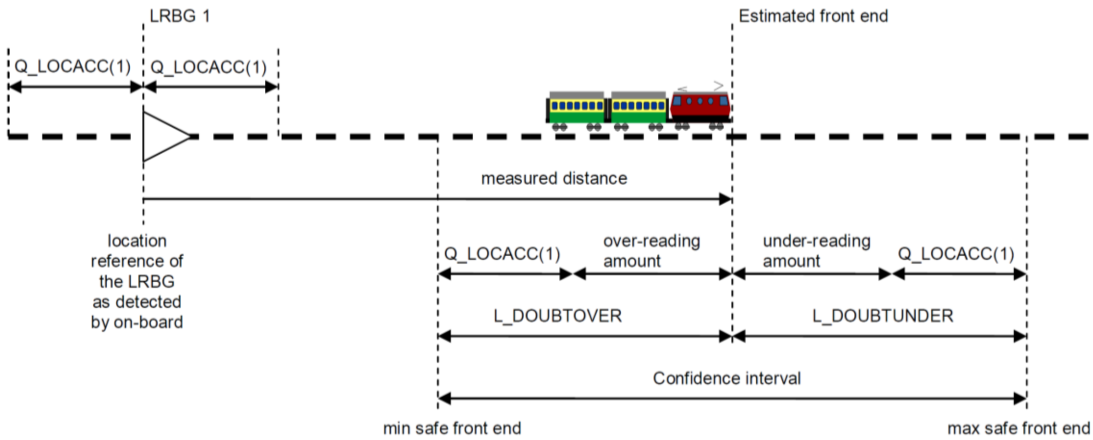
[traceability]: D21.1 § 6.3.3.

[END REQ]

Form these elements, we can state that the Under / Over Estimation does include the reference location inaccuracy AND the ASTP processed inaccuracy.

4.2.2 Clarification on the definitions

Subset26 baseline 4 representation



WP21 representation

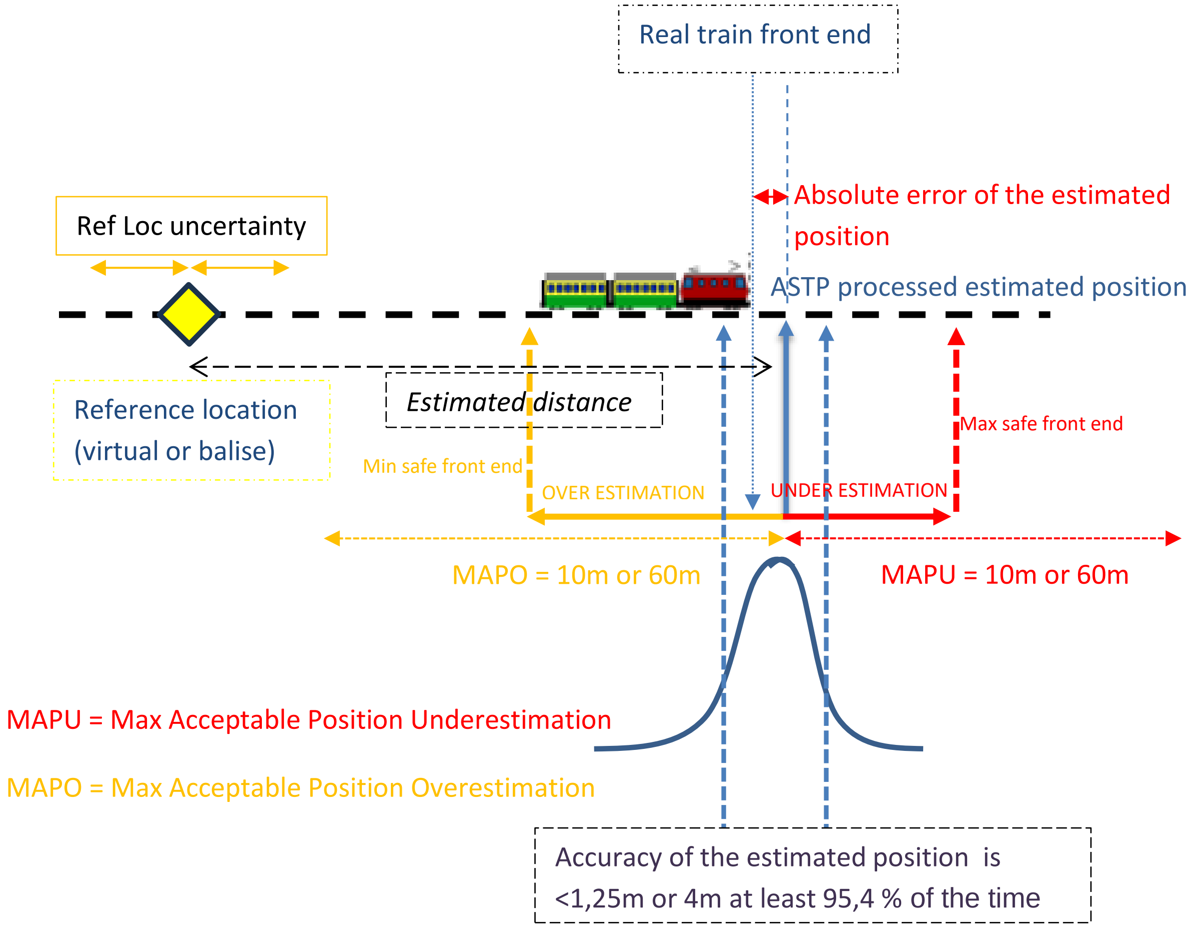


Figure 15 : localisation definitions

To be noticed that the underestimation and overestimation are expressed in relation to the estimated front end to stick to the ETCS definitions and to calculate the Max Safe and Min Safe position.

The MAPU and MAPO are referenced to the real position of the train.

4.2.3 Case of the reference location uncertainty

Case 1: The reference location is virtual, not related to a physical element and included in the digital map.

In this case, ASTP shall provide a position (GNSS, finger printing or map matching), pinout this position on the digital map and generate the travelled distance to the virtual reference location, once crossing this virtual reference location is ensured at the required SIL or THR (e.g. 1E9ev/h). The inaccuracy of this virtual reference location within the digital map is questionable if not linked to a physical element present on the tracks.

Case 2: The reference location is physical, its position is available in the digital map and also detectible by the ASTP, as balises.

This case can be divided in two subcases:

Subcase 2.1: the ASTP provide a position (GNSS, finger printing or map matching), pinout this position on the digital map and generate the travelled distance to the reference location available in the map (equivalent to case 1 since the balise position is defined during the studies prior to installation).

Subcase 2.2: the ASTP pinout the position of the balise on the map using the received balise telegram then the ASTP generate the travelled distance to the detected balise location. In this case, the ASTP shall add the Q_LOCACC parameter to the Overestimation of the estimated distance and the Underestimation of the estimated distance.

Case 3: the reference location is physical (balise) and its position is not available in the digital map. This case is not relevant in the scope on this TN since the subset 41 is applied in this case.

Case 4: The reference location is physical and included in the digital map but not detectible by the ASTP.

In this case, the ASTP shall provide a position (GNSS, finger printing or map matching), pinout this position on the digital map and generate the travelled distance to the reference location available in the map, once crossing this reference location is ensured at the required SIL THR (e.g. 1E9/h). The inaccuracy of the reference location shall be included in the Overestimation of the estimated distance and the Underestimation of the estimated distance. This inaccuracy is related to the generation of the digital map (lidar acquisition for example) and can differ from map to map.

4.2.4 Case of the location inaccuracy

The localisation inaccuracy is linked to the sensor set and the algorithms.

We can distinguish two types of errors:

- The cumulative inaccuracy as generated by “non-native position” sensors such as wheel sensors, doppler radars and IMU. In this case, the travelled distance and the related inaccuracy can only grow, until no continuous “native in position” sensor such as balise or GNSS+EGNOS sensor or optical radar can contribute or reset bias corrections .

- The noise inaccuracy that is not related to the movement of the train, typically the GNSS or the IMU behaviour at standstill. In this case, we recommend adding a requirement stating that the estimated travelled distance cannot decrease if no rollback movement is detected (to be noticed that rollback detection shall then be managed with sensors not affected by noise inaccuracy or with detectable noise inaccuracy). Nevertheless, this does not apply to the Overestimation of the estimated distance and the Underestimation of the estimated distance that shall take benefit of new sensor sets.

4.2.5 Error budget allocation

Since WP21 focus on the needs and not on the design of the ASTP, the error budget allocation shall be handled in WP22 considering the common architecture and the results of demonstration.

The topic shall also be pushed to WP27 and other WP dealing with the digital map generation to check the feasibility.

Due to the fact that the error budget is shared between several subsystems as the ASTP (sensors + Algorithms), the digital map (accuracy of the map related to the initial generation of the data and the maintenance on the tracks) and the BTM if used, it is obvious that this error allocation will have a major impact on the achievability of the performance required especially for the areas with constraints (1.25m for the estimated position accuracy and 10m for the ½ CI) .

5. HOW TO HANDLE TECHNICALLY THE IDENTIFICATION OF THE 60 MIN AREA AND THE 10M AREA

This point shall be discussed in WP22 since deeply related to the sensor set and the agreed common architecture.

5.1 OPTION 1 : BALISES TO IDENTIFY THE AREA WITH CONSTRAINTS.

In this case, an exported constraint can be created to install a balise with a low Q_LOCACC 65m before an area with constraints. In this case, we can secure the fact that the ASTP may achieve the requested performance taking benefit of the presence of a BTM onboard for retro compatibility issues. Also, if a balise is installed before entering large stations with several parallel tracks, the ASTP will need to handle track selectivity if no other balises are installed in the station.

5.2 OPTION 2 : DIGITAL MAP

Areas with constraints are defined geographically and some engineering rules may be needed to fulfil the need. Nerveless, the need to embed this information in the digital map is not mandatory since it will not have a direct impact on the ASTP behaviour.

5.3 OPTION 3 ; ASTP ACQUIRE THE MOVEMENT AUTHORITY

Since the Movement Authority is not always available and since having the Movement Authority will not modify the behaviour of the ASTP, acquiring the MA is not considered mandatory concerning this TN. **TO BE AWARE** that the MA may be needed for track selectivity issues that are not handled in this TN.

5.4 OPTION 4 ; THE ASTP IS BLIND AND THE ZONES ARE ONLY CONTRACTUAL OBJECTIVES.

It seems to be the best option. It will be the role of the engineering studies, for example, to identify the needs to add balises in a zone where the ASTP may struggle to achieve the required performances.

6. DECISIONS TO BE TAKEN

6.1 Number of areas

From the table defined in§3.2.3, a consensus is found to state that the definition of two areas (with and without constraints) as defined in D21.1 is the best compromise between the user needs and the complexity toward the ASTP design.

6.2 Area definition

From the table defined in§3.3.4 (available thereafter), three proposals are done. Since this decision may have some impact on the operational rules, WP21 export the final decision to the System Pillar.

Area definition	Advantages	Disadvantages	Comment
Areas are defined only geographically	-Areas are known in advance and the achievability of the requirements can be verified prior to operation.	-ASTP shall fulfil the high accuracy and reduced CI constraints depending on the train position without considering the train operation	
Areas are related to the operation or speed of the train (Distance to stopping point or EoA or the speed)	- ASTP fulfil the high accuracy and reduced CI constraints depending on the train operation and then only when needed.	-Areas are not known in advance and the achievability of the requirements cannot be verified prior to operation. -ASTP need to acquire the Movement Authority or equivalent data that is not always available. - If only speed is used, ASTP will need to fulfil the high accuracy and reduced CI constraints even when not needed (slow freight train).	
Areas are defined geographically but the accuracy and reduced CI constraints are applied if the train is at	- Areas are known in advance and the achievability of the requirements can be verified prior to operation.		

low speed AND is on an area with constraints	- ASTP fulfil the high accuracy and reduced CI constraints under a defined speed (comparable to the speed related model) but only specific area.		

6.3 AVAILABILITY OBJECTIVES

From the table defined in§3.5, (available thereafter), Four proposals are done. Since this decision may have some impact on the operational rules, WP21 export the final decision to the System Pillar.

Availability objectives definition	Advantages	Disadvantages	Comment
The average computed 1/2 CI shall not grow more than 10m in the area with constraints (assuming that they will not be longer than 5000m) and 60 m on the last 5000m in the other areas.	- Equivalent of the definition of subset 26 Baseline 4	- an averaged objective can hide problematic behaviour	
The computed 1/2CI shall decrease from relaxed to constraint area and become lower than Max 1/2 CI (10m) before X meters and before Y seconds after entering a constraint zone. (both distance / time conditions to comply). The values will be defined taking into account the results of the demonstration	- Overrun is considered acceptable only during the transition which is a good compromise between the RU/IM needs and the complexity of the ASTP design.	- No overrun is considered acceptable when the train is running in an area without constraint which may impact the ASTP complexity.	
Areas are defined geographically but the accuracy and reduced CI constraints are applied if the train is at low speed AND is on an area with constraints	- Areas are known in advance and the achievability of the requirements can be verified prior to operation. -ASTP fulfil the high accuracy and reduced CI constraints		

	depending on the train operation and then only when needed.		
Considering the integration of the absolute overriding (meter x meter or meter x second) to define an acceptable behaviour.	-In this case, the overrun impact is represented in a better way (a small overrun will not be sanctioned in opposition to a significant overrun)	-since the absolute overrun is considered, it will have the same sanction on the area with and without constraints	
Considering the integration of the relative overriding (% x meter or % x second) to define an acceptable behaviour.	-In this case, the overrun impact is represented in the best way (a small overrun will not be sanctioned in opposition to a significant overrun taking into account the area with and without constraints)		

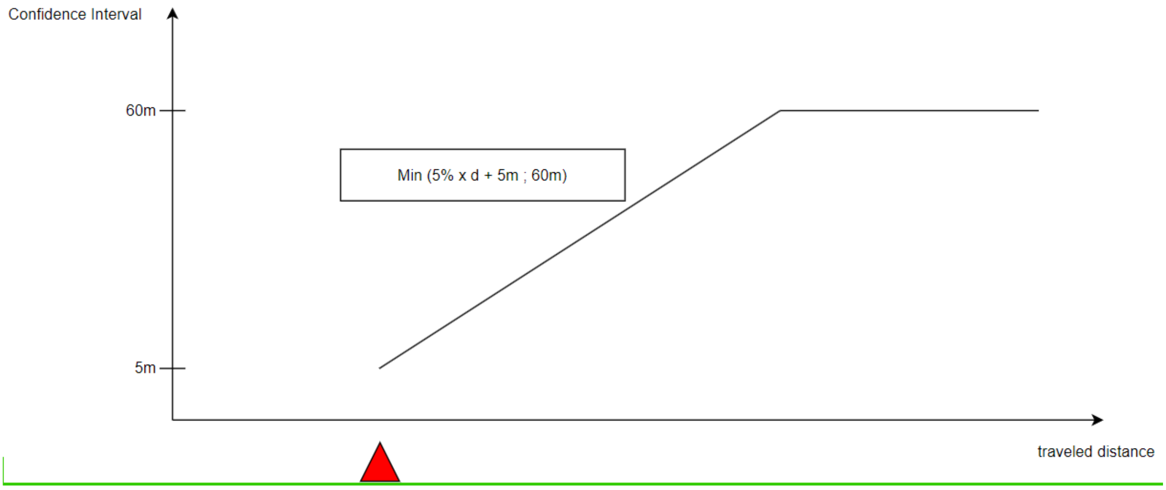
7. OPINION OF THE SYSTEM PILLAR – TRAIN CS ON TECHNICAL NOTE N°5

n°	Decisions to be taken	ASTP team final opinion
1	Number of areas	Train CS have not strong opinion, we agree to start with only 2 Areas. We assume that to add additional areas later on has no impact on CCS-OB. But what is the impact on the Infrastructure? Impact on the Digital map: constraint area = high accurate DM, and non constraint area = low accurate DM? For the ASTP, what does it need to be able to achieve a precision of 10m instead of 60m? thanks to augmentation data, thanks to accurate "micro mapping" of the DM?
2	Area Definition: • Areas are defined only geographically, or • Areas are related to the operation or speed of the train (Distance to stopping point or EoA or the speed), or • Areas are defined geographically but the accuracy and reduced CI constraints are applied if the train is at low speed AND is on an area with constraints	We prefer the first definition: Areas are defined only geographically. And the type of area should be stored in the Digital Map and then acquire by the ASTP via the REPository.
3	Availability objectives: • The average computed 1/2 CI shall not grow more than 10m in the area with constraints (assuming that they will not be longer than 5000m) and 60 m on the last 5000m in the other areas. • Or, the computed 1/2CI shall decrease from relaxed to constraint area and become lower than Max 1/2 CI (10m) before X meters and before Y seconds after entering a constraint zone. (both distance / time conditions to comply). The values will be defined taking into account the results of the demonstration. • Or, areas are defined geographically but the accuracy and reduced CI constraints are applied if the train is at low speed AND is on an area with constraints. • Or, considering the integration of the absolute overriding (meter x meter or meter x second) to define an acceptable behaviour.	Please confirm that this question is related to how decline the "monitoring of accuracy" function (CR1389) for absolute positioning. Depending which logical component will implement this new function (adapted to the absolute localisation), the interface specification will be different and consequently will impact the Basic ASTP target. We have the feeling that it should be the ETP which should implement this new function based on inputs from ASTP. But we can't right know specify the detailed of this new function (e.g. it took 1 year to agree on a solution on the CR1389 at EECT level) and consequently not identify if a new input from ASTP would be necessary. Our proposal is to let localisation specialist from WP22 to identify how to cover the CR1389 need with an absolute localisation.

	• Or, considering the integration of the relative overriding (% x meter or % x second) to define an acceptable behaviour.	

In addition, we would like to share the following:

- It should be verified if the WP21 proposal can fulfil the requirement 4.6.1.1 from subset 40.
- The performance figures shall be confirmed or corrected by the WP22 demonstrators.
- In the TN#5, there is the following requirement: “The estimated travelled distance cannot decrease”. This is a new requirement without analysis provided, so we can't confirm for the moment.
- To also take the benefit of “classical sensor” in an area where absolute positioning is providing, we would like to propose the following refinement of the accuracy requirement: Min (5% x d + 5m ; 60m)



APPENDIX H: TECHNICAL NOTE #6

Technical Note #6

Accuracy Objectives

Author	Benoit ABISSET (ATSA)
Partners	U.Kaelberer (GTSD), Petr Kačmařík (AZD), Marc Sarrat (SNCF)
Date	22/07/2024
Document Code	R2D-WP21-I-SNCF-TN6-01
Status	Final

Document status		
Revision	Date	Description
0.1	10/06/2024	First issue
0.2	24/06/2024	Feedbacks from reviewers (U.Kaelberer-GTSD, Petr Kačmařík-AZD, Marc Sarrat-SNCF)
1.0	22/07/2024	Final version

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

1. Terms and abbreviation

1.1 Abbreviations

Abbreviation	Meaning
ADM	Automatic Driving Module
APM	Automatic Processing Module
ASTP	Advanced Safe Train Positioning
ATO	Automatic Train Operation
ATP	Automatic Train Protection
BG	Balise Group
CCS	Control Command Signalling
GoA	Grade of Automation
ISM	Incident Solving Manager
LRBG	Last Relevant Balise Group
LZ	Localization
PDF	Probability Density Function
PER	Perception
REP	Repository
SIL	Safety Integrity Level
TCI	Train Confidence Interval
TN	Technical Note

1.2 Terms

Terms	Definition	Source
Automatic Driving Module	The Automatic Driving Module component is in the train and drives a train automatically. Application: GoA2, GoA3, GoA4.	[7]
Automatic Processing Module	The Automatic Processing Module component is in the train and should substitute driver and train attendant responsibilities for reacting in case of incident. It manages mission execution, safe reflexive reactions, evaluated reactions and safety procedures in cooperation with ISM.	[7]
Accuracy	The difference between true and estimated values with a defined probability. Nota: this term should be understood in the following document as defined above and not as defined in subset 026. For more details on this subject, see Technical Note #5 and D21.1	[1]
Estimated position	The position the ERTMS/ETCS on-board equipment estimates the train front is at, with the highest probability according to the physical characteristics of the train and to the odometer working conditions. It is expressed as a distance from a location reference detected by the on-board.	[2]
Estimated speed	The speed the odometer estimates the train is running at, with the highest probability according to the physical	[2]

	characteristics of the train and to the odometer working conditions	
Max safe front end. [ERTMS/ETCS]	The maximum safe front end position differs from the estimated position by the Under-reading Amount in the distance measured from the LRBG/ORBG plus the Location Accuracy of the LRBG/ORBG plus, when relevant, the difference between the max safe consist length and nominal consist length in front of/in rear of the engine, depending on whether the train orientation is the same as/opposite to the active cab respectively.	[2]
Over-reading amount [ERTMS/ETCS]	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 Eurobalise specifications.	[2]
Perception	The Perception component is in the train and senses the Physical Railway Environment in place of a driver.	[7]
Reference location	A location on the track (e.g. balise group reference location) used as a reference for the information sent from trackside or for the train position	[2]
Speed Confidence Interval [ERTMS/ETCS]	The interval within which the ERTMS/ETCS on-board assumes the actual train speed with a defined probability.	[2]
Train Position Confidence Interval [ERTMS/ETCS]	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 balise group.	[2]
Under-reading amount. [ERTMS/ETCS]	The distance the train may have travelled further 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 Eurobalise specifications.	[2]

2. Scope and purpose

2.1 Reminder of the open issue

[OI: FP2-ASTP-OPEN-ISSUE-12]: Accuracy Objectives

[Open Issue]: the values defined for the confidence interval and estimated position accuracy need to be confirmed.

[traceability]: D21.1 § 6.3.3

[Impact on ASTP]: Significant.

[Next step]: Decision to be taken with CCS onboard architects (System Pillar).

[END OI]
[OI: FP2-ASTP-OPEN-ISSUE-15]: Safe 3D position

[Open Issue]: The safety requirement of the 3D absolute position needs to be defined.

[traceability]: D21.1 § 7.1.5

[Impact on ASTP]: Significant.

[Next step]: Decision to be taken with CCS onboard architects (System Pillar).

[END OI]

2.2 Issues to be resolved

Issue 1: What is the safety level required for positioning information required for ATO functions?

Issue 2: Respect to the safety level, what is the accuracy of positioning information required for ATO functions?

2.3 Scope

In the context of train automation, the CCS would become much more complex. It will be composed of much more subsystems as today. The ability of new subsystems to fulfill new requirements would depend in the capacity of ASTP to provide adapted positioning information. Then, ASTP is a key enabler for automation, and plays a central role in the construction of the new CCS.

In the one hand, an ASTP which provides better information as required would result in an expensive and unattractive solution. In the other hand, an ASTP which does not fully fulfil the needs of the users would result in an unsuitable solution. Then, each user would require additional sensors.

Finally, the new CCS will possibly be gradually deployed. ASTP will in this case be available before GoA4 (Cf. STIP [9]). It is required to anticipate the needs of the users (the best we can) in order to be sure that, when it will be deployed, ASTP will be ready for future users such as GoA4. Consequently, designing ASTP requires to know the needs of the users in terms of accuracy, safety and needs due date. Then, the purpose of this Technical Note is to retrieve all the needs expressed by subsystems, and to adapt accordingly the requirements of ASTP.

WP6 cannot express any official needs regarding ATO up to GoA4, and perception functions. Then, the TN#6 core team has decided to consult experts from WP6 and previous Shift2Rail projects (X2Rail-4, TAURO WP4.1, etc.) to retrieve a global view of each need.

2.4 Not in scope

In the following of this note, we assume as assumption that the only user of SIL-4 positioning information is ETCS. ETCS needs are already fully expressed by the current ETCS standards, and for future ASTP, in projects such as X2R5, EUG, CLUG and D21.1. Therefore, ETCS needs are not to be addressed and are out of scope of this Technical Note. The 3D position is considered only as track constrained. Namely, the 3D position is not the rough 3D position but the 3D position filtered with the track map. The needs to fulfill Track selectivity function are not in the scope of that note.

The group has not achieved to retrieve Information regarding ATO needs for speed, acceleration and Jerk. Then, this Technical Note does not treat with these topics.

3. Context

3.1 Disclaimer Chapter 2

To be noticed that the texts or elements available in this chapter 3 are collected from other documents without any modifications or interpretation from the working group. The statements, facts or information present in this chapter may not reflect the ideas or point of view of the working group and are presented to help understanding and resolving the issue considering all the available points of view.

3.2 Positioning context

3.2.1 Positioning in current TSI

In current specifications, SIL-4 1D Positioning is described only for ATP purposes. The estimated train front end, derived from the measured distance is currently defined in [5].

The odometry shares in real time:

- The estimated front end,
- The max safe front end,
- The min safe front end.

The max safe front end and min safe front end values are used by ETCS for vital functions.

The estimated front end is used by ETCS for non-vital functions.

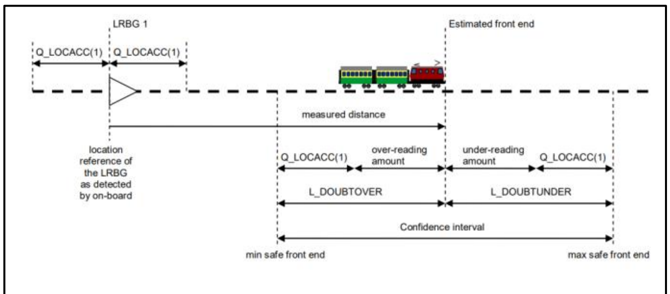


Figure 13a: Train confidence interval and train front end position in reference to LRBG

Figure 1: SUBSET-026 [5]: Train Confidence Interval

The performance required for the confidence interval is described in [3]:

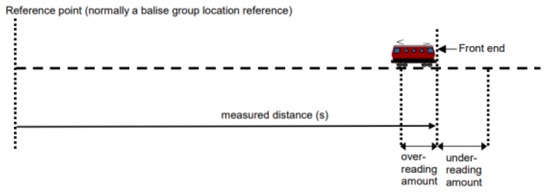
Description	Accuracy of distances measured on-board
Start Event	not applicable
Stop Event	not applicable
Value	for every measured distance s the accuracy shall be better or equal to ± (5m + 5% s), i.e. the over reading amount and the under reading amount shall be equal to or lower than (5m + 5% s). 
Notes	This performance requirement includes the error for the detection of a balise location, as defined in the Eurobalise specifications. Also in case of malfunctioning the on-board equipment shall evaluate a safe confidence interval.

Figure 2: SUBSET-041 [3]: Performance requirements: Accuracy of distance measured on-board

There is no performance requirement on the estimated front end.

3.2.2 Evolution of positioning in D21.1-D21.2

1D Position

The D21.1 [1] §6.3 refines the performances requirements to improve ATP operational performances. Two models of 1D position are proposed. The criteria are based on ATP uses cases, not ATO use cases.

Moreover, the D21.1 proposes to constrain the estimated position performance.

Type of areas	Estimated position accuracy along the track with a defined probability of p=95.4%
Area with negligible constraints	+/- 4 m
Area with constraints	+/- 1.25 m

Figure 3: D21.1 [1]: Estimated train front end position accuracy performance requirements

This constraint aims namely to improve stop accuracy in stations. However, the real-time accuracy of the estimated train front end position is not shared to the users.

3D Position

In D21.1, ASTP provides the users with the 3D Position of the train front end.(this point is currently in discussion in Technical Note #1, to be confirmed)

The 3D Position uncertainty is provided through the covariance matrix of the 3-axis coordinates. Here can be extracted each required standard deviation.

WP21 requires 2σ accuracy<5m, see D21.2 [8] [REQ: FP2-ASTP-SRS-044].

There is no safety requirement on standard deviations. Indeed, this function is considered as not related to safety.

Link between 1D and 3D Positions

The 3D position is considered as “Track constrained” (cf.§2.3).

7.1.5.1.1 Data properties

Following, a list of identified data properties that are provided as part of the function's output.

3D Position. 3-axis coordinates for the train front end position. These coordinates are track constrained.

Figure 4: D21.1 [1] 3D Position property

3.2.3 X2Rail-4 and TAURO WP4.1 positioning exported constraints on ASTP

X2R4 GoA3/4 Specification [7] exports constraints on ASTP to provide 1D and 3D positions.

Each value is associated with its standard deviation. However, there is neither safety nor performance requirements on the standard deviations.

1D Position

The 1D position refers to the beginning of the segment from which the train is running.

Interface	Packet name	Variable name	Description	Number of bit	Signed (S) / Unsigned (U)	Resolution	Values
C62	NAV_FROM_LZ	D_TRAVELLED_DISTANCE	Current value of travelled space. Note: The signal TRAVELLED_DISTANCE is based on train orientation and must increase when the train moves from cab2 to cab1 and decrease when the train moves from cab1 to cab2.	32	INT32	1 mm	-2^31 .... +(2^31- 2) 2^31- 1: unknown
C62	NAV_FROM_LZ	D_LOC_REF_CAB1	Current value of localization reference of cab 1 on the segment.	32	INT32	1 cm	-2^31 .... +(2^31- 2) +(2^31- 1): unknown
C62	NAV_FROM_LZ	M_LOC_REF_SIGMA_CAB1	Standard Deviation related to position on segment (D_LOC_REF_CAB1)	16	UINT16	1 cm	0 .... 2^16-2 2^16-1 = unknown
C62	NAV_FROM_LZ	NID_C_CAB1	Identity of the SP's country of region for the cabin 1. Code used to identify the country or region in which the segment is situated. These need not necessarily follow administrative or political boundaries	10	UINT16	integer	0-1023 2^16-1 = unknown
C62	NAV_FROM_LZ	NID_SP_CAB1	SP identity for the cabin 1. Unique number, in the country NID_C, related to the current segment.	32	UINT32	NA	0 .... 2^32-2 2^32-1: Unknown
C62	NAV_FROM_LZ	D_LOC_REF_CAB2	Current value of localization reference of cab 2 on the segment.	32	INT32	1 cm	-2^31 .... +(2^31- 2) +(2^31- 1): unknown
C62	NAV_FROM_LZ	M_LOC_REF_SIGMA_CAB2	Standard Deviation related to position on segment (D_LOC_REF_CAB2)	16	UINT16	1 cm	0 .... 2^16-2 2^16-1 = unknown
C62	NAV_FROM_LZ	NID_C_CAB2	Identity of the SP's country of region for the cabin 2. Code used to identify the country or region in which the segment is situated. These need not necessarily follow administrative or political boundaries	10	UINT16	integer	0-1023 2^16-1 = unknown
C62	NAV_FROM_LZ	NID_SP_CAB2	SP identity for the cabin 2. Unique number, in the country NID_C, related to the current segment.	32	UINT32	NA	0 .... 2^32-2 2^32-1: Unknown

Figure 5: Goa3/4 Packets [6]: 1D Positioning Information

3D Position

1	Interface	Packet name	Variable name	Description	Number of bit	Signed (S) / Unsigned (U)	Resolution	Values
2	C62	NAV_FROM_LZ	M_POS_CAB1_LATITUDE	Current latitude coordinates of the cabin 1 of the train (WGS84)	32	INT32	° x 10^-7	-900000000 .... 900000000 2^31-1 = unknown Other values: spare
3	C62	NAV_FROM_LZ	M_POS_CAB1_LONGITUDE	Current longitude coordinates of the cabin 1 of the train (WGS84). 0 corresponds to (Greenwitch meridian). The value increments from West to East	32	INT32	° x 10^-7	-1799999999 .... 1800000000 2^31-1 = unknown Other values: spare
4	C62	NAV_FROM_LZ	M_POS_CAB1_SN_ACCURACY_SIGMA	Standard deviation along South-North axes for cabin 1	16	UINT16	0.1 m	0 .... 2^16-2 2^16-1 = unknown
5	C62	NAV_FROM_LZ	M_POS_CAB1_WE_ACCURACY_SIGMA	Standard deviation along West-East axes for cabin 1	16	UINT16	0.1 m	0 .... 2^16-2 2^16-1 = unknown
6	C62	NAV_FROM_LZ	M_POS_CAB1_ALTITUDE	Current ellipsoid altitude coordinates of the cabin 1 of the train (WGS84).	32	INT32	0.1 m	-2^31 ....2^31- 2 2^31-1 = unknown
7	C62	NAV_FROM_LZ	M_POS_CAB1_ALT_ACCURACY_SIGMA	Standard deviation for altitude, for cabin 1	16	UINT16	0.1 m	0 .... 2^16-2 2^16-1 = unknown
8	C62	NAV_FROM_LZ	M_POS_CAB2_LATITUDE	Current latitude coordinates of the cabin 2 of the train (WGS84)	32	INT32	° x 10^-7	-900000000 .... 900000000 2^31-1 = unknown Other values: spare
9	C62	NAV_FROM_LZ	M_POS_CAB2_LONGITUDE	Current longitude coordinates of the cabin 2 of the train (WGS84). 0 corresponds to (Greenwitch meridian). The value increments from West to East	32	INT32	° x 10^-7	-1799999999 .... 1800000000 2^31-1 = unknown Other values: spare
10	C62	NAV_FROM_LZ	M_POS_CAB2_SN_ACCURACY_SIGMA	Standard deviation along South-North axes for cabin 2	16	UINT16	0.1 m	0 .... 2^16-2 2^16-1 = unknown
11	C62	NAV_FROM_LZ	M_POS_CAB2_WE_ACCURACY_SIGMA	Standard deviation along West-East axes for cabin 2	16	UINT16	0.1 m	0 .... 2^16-2 2^16-1 = unknown
12	C62	NAV_FROM_LZ	M_POS_CAB2_ALTITUDE	Current ellipsoid altitude coordinates of the cabin 2 of the train (WGS84).	32	INT32	0.1 m	-2^31 ....2^31- 2 2^31-1 = unknown
13	C62	NAV_FROM_LZ	M_POS_CAB2_ALT_ACCURACY_SIGMA	Standard deviation for altitude, for cabin 2	16	UINT16	0.1 m	0 .... 2^16-2 2^16-1 = unknown

Figure 6: Goa3/4 Packets [6]: 3D Positioning Information

TAURO WP4.1 [4] uses X2R4 [6] exported constraints. Moreover, it requests an accuracy better than 5m for each value of 3D position. However, there is no safety requirement expressed on the 3D position.

11.4.2.1.1	Localization shall guarantee the accuracy of the current latitude coordinates of each cabin of the train better than 5 meters.
11.4.2.1.2	Localization shall guarantee the accuracy of the current longitude coordinates of each cabin of the train better than 5 meters.
11.4.2.1.3	Localization shall guarantee the accuracy of the current ellipsoid altitude coordinates of each cabin of the train better than 5 meters.

Figure 7: TAURO WP4.1 [4]: Required position accuracy

Link between 1D and 3D positions

X2R4 GoA3/4 Specification [7] exports a constraint regarding the consistency between 1D position and 3D position.

(LZ-1.1) GoA3/4 exported constraint: LZ shall convert the train position in WGS84 coordinates (World Geodetic System 1984) into track coordinates i.e. a confidence interval defined on the path provided by REP.

Figure 8: LZ-1.1 from Go3/4 specification [7]

3.3 Attitude context

3.3.1 Attitude in D21.1-D21.2

Absolute rotational angles

In D21.1, ASTP provides the users with the absolute rotational angle values.

The attitude uncertainty is provided through the covariance matrix of the rotational angles. Here can be extracted each required standard deviation.

WP21 requires 2σ accuracy<0,1° for yaw and 0,5° for pitch and roll angles, see D21.2 [8] [REQ: FP2-ASTP-SRS-048].

The attitude is considered as not related to safety.

Angular rate

In D21.1, ASTP provides the users with the absolute angular rate values.

The attitude uncertainty is provided through the covariance matrix of the angular rate. Here can be extracted each required standard deviation.

There is no performance requirement on the accuracy.

There is no safety requirement on standard deviations. Indeed, this function is considered as non-safety related.

3.3.2 X2R4 and TAURO attitude exported constraints on ASTP

X2R4 [6] requests ASTP to provide attitude information.

Each value is associated with its standard deviation. However, there is neither safety nor performance requirements the standard deviations.

37	C62	NAV_FROM_LZ	M_TRAIN_ROLL	Current train roll orientation on local tangential referential.	16	INT16	0.01°	- 17999 .... 18000 2^15-1 = unknown Other values: spare
38	C62	NAV_FROM_LZ	M_TRAIN_ROLL_SIGMA	Standard deviation for roll information	16	UINT16	0.01°	0 .... 2^16-2 2^16-1 = unknown
39	C62	NAV_FROM_LZ	M_TRAIN_PITCH	Current train pitch orientation on local tangential referential.	16	INT16	0.01°	- 8999 .... 9000 2^15-1: unknown Other values: spare
40	C62	NAV_FROM_LZ	M_TRAIN_PITCH_SIGMA	Standard deviation for pitch information	16	UINT16	0.01°	0 .... 2^16-2 2^16-1 = unknown
41	C62	NAV_FROM_LZ	M_TRAIN_HEADING	Current train heading orientation on local tangential referential.	16	INT16	0.01°	0 .... 35999 2^16-1 = unknown Other values: spare
42	C62	NAV_FROM_LZ	M_TRAIN_HEADING_SIGMA	Standard deviation for heading information	16	UINT16	0.01°	0 .... 2^16-2 2^16-1 = unknown

Figure 9: Goa3/4 Packets [6]: Attitude Information

TAURO WP4.1 [4] uses X2R4 [6] exported constraints. Moreover, it requests an accuracy better than 0.3 degrees for roll and pitch, and better than 1 degree for heading.

11.4.2.1.4 Localization shall guarantee the accuracy of the train roll orientation on local tangential referential better than 0.3 degree.

11.4.2.1.5 Localization shall guarantee the accuracy of the train pitch orientation on local tangential referential better than 0.3 degree.

11.4.2.1.6 Localization shall guarantee the accuracy of the train heading orientation on local tangential referential better than 1 degree.

Figure 10: TAURO WP4.1 [4]: Required attitude accuracy

3.4 GoA Context

As illustrated, 3 contexts are considered in this Technical Note, which could lead to different needs and accuracy objectives, depending on the level of development of the CCS.

- The GoA1 context is only composed of ETCS needs,
- The GoA2 context is composed the GoA1 context needs and needs linked to automatic driving (ATO-OB or ADM needs),
- The GoA4 context is composed of GoA2 context needs and needs linked to driverless operations (APM and PER).

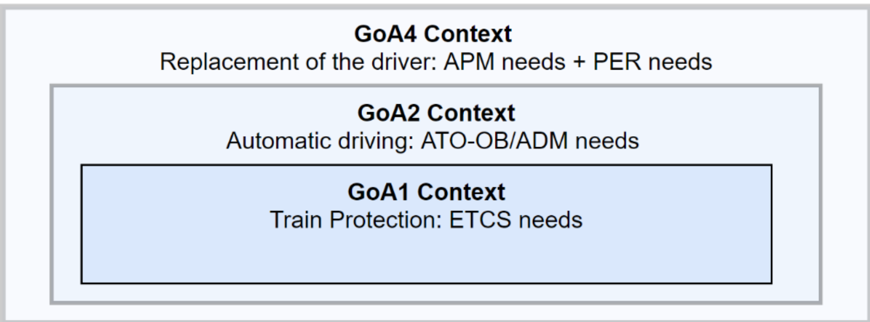


Figure 11: GoA Contexts illustration

4. Feedbacks from WP6.5 experts

4.1 Introduction

The Chapter 3 reveals differences between GoA3/4 Specification [7] and D21.1 [1]. Moreover, X2R4 [7] does not provide all the needs required to design ASTP. There is a lack of safety and performance requirements. X2R4 activities are finished, but ATO up to GoA4 specification development is transferred to WP6.5. This WP is in charge to refine the ATO GoA4 specifications.

In this context, the WP21 has decided to challenge WP6.5 regarding X2R4 exported constraints on ASTP performance and safety requirements.

A questionnaire has been sent to WP6.5 to open discussion. Each question is linked to a need of requirement refinement. The answers are presented and analysed in this chapter.

4.2 Disclaimer chapter 3

The WP6.5 deals with global performance of the system "Up to GoA4". The performance of ASTP in the context of ATO is a lower level of engineering, not yet studied. Then WP6.5 and its system experts are not relevant to provide exported constraints regarding ASTP performances.

The WP6.5 experts can only provide a collegial guidance according to their experience. All the items considered from WP6.5 do not engage WP6.5 responsibility. They have no ambition of being complete or serving as reference. They may fill a broader conversation in the WP21 community. Their consolidation in WP21 does not engage WP6.

4.3 Questionnaire sent to WP6.5

In the GoA2 context, there is a need to define what ATO-OB/ADM would expect from a localization system.

What would be the gap respect to TSI CCS 2023?

- Stopping accuracy?
- Energy saving tropics?
- Stopping points close to buffers?

Did you already list real operational cases to justify these gaps?

In the GoA4 context, what would be the needs for instance in the following areas:

- Station area?
- Tunnel area?
- Level crossing area?
- Start of mission area?
- Area where train may have to run on sight? (Obstacle expected on the track ahead)
- Running at caution area?

Do APM and PER have the same needs?

What is the impact of speed respect to localization needs?

4.4 Feedback analysis

The questionnaire feedback enables to make the following assumptions:

- ATO positioning needs linked to automatic driving (GoA2 context) seems not related to safety.
- ATO positioning needs linked to replacement of the driver (GoA4 context) should be targeted as SIL2.
- 3D Information, and especially attitude and position are used to help Perception. Attitude and position may be used by Perception to perform safety-related functions.
- 5m accuracy seems sufficient at 2σ for all systems replacing the driver.
- APM needs are not yet defined. Then, it seems today easier to define needs at higher level, namely for GoA4 context.

The questionnaire feedback provides no Information regarding:

- Performance/safety requirements required for attitude,
- The need to provide GoA4 ATO with 1D information,
- The need to provide GoA4 ATO with 3D speed, 3D acceleration, Jerk.

5. Open issues analysis and decisions

The table below gathers all the needs in term of accuracy performance and safety. They are retrieved from current specifications and discussions with WP6.5. This table purposes to compare working groups assumptions and to reveal where is lack of requirements for ASTP.

Parameters		D21.1 & D21.2 reqs	(X2R4) ∪ (TAUROWP4.1) reqs	WP6.5 needs
1D position (excluding ETCS needs)	Values	1D position of train front end	1D position for cab 1 1D position for cab 2 Ref location: REP path	GoA2 context only?
	Performances	95,4% of estimated values +-4m in area with negligible constraints, +-1,25m in area with constraints.	5m accuracy	5m accuracy at 2σ
	Uncertainty	Not provided	Standard deviation	SIL-2 to be targeted
	Safety related?	Not safety related	Safety level not defined.	Yes, in the following UCs: Door release/opening, stop in platform
3D position	Values	[latitude, longitude, altitude]	[latitude, longitude, altitude]	GoA4context only
	Performances	[2,5m; 2,5m; 2,5m] at 2σ	[5m; 5m; 5m]	[5m; 5m; 5m] accuracy at 2σ
	Uncertainty	Covariance matrix	Standard deviation for each 3-axis value	TBD
	Safety related?	Not safety related	Safety level not defined	SIL-2 to be targeted
3D attitude Absolute rotational angle	Values	[Yaw, pitch, roll]	[Yaw, pitch, roll]	GoA4 context only
	Performances	[0,1°; 0,5°; 0,5°] accuracy at 2σ	[1,0°, 0,3°, 0,3°] accuracy	Not considered
	Uncertainty	Covariance matrix	Standard deviation for each 3-axis value	TBD
	Safety related?	Not safety related	Safety level not defined	SIL-2 to be targeted
3D attitude Angular rate	Values	[Yaw, pitch, roll]/dt	Not considered	Not considered
	Performances	Best effort	Not considered	Not considered
	Uncertainty	Covariance matrix	Not considered	Not considered
	Safety related?	Not safety related	Not considered	Not considered
Link btw 1D and 3D		3D Position considered as Track Constrained.	Cf LZ-1.1 Figure 8	Not considered

Table 1: Comparison between ATO needs and deliverables.

Note:

The approaches on how to properly specify the quality of estimated values (1D and 3D positions, vehicle frame attitude, etc.) provided by ASTP for the perception system were discussed. Unfortunately, the consensus has not been reached yet. In principle, there are two ways how to formulate such quality requirements: a) using the confidence interval (requiring that the true value lies within the confidence interval with the defined probability), or b) using the parameter(s) of the given PDF (the error of the estimated value can be characterised with this pdf and it is fully defined with its parameter(s); typically, the Gaussian distribution with zero mean and certain standard deviation (sigma) is used).

a) confidence interval

For any safety-related function (function with associated SIL) the quantitative safety requirements are expressed with an acceptable hazard rate which this function has to fulfil (in CENELEC standard denoted as TFFR). For ASTP, the hazard can be naturally defined as a condition when "provided confidence interval for estimated value doesn't cover the true value, i.e. the true value is outside of the estimated confidence interval). Therefore, the confidence interval has to be defined for any safety output (since this is the way how the hazard is defined) regardless that the requirements on provided value quality are specified differently (e.g. using pdf parameter(s)).

b) parameter(s) of given pdf

For GNSS it becomes typical that the performance is specified using the 95 quantile (which is 2 sigma value for Gaussian pdf). E.g. this is a way how the position accuracy is specified in [10] and [11]. The specification using formulation with "2-sigma" is also widely used since GNSS positioning error can be well-modelled with Gaussian pdf. The benefit of this specification is that is widely used for expressing the quality of estimated position (mostly in non-safety related systems) and is well intuitively understood.

Whenever the formulation of specification uses "2-sigma" (not 95% quantile) care must be taken regarding the exact meaning. It has to be clear (ideally, has to be explicitly mentioned) if the meaning is 95 quantile only, or if Gaussian pdf is also assumed in addition. The specification based on any quantile (not only 95%) is of course more generic.

6. Decisions to be taken

Issue 1: What is the safety level required for positioning information required for ATO functions?

Decision 1: WP21 proposal (consensus is found): some safety-related GoA3/4 Use-Cases are found in previous project for 3D position and attitude. Then, SIL2 can be targeted as a preliminary approach for 1st step of development.

Nota: there is no information regarding 3D Speed, acceleration and jerk in previous projects.

Issue 2: Respect to the safety level, what is the accuracy of positioning information required for ATO functions?

Decision 2: WP21 proposal (consensus is found)

- For 1D and 3D position, an accuracy of 5m seems sufficient in GoA2 and GoA3/4 context.
- For attitude, the following accuracy [yaw:1,0°; pitch:0,3°; raw:0,3°] seems sufficient for the GoA4 context.

REFERENCE DOCUMENTS

N°	Title	Reference / Version	Provider
[1]	Operational needs and system capabilities of an ASTP system (Use Cases)	D21.1 v12	R2D
[2]	Glossary of Terms and Abbreviations	SUBSET-023 v4.0.0	ERA
[3]	Performance Requirements for Interoperability	SUBSET-041 v4.0.0	ERA
[4]	Updated GoA3/4 Specification | Lineside Signalling Interpretation	TAURO D4.2Appendix A	Shift2Rail
[5]	System Requirements Specification	SUBSET-026 v4.0.0	ERA
[6]	GoA3/4 Packets	La_GoA34_AppendixA v1.0.0	Shift2Rail
[7]	GoA3/4 Specification	La_GoA34 v1.0.0	Shift2Rail
[8]	System requirements of ASTP system	D21.2 v05	R2D
[9]	STIP Standardisation and TSI Input Plan	V1	EU-Rail
[10]	EGNOS Safety of Life (SoL) Service Definition Document	V3.5	EUSPA
[11]	GPS Standard Positioning Service Performance Standard	5th Edition, April 2020	GPS

Automatic driving context:

In this context, there is a need to define what ATO-OB/ADM would expect from a localization system.

What would be the gap respect to TSI CCS 2023?

- *Stopping accuracy?*
- *Energy saving tropics?*
- *Stopping points close to buffers?*

Did you already list real operational cases to justify these gaps?

No comparison with TSI CCS 2023 was performed (see general statement). It seemed important to classify the use-case by SIL level, as safety expectations are contradictory with accuracy expectation (at constant cost).

- SIL4 use-cases: Requirements for train protection use-cases have been elicited by ETCS (5m after a Balise +- 5% of the distance since this balise). They are proven in use and were not challenged, even based on the sensor technology part of ETCS.
- SIL~2: the autonomous train introduces a list of safety relevant use-cases formerly dealt with by the driver. Their criticality is lower than train protection (SIL4). It is higher than basic integrity (SIL0). An estimation is currently under development. Therefore, this estimation will be deemed SIL~2 in the following.
  Several SIL~2 use-cases were identified, that may be taken into account in the WP21 estimation:
  - Stop at platform: the doors should be in front of the platform, also for a passenger train longer than the platform. DB dimensions its platforms so that 5m accuracy is enough to stop the train safely, given the max length/distance between extreme doors of a train. This use-case gives easily a reference value not to be exceeded for SIL~2.
  - Merge obstacles: location is a key comparison criterion while merging obstacles along the track sensed by track-side detectors, the train itself, other trains. A 10cm precision for the obstacles would permit to differentiate most obstacles. The position inaccuracy of the train impacts the positioning inaccuracy of the humans/obstacles sensed by the train.

  Yet, if several obstacles are close to each other, relative distances may help merging. Also, the obstacle properties may help. Lastly, obstacles themselves may move out of sensing fields. The accuracy of their position may decrease over time, according to their max motion speed.

  Therefore, setting requirements stricter than the already existing 5m above seemed excessive.
  - For coupling or parking in an aged depot, with trains longer than initially planned (urban use-case), the requirement is to staple trains with a 15 cm interval. However, perception takes this burden (SIL~2) by estimating a distance from train to train. The train positioning will only define the range in which the next train's coupling shall be searched. Here again, the 5m above seems reasonable already.
- SIL0

If a train shall stop at a platform with platform doors, the overall budget is 10cm, incl. train position control. Taking half of it for the train position measurement leads to 5 cm toward reality (train positioning + map). Here again, perception may help.
If platform doors are excluded from the scope (rather an urban use-case, emergence of perception as 'real-world-related' positioning vs. track-map related positioning,
A high requirement should be that of disabled person trying to board a train stopping shortly (also with assistance). This person (and/or his/her assistant) would expect his/her door to be at a certain place.
Here the ATO requirements set by ATO and ATP, littler than the 5m above, would be highly sufficient.

Interaction SIL4-SIL~2-SIL0

ATO has the responsibility to avoid triggering ATP and SIL~2 protections (mostly APM scenarios).

As a consequence, independently of its own confidence interval, ATO sill stay in rear of the SIL4 MA, by the ATP's CI and of some SIL~2 End of Authority by the SIL~2 confidence intervals.

For instance, if a signal protects switches right after a platform:

- An ATP confidence interval of 50m and an ATO confidence interval will lead the train to stop 51 m in rear of the Signal's Supervised location/EoA.
- If a train has a stopping to be reached with 5 m accuracy to avoid doors opening on 0pthe void, this budget shall be shared between SIL2 (ex: 4 m) and ATO (ex: 1m remaining)

GOA3/4 Context:

We try to define specific areas to mitigate the accuracy needs for GoA34 needs.

What would be the needs for instance in the following areas:

- *Station area?*
- *Tunnel area?*
- *Level crossing area?*
- *Start of mission area?*
- *Area where train may have to run on sight? (Obstacle expected on the track ahead)*
- *Running at caution area?*

General driving use-case would gain interest – flank protection, switch protection, train protection, releasing movement authority. But

- requirements depend on your SIL focus (protection, operation performance, obstacle coordination).
- it depends on your train length and station geometry.
- SIL interleave their influences

To get the defining values (~99 % rolling stock, ~99,99% stations) in an industrial way, you would have to simulate your use-cases on the complete map of Europe, or at least exemplary portions of the track. This was neither WP5 nor WP6, hence the disclaimer. We also lack the experts about track engineering.

Do APM and PER have the same needs?

- PER itself, while fed by a map, may help precise an existing positioning.
- PER position imprecision impedes the merging function in APM, which is only emerging. In case of a curve, PER position imprecision also impedes the estimation of the relative distance of an obstacle to the track. Due to the distance to the sensor, the heading delta should be estimated too.

With WP5, only 2 obstacle use-cases are coordinated between train and trackside: person on track and fire on embankment. They are specified exemplarily at first - other perception scenarios are not coordinated.

What is the impact of speed respect to localization needs?

Rising speed seams to tend to mean lowering the precision needed, at least for a line's performance:

- Track-side density: the faster you drive, the lower the density of switches, that would reduce the room for your train. See the 'database simulation' above.
- Train density: The confidence interval is a distance. When the speed rises, it is driven through in less time. 10m are driven in 0.1s at 360 km/h. They are driven in 10 s at 3,6 km/h.

If you consider a throughput of a train every 150 second (urban), 10 seconds are *a lot*. But even there, 0.1 second are not the point.
For SIL4, this is counterbalanced by the fact that braking curves are the longest at high speed, i.e. the room budget for the train is the lowest. With virtual blocks, some threshold effects may happen if you exceed the room budget originally foreseen by the original (real) fix block.

Again, a simulation seems necessary... or a competent rule of thumb. Your model (in stations, in inter-station) seems a pragmatic idea at first.

APPENDIX I: TECHNICAL NOTE #8

TECHNICAL NOTE #8 :

NEEDED DATA FROM CMD FUNCTION

Author	Adrien GHARIOS (SNCF)
Partner	Bernhard STAMM (SMO)
Date	07/06/2024
Document Code	R2D-WP21-I-SNCF-TN8-02
Status	Final

Document status		
Revision	Date	Description
01	22/05/2024	First issue
02	07/06/2024	Final verison – updated following comments

TABLE OF CONTENTS

1. OBJECT OF THE WHITE PAPER

1.1 Reminder of the open issue

[OI: FP2-ASTP-OPEN-ISSUE-17]: *CMD providing moved distance*

[Open Issue]: The requirement to provide the distance the train has moved while it has been powered off has to be confirmed.

[traceability]: D21.1 § 9.1.18

[Impact on ASTP]: Significant.

[Next step]: Decision to be taken with CCS onboard architects (System Pillar).

[END OI]

1.2 Issues to be resolved

Issue 1: Shall the CMD provide the distance the vehicle has moved while not powered in addition to a Boolean information (train did not move / train moved, or movement cannot be excluded)?

Issue 2: Shall the ASTP consider the distance the vehicle has been moved while not powered to compute the initial confidence interval?

Issue 3: If the CMD does not provide the distance the vehicle has been moved while not being powered, shall the distance, specified in BL4 Subset.026 3.15.8.1.1 to detect cold movement, be used to compute the initial confidence interval?

2. CONTEXT

To be noticed that the texts or elements available in this chapter 0 are collected from other documents without any modifications or interpretation from the working group. The statements, facts or information present in this chapter may not reflect the ideas or point of view of the working group and are presented to help understanding and resolving the issue considering all the available points of view.

2.1 Reminder of D21.1 v11

D21.1 defines a function related to the acquisition of the Cold Movement information as:

7.1.18 ASTP_SF-109: Acquire Cold Movement

Rationale: Information about whether (and potentially how far) an engine/train has moved or not during ETCS' "no power"-mode to consider the information as part of the initialisation of the localisation system. Sometimes, slight movements can occur, for example during coupling. Therefore, information about the moved distances is needed, to evaluate if the moved distances are neglectable or can be even used for localisation correction.

OPEN ISSUE 17: The distance moved during train is powered off has to be confirmed.

7.1.18.1.1 Data properties

Following a list of identified data properties that are seen useful as part of the function's output.

Movement flag. Indicates, if a movement took place in general.

Moved distance. Indicates, the distance moved during "no power"-mode along with the indication of direction (To be confirmed).

2.2 X2R5 references

CMD is mentioned in Deliverable D5.2 (v 02-05-2023) :

In Figure 7-4 it is shown the insight architecture specification of the E_ODO-OB. In this illustration the system defines interfaces to sensors, such as GNSS sensor, Accelerometers, Gyroscopes and Wheel Angular Speed sensors. In addition, it also allows to receive information from trackside such as a digital map or augmentation information for GNSS as well as some practical information from ETCS-OB such as active cab (depicted as Train Dynamic Data) , Cold Movement Detection (CMD) or Balise identifiers. All these inputs lead to the Safe Fusion Algorithm (SFA) that is responsible to estimate a safe front train position and speed. The output of this functional block then feeds into other subsystems in the train such as the ETCS-OB and it could also be sent to tE_ODO-TS. In order to retrieve the information from track side a "Data Client Manager" functional block is defined as a gateway to E_ODO-TS. Finally, a "Position Reporting Manager" is responsible to send back to E_ODO-TS the positioning information so that it can be used by trackside.

- ETCS-OB:
  - ETCS-OB does not need to provide the active cab nor train length to the E_ODO-OB anymore.
  - CMD is by now out of the scope of this analysis.

8.4 Summary of the changes from previous architecture

In the following list, it is summarised the main changes that apply for each function block with respect to its original description defined in [2]:

- The Safe Fusion Algorithm (SFA) block:
  - In the new architecture SFA is still responsible to estimate the absolute position, speed, travel distance and acceleration. However, it is now referred to the fix body frame instead of the front of the train.
  - CMD is currently out of the scope of this functional block.

CMD is mentioned in Deliverable D5.5 (v 18-12-2023)

5.3.2.7 Cold Movement Detection (Safety Related Optional Input)

Cold Movement Detection information to maximise the availability of the system performance after switched on.

2.3 CMD DEFINED IN SUBSET 26

CMD is mentioned in the subset 26 v400:

3.6.7 Supervision of distances not referred to balise groups

3.6.7.1 Independently from the train position in relation to balise groups (see 3.6.1.3), the ERTMS/ETCS on-board equipment shall calculate the remaining distance to be travelled by the train in relation to the following distances as soon as their supervision is started or re-started:

a) the maximum distance the train can move (National/Default Value) in relation to the Roll Away Protection (see section 3.14.2), the Unauthorised Direction Movement Protection (see section 3.14.3) and the Standstill supervision (see section 4.4.7.1);

b) the maximum distance for reversing (National/Default Value) in Post Trip mode (see 4.4.14.1.3);

c) the distance for train trip suppression (National/Default Value) after the Override function has been triggered (see clause 5.8.4.1 b));

d) the fixed distance over which the on-board balise transmission alarms are ignored, before a safety reaction is triggered (see clauses 3.15.7.2 and 5.22.5.1 a));

e) the fixed distance for small movements in No Power mode (see clause 3.15.8.1.1), in relation to the Cold Movement Detection function;

3.15.8 Cold Movement Detection

3.15.8.1 After being switched off (i.e. once in No Power mode), the ERTMS/ETCS on-board equipment shall be capable, if fitted with, to detect and record whether the engine has been moved or not, during a period of at least 72 hours.

3.15.8.1.1 To allow small movements e.g. for coupling in No Power mode, the ERTMS/ETCS on-board equipment shall consider that no cold movement has occurred as long as the train does not move for more than 2m away from the train position stored when No Power mode was entered.

3.15.8.2 When powered on again, the ERTMS/ETCS on-board equipment shall use, if available, the memorised information about cold movement in order to update the status of information stored by on-board equipment (see chapter 4 section 4.11 for details).

3.15.8.3 Note: information memorised by Cold Movement Detection function is considered as not available if:

a) no Cold Movement Detection function is implemented in the ERTMS/ETCS on-board equipment, OR

b) the Cold Movement Detection function has encountered a condition, during the No Power period, which prevents the use of the Cold Movement information (e.g. the battery ensuring the Cold Movement Detection function has run down during the No Power period).

4.4.4 NO POWER

4.4.4.1 Description

4.4.4.1.1 When the ERTMS/ETCS on-board equipment is not powered, the equipment is in the No Power mode.

4.4.4.1.1.1 Note: in order to ensure cold movement detection function, some parts of the ERTMS/ETCS on-board equipment may be fed by an auxiliary power supply.

4.4.4.1.2 The ERTMS/ETCS on-board equipment shall permanently command the emergency brake.

4.4.4.1.3 Intentionally deleted.

4.4.4.2 Used in levels

4.4.4.2.1 Used in all levels: Level 0, level 1, level 2 and level NTC.

4.4.4.3 Responsibilities

4.4.4.3.1 The ERTMS/ETCS on-board equipment has no responsibility in this mode, except commanding the emergency brake and (optionally) monitoring cold movements.

4.4.4.3.2 The notion of responsibility of the driver is not relevant for the No Power mode.

4.4.4.3.3 If it is required to move a loco in NP mode as a wagon, ETCS brake command must be overridden by external means.

4.11 What happens to stored information when exiting NP mode

4.11.1.1 Status of stored information, which is set to "Invalid" when No Power mode is entered, shall be affected, when relevant, by information from the Cold Movement Detection function, according to the following table:

	Status of On-board stored information														
	EOLM information			Train Position			ERTMS/ETCS Level			Table of trackside supported levels			RBC contact information		
Transition conditions	Un-known	Invalid	Valid	Un-known	Invalid	Valid	Un-known	Invalid	Valid	Un-known	Invalid	Valid	Un-known	Invalid	Valid
No Cold movement occurred		●→ (to Valid)			●→ (to Valid)			●→ (to Valid)			●→ (to Valid)			●→ (to Valid)	
Cold movement detected or Cold movement information not available		←● (to Un-known)									←● (to Un-known)				

4.11.1.2 Note: Status of stored information, which remains valid after NP mode has been entered, is not affected by information from the Cold Movement Detection function.

4.11.1.3 If a cold movement has been detected (see section 3.15.8), or the Cold Movement Detection function is not able to confirm that no cold movement has taken place, no change of status of information to “valid” shall be made until it has been validated by a different means than cold movement detection.

4.11.1.4 In case Supervised Manoeuvre, Shunting or Passive Shunting mode was left to No Power mode and a stored and not yet evaluated immediate level transition order or conditional level transition order has to be evaluated (see 4.4.8.1.5, 4.4.20.1.11 and 4.4.21.1.11.1), the following shall apply:

a) The above table in 4.11.1.1 shall not affect the previously applicable level and the table of trackside supported levels, which were set to "Invalid" when No Power mode was entered;

b) The previously applicable level which was set to "Invalid" when No Power mode was entered, shall be considered as the current level for the evaluation of the immediate level transition order or the conditional level transition order;

c) By exception to 5.10.4.1 b), any level change, which result from the immediate level transition order or the conditional level transition order, shall not lead to any driver acknowledgment;

d) The table of trackside supported levels, which was applicable and was set to "Invalid" when No Power mode was entered, shall be deleted;

e) The level and the table of trackside supported levels, which result from the immediate level transition order or the conditional level transition order, shall be set to “invalid” and the above table in 4.11.1.1 shall be applied to them by analogy.

2.4 CMD IN TSI CCS 2023

TSI CCS 2023 defines that the CMD will be mandatory from 2028 and then will be available for the ASTP.

Source : https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1695&qid=1694158367331

No	TSI point(s)	TSI point(s) in previous version	Explanation on TSI change	Transition regime			
				Design phase started after TSI enters into force	Design phase started before TSI enters into force	Production phase	Vehicle in operation
CMD							
11	4.2.2 (b) – Cold Movement Detection	CMD Optional	CMD Mandatory	Directly applicable when ETCS is installed for the first time into a vehicle design.	Applicable from 1 January 2028 when ETCS is installed for the first time into a vehicle design.	Applicable on newly built vehicles placed on the market from 1 January 2030.	Not applicable

3. OPEN ISSUE ANALYSIS AND DECISIONS

ASSUMPTION = Assumption made by the working group based on the inputs provided in § 0 but may be contested due to the unavailability of reliable data or evolution of the input data.

ASSUMPTION 1 : The CMD will be mandatory at the time the ASTP will be released.

ASSUMPTION 2 : The use of the CMD in ETCS BL4 only validates or invalidates the saved position (refer to S26 §4.11). The saved position is not reworked taking into account the threshold to detect a cold movement. However, the remaining distance to be travelled does take into account the fixed distance for small movements (refer to § 3.6.7.1)

ASSUMPTION 3 : The CMD will be safety related and shall provide a movement detection with a SIL4 level. The feared event is assumed to be: The CMD does provide a “No Cold Movement Detected” when the train has moved by more than the specified value (2m).

ASSUMPTION 4 : It is assumed that adding 2 m to the CI, when powering on the ASTP, will not significantly impact train operation.

ASSUMPTION 5 : Providing only a “Boolean” information (train did not move / train moved or CMD cannot grant the information in safety) will ease the CMD development.

ASSUMPTION 6 : In case the trackside train detection is removed (Pure moving block), not taking into account the uncertainty to detect a cold movement may lead to feared events (this needs to be analysed by a RAMS engineer). Since the ASTP introduction will introduce major modifications to the CCS-OB, taking into account the uncertainty parameter to detect a cold movement is not a major modification.

4. DECISIONS TO BE TAKEN

Issue 1: Shall the CMD provide the distance the vehicle has moved while not powered in addition to a Boolean information (train did not move / train moved, or movement cannot be excluded)?

Decision 1 : WP21 proposal (consensus is found) : WP21 recommend that the CMD only provide à Boolean information.

Issue 2: Shall the ASTP consider the distance the vehicle has been moved while not powered to compute the initial confidence interval?

Decision 2 : WP21 proposal (consensus is found) : Since WP21 recommend that the CMD only provide à Boolean information, the issue 2 is not relevant anymore.

Issue 3: If the CMD does not provide the distance the vehicle has been moved while not being powered, shall the distance, specified in BL4 Subset.026 3.15.8.1.1 to detect cold movement, be used to compute the initial confidence interval?

Decision 3 : WP21 proposal (consensus is found) : WP21 recommend that the ASTP shall take into account the distance to detect a cold movement (2m) to compute the initial confidence interval.

5. ACTIONS

1) The open issue shall be deleted from WP21 since the issue is solved or not considered as an issue.
2) In D21.1, references to the open issue or the travelled distance shall be deleted.
3) In D21.1, the fixed distance for small movement shall be introduced. This fixed distance shall be a parameter with a value of 2 m.
4) In D21.2, the fixed distance for small movement shall be introduced. This fixed distance shall be a parameter with a value of 2 m.
5) In D21.2, a requirement shall be created: while initialising, ASTP shall considered the fixed distance for small movement to generate the underestimation and the overestimation of the travelled distance.

6. OPINION OF THE SYSTEM PILLAR – TRAIN CS ON TECHNICAL NOTE N°8

n°	Assumptions	ASTP team final opinion
1	The CMD will be mandatory at the time the ASTP will be released	We agree, the CMD will be mandatory at the time the ASTP will be released.
2	The use of the CMD in ETCS BL4 only validates or invalidates the saved position (refer to S26 §4.11). The saved position is not reworked taking into account the threshold to detect a cold movement. However, the remaining distance to be travelled does take into account the fixed distance for small movements (refer to § 3.6.7.1)	First part of the assumption is ok: "The use of the CMD in ETCS BL4 only validates or invalidates the saved position (refer to S26 §4.11). The saved position is not reworked taking into account the threshold to detect a cold movement.". But the second part is wrong, there was a misunderstanding of the clause 3.6.7.1 of subset 026. This clause only require to the CCS-OB to be able to calculate the travelled distance when the CCS-OB is in no power.
3	The CMD will be safety related and shall provide a movement detection with a SIL4 level. The feared event is assumed to be: The CMD does provide a “No Cold Movement Detected” when the train has moved by more than the specified value (2m).	Agreed
4	It is assumed that adding 2 m to the CI, when powering on the ASTP, will not significantly impact train operation.	Agreed
5	Providing only a “Boolean” information (train did not move / train moved or CMD cannot grant the information in safety) will ease the CMD development.	Agreed
6	In case the trackside train detection is removed (Pure moving block), not taking into account the uncertainty to detect a cold movement may lead to feared events (this needs to be analysed by a RAMS engineer). Since the ASTP introduction will introduce major modifications to the CCS-OB, taking into account the uncertainty parameter to detect a cold movement is not a major modification.	No opinion. Note: Currently in the Train CS domain, the "On-board Track Train Detection" is out of scope.

Issues

n°	Issues	WP21 decision	ASTP team final opinion
1	Shall the CMD provide the distance the vehicle has moved while not powered in addition to a Boolean information (train did not move / train moved, or movement cannot be excluded)?	WP21 proposal (consensus is found) : WP21 recommend that the CMD only provide a Boolean information.	The CMD shall only provide a Boolean information.
2	Shall the ASTP consider the distance the vehicle has been moved while not powered to compute the initial confidence interval?	WP21 proposal (consensus is found) : Since WP21 recommend that the CMD only provide a Boolean information, the issue 2 is not relevant anymore.	Issue 2 not relevant anymore as the CMD shall not provide the distance travelled when the train is power off.
3	If the CMD does not provide the distance the vehicle has been moved while not being powered, shall the distance, specified in BL4 Subset.026 3.15.8.1.1 to detect cold movement, be used to compute the initial confidence interval?	WP21 proposal (consensus is found) : WP21 recommend that the ASTP shall take into account the distance to detect a cold movement (2m) to compute the initial confidence interval.	First, when the CMD function was specified, the necessity to take into account the CMD threshold in the CI when no cold movement occurred was not identified. But it should not have any difficulty to do it in the ASTP. So we agree to take into account the CMD threshold in the CI when no cold movement occurred. But if a Cold movement occurred, the Train position and CI shall be deleted. In addition, it should be the job of the ASTP to store the Train position (and CI) when the train is power off, and then reuse it if CMD confirms that no cold movement occurred.