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X2RAIL 5

X2Rail-5

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1 Executive Summary

This document reports the activities carried out in the sub-task 5.3.2 of the X2Rail-5 WP5.

Starting from the Gap Analysis (Subtask 5.3.1), closely following the results of standardization activities (Subtask 5.2.3) and taking into account the feedback from demonstrations (results of X2Rail-5 WP6 and X2Rail-5 WP7), the final target of this Subtask is to prepare an overall concept of how Satellite-Based Fail-Safe Train Positioning systems could be integrated in current and future CCS systems and to provide an analysis of range of impacts on ETCS specifications for presentation to ERA.

The first activity carried out concerns the identification of features and their interactions in order to be able to introduce the fail safe and interoperable train positioning solutions into the effective use.

Once the macro functions have been identified, we move on to an analysis of the possible commonalities and synergies between X2Rail-2 Stream 1 and X2Rail-2 Stream 2.

The objective is to analyse the most effective approach for future developments by considering short term and long-term solutions and linked cost-benefits.

The determination of the cost benefit analysis was not able to go into much detail as there is little objective data linked to just as few funded research projects. What is reported in the cost benefit analysis is related to the result coming from consideration made also in other projects not having any evidence for real implementation. It was not possible to assess the detailed economic impact of the changes necessary to introduce the FSTP as defined in X2Rail-5.

In this regard, considerations were also made based on the experience of the partners involved which offered a favourable scenario for the introduction of the FSTP as it does not improve the figure of eliminating a certain number of Eurobalises from the tracks but also the train detection systems.

the comparison activity between the two streams and the search for a solution that can be used both in the context of the introduction of virtual Eurobalises and in the production of an odometry and train position system has produced a satisfactory result for the state of progress of the project.

associated with this scenario, the hypotheses for the introduction of the FSTP system within the current scenario of the TSI associated with the ETCS SRS version 4 were then developed.

In chapter 6, the gaps for each Stream were highlighted that will have to be overcome to introduce the corresponding solution in the new TSI.

The strategy identified for the migration highlighted the backward and forward compatibility aspects, providing a feasible path considering the current TSIs.

There is still work to be done to have a product ready to be introduced for the commercial service but what has been achieved lays solid foundations for future developments that will take place within the Europe's Rail project which is the natural continuation of this.

Another result that was achieved is that the initial misunderstandings that arose between the two streams created during the X2Rail-2 project were ironed out and except for an initial period of alignment difficulties everything then passed in a linear way.

The objectives of the task associated with this document were achieved although with a small delay compared to the timing expected from the X2Rail-5 project due to the initial moment of misunderstanding described above which was then overcome.

2 Table of Contents

2.1 Table of Figures

2.2 Table of Tables

3 Abbreviations and acronyms

Abbreviation / Acronyms	Description
ATPL	Along the Track Protection Level
BT	Balise Telegram
BTM	Balise Transmission Module
CBA	Cost Benefit Analysis
CCM	Change Control Management (ERA process)
CCS	Control-Command and Signalling
CI	Confidence Interval
CMD	Cold Movement Detection
DM	Digital Map
DoF	Degrees of Freedom
EGNOS	European Geostationary Navigation Overlay System
ERA	European Union Agency for Railways
ERTMS	European Rail Traffic Management System
ESTP	Estimate Safe Train Position
ETCS	European Train Control System
EUG	EEIG ERTMS USERS GROUP
EVC	European Vital Computer
FFFIS	Form-Fit Functional Interface Specification
FRMCS	Future Railway Mobile Communication System
FSTP	Fail Safe Train Positioning
GA	Grant Agreement
GI	Gap Indicator
GNSS	Global Navigation Satellite System
GSM-R	Global System Mobile for Railway
ICD	Interface Control Document
IM	Infrastructure Manager
IMU	Inertial Measurement Unit
IXL	Interlocking
L1	GNSS Frequency L1
LRBG	Last Relevant Balise Group
MOPS	Minimum Operational Performance Standard
NLOS	Non-Line of Sight
OB	On Board
OBU	On Board Unit
ODO	Odometry
PR	Position Report
PVT	Position Velocity and Time
RAIM	Receiver Autonomous Integrity Monitoring
RAMS	Reliability, Availability, Maintainability, Safety
RBC	Radio Block Centre
RF	Radio Frequency
RTCA	Radio Technical Commission for Aeronautics
RU	Railway Undertaking
SBAS	Satellite Based Augmentation System
SFA	Safe Fusion Algorithm

Abbreviation / Acronyms	Description
SIL 4	Safety Integrity Level 4
SiS or SIS	Signal in Space
SM	Shunting Mode
SoL	Safety of Life Service
SoM	Start of Mission
SRS	System Requirements Specification
STM	Specific Transmission Module
SV	System Version
TBD	To Be Define
THR	Tolerable Hazard Rate
TS	Track Side
TSI	Technical Specification of Interoperability
VB	Virtual Balise
VBR	Virtual Balise Reader
VBTS	Virtual Balise Transmission System
WP3	Work Package n 3 of the project X2Rail-2
WP5	Work Package n 5 of the project X2Rail-5
WP6	Work Package n 6 of the project X2Rail-5
WP7	Work Package n 7 of the project X2Rail-5
X2R2	Project X2Rail-2
X2R5	Project X2Rail-5

4 Introduction

The document describes the path followed within the X2Rail 5 WP5 task 5.3.2 project to define a set of shared requirements and the consequent migration strategy to introduce the system on existing and future lines.

Chapter 5 is mainly aimed at reporting what was done in X2Rail-2 to be used as a reference for activities in X2Rail 5. Chapter 5 shows the main functions of the FSTP specified in X2Rail-2 Stream1 and X2Rail-2 Stream2, this chapter allows you to have an overview of the topics covered and leads the reader to a gradual approach to the issues.

Chapter 6, always divided for each FSTP (X2Rail-2 Stream1 & X2Rail-2 Stream2) describes in a clear and detailed way how to integrate how each FSTP into the current CCS. Chapter 6, on the other hand, clarifies some open points or describes the evolution of the project using the experience made in the Work Packages WP5, WP6 and WP7.

Chapter 7 reports the communalities and the differences that are present in the two Streams. These are the starting point for the definition of the future FSTP that is described in the chapter 8. The FSTP in chapter 8 will be the reference for

Chapter 9 reports mainly the Cost Benefit and Impact Analysis based on the activities performed in X2Rail-2, X2Rail-5 and in other projects.

The migration strategy and the roadmap to be followed to introduce the future FSTP in the CCS system is described into chapter 10.

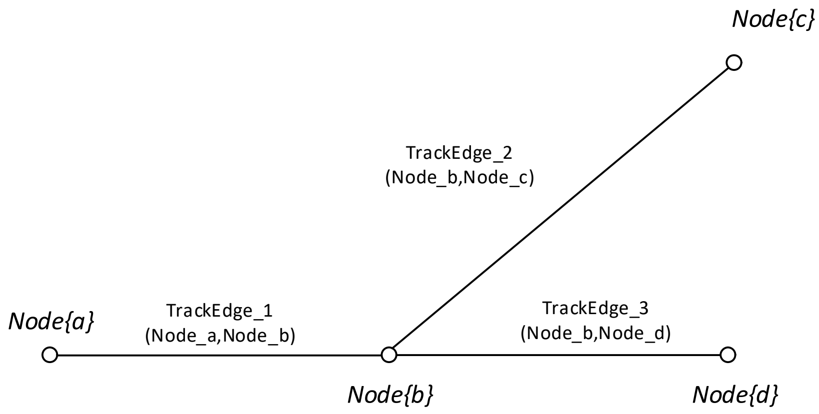
The Chapter 11 with the conclusion and the references, chapter 12, close this document.

5 Functions

5.1 Common Definitions

This paragraph contains definitions that are in common use throughout the document. This to avoid subjective interpretations during the explanation of the topics.

Concept	Definition/Description
1D Pos(t)	Position estimation constrained to the track, without any track-route ambiguity. It is linked to the distance travelled since the system was turned on.
3D Pos(t)	Position estimation not constrained to any track-route.
Absolute Fail-Safe Train Position	The Absolute Fail-Safe Train Position is the Absolute Train Position together with Train Position Confidence Interval.
Absolute Train Position	The Absolute Train Position of the front of the train along the track centreline. This value can either be given with a global reference system (2D or 3D) or by referring to a given reference point (e.g. a point from the digital map or the LRBG provided by the ETCS-OB) plus the travelled distance from this reference point (1D with orientation).
Accumulative Travelled Distance	This value refers to 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
Accumulative Travelled Distance Reliability	The "Accumulative Travelled Distance Reliability" is defined as the mean time between two events that exceed a defined error limit whenever no failure is encountered on sensors and excluding maintenance errors. Notice that Maintenance error is considered any error occurred introduced by human action in the maintenance process of the localisation unit. For instance, whenever a new wheel diameter needs to be updated on the ETCS configuration and the introduced value is not aligned with the wheel diameter installed.
Constant Speed Interval	"Constant Speed" is considered in time intervals whenever the averaged true acceleration for nn seconds does not exceed f.f m/s2. The definition is used in §6. The constants nn and f.f are to be defined (TBD, e.g. for nn=5s acceleration less than f.f=0.2 m/s²). see also Transition Speed Interval.

Digital Map	Digital representation of the line travelled by the train. It represents the complete set of trackside related information (e.g. track geometry, objects locations, Eurobalises etc.). The geometric model of the track is an oriented graph. The graph orientation convention allows to define unambiguously the LEFT (L) and RIGHT (R) nodes of any given edge. (Conventional Track Orientation) Track Edges represent one physical track that connects a start node with an end node. Each track edge has a fixed nominal direction and a reverse direction, sometimes also named as up/down directions.  **Figure 1: Topological representation of the digital map.** For each position on the track edge multiple information can be added to the digital map. For instance, curvature profile, gradient profile or GNSS data (e.g., a list of sequenced latitude and longitude pair of information, 3D Cartesian coordinates XYZ, …), can be used to enrich the information of the digital map. In turn, this information could be used by the fusion algorithm to estimate a position. Furthermore, the digital map can also store additional data such as reference locations which, along with some Eurobalise telegram information, could become useful data to report crossed geolocations to the ETCS.
Estimated Pos (1D)	Is the current Estimated Position of the Virtual Antenna along the Linear Path. It corresponds to the Virtual Antenna offset from the beginning of the path (according to its order/orientation).
Longitudinal Fail Safe Train Speed	Longitudinal Train Speed together with Speed Confidence Interval.

Longitudinal Train Speed	The 1D train speed of the front of the train including its confidence interval. (including nominal / reverse information):
Longitudinal Train Speed	The 1D train speed of the front of the train. (including nominal / reverse information).
Mandatory Input	They are inputs that must be used by the system in order to obtain the expected results.
Optional Input	They are inputs that can be used by the system to obtain the expected results.
Reference Location Definition	Subset-023 [20] already defines Odometry reference location as “The reference location to which refers the train-based odometer distance reading”. In this paper, “reference location” is referred to a common geographical point along the track, on centre line and with orientation. A reference location can either represent a physical balise, defined by its physical location and orientation, or a defined location along the track combined with the orientation of the underline track edge. The start or the end of a track edge can also be defined as a reference location; however, it is expected that the digital map may integrate dedicated reference locations to report positioning information to the ETCS.
Relative Distance	Train travelled distance and its confidence interval since switch on (unknown absolute starting point).
Safety Related Input	These are inputs that have an impact on the safety of the system and its processing. These inputs must have a declared and certified level of safety
Sensor Failure	A sensor failure is considered any time a hardware failure or communication error occurs between the sensor hardware and functional reader. The lack of information or misleading information due to environmental conditions are not considered sensor failure. For instance, slip and slide from a tachometer is not a sensor failure, but the detection of a wire cut on a tachometer is considered a sensor failure. Similarly, a GNSS outage is not considered a sensor failure; however, an error in communication channel for raw data is considered a failure
Speed Confidence Interval	The interval within which the ERTMS/ETCS on-board assumes the actual train speed with a defined probability. [20]

Speed Interval	Two types of speed intervals are defined for a dedicated CI calculation: Constant Speed and Transition Speed. (see dedicated definitions)
Train absolute position:	The absolute position of the front of the train along the track together with its confidence interval. This value can either be given with a global reference system (2D or 3D) or by referring to a given reference point (e.g. a point from the digital map or the LRBG provided by the ETCS-OB) plus the travelled distance from this reference point (1D with orientation).
Train Position Confidence Interval	The distance interval within which the ERTMS/ETCS on-board assumes the actual train position is, with a defined probability. It comprises the odometer over-reading and under-reading amounts, plus twice the location accuracy of the reference balise group. [20] Confidence Interval is a boundary defined as the Under/Over reading amount of a measured or estimated value, for instance for speed or travelled distance, within which the true value lies with a certain probability. In ETCS Confidence Interval on travelled distance in a given time t or position p can be calculated by as follows: ETCS_CI_Trav.Dist(t) = 2×Balise Read error + 2×Q_locacc + Trav.Dist.SwitchOnCI(t) – Trav.DistSwitchOnCI(T_LRBG). ETCS_CI_Trav.Dist(p) = 2×Balise Read error + 2×Q_locacc + Trav.Dist.SwitchOnCI(p) – Trav.DistSwitchOnCI(P_LRBG).
Transition Speed Interval	This interval describes the train dynamic during it changes speed by accelerating or braking. This interval is active whenever the train is not in “Constant Speed”.

Table 1: Common definitions

5.2 Function of X2Rail-2 WP3 Stream 1

The reference architecture of the system described in this chapter is shown in Figure 4.

5.2.1 Description of the function

The FSTP solution proposed in X2Rail-2 WP3 Stream 1 is based on the concept of the virtualization of the physical Eurobalise, therefore it is referred to as Fail-Safe Train Positioning (**FSTP**) based on Virtual Balise (**VB**). The FSTP works in cooperation with ETCS and does not implement ETCS functions.

The “Virtual Balise Detection” is the main function of Stream 1 enhanced train positioning, that uses a multi-sensor technology for estimating the Safe Position of the Train (in the Estimated Safe

Train Position –ESTP- functional block 1D Pos(t)) to evaluate a condition of “matching” between such Position and the known VB Location; in this case, a VB detection event occurs and the related Balise Information is sent to ETCS Kernel as a Real BTM function would [1].

FSTP Stream 1 is based on a combined use of ETCS odometry, Digital Map, Dynamic Route info and GNSS Positioning technologies, optionally improved by additional kinematic sensors (e.g. IMUs).

The FSTP based on VB uses the principles of the current ERTMS/ETCS system, complementing the BTM with the management of the *Virtual Balise*.

In other words, the FSTP emulates the BTM behaviour with respect to the ERTMS/ETCS Kernel, thus leaving unchanged the ERTMS/ETCS location principles described in Subset-026 §3.6 [11] (e.g., Train Position Confidence Interval and Relocation, Position Reporting to the RBC, …).

The concept of VB is useful to translate the satellite-based location determination into the legacy balise language. The detection of the Virtual Balises is accomplished by mapping the augmented GNSS-based Position-Velocity and Time – PVT- to the DM and comparing the current position on the map with the Virtual Balises locations referenced in the map as well.

Once the detection has been performed, the FSTP executes the same actions as the real BTM: provide information suitable for detecting and evaluating the location reference of the (Virtual) Balise, making this information available to the ERTMS/ETCS Kernel (see “Localisation” section of Subset-036 [13], § 4.4.6.2.4).

Since the VB management function is an additional function which complements the BTM one, it is possible for a train equipped with Stream 1-related FSTP to run on a line not equipped for the FSTP solution.

The possibility of excluding the BTM function for “isolated” lines equipped for Stream 1-related FSTP remains to be investigated and will be analysed in the future.

FSTP in cooperation with ERTMS/ETCS and Dynamic Route info is able to perform train positioning, when the ETCS identified in which track the train is located.

The initial position with track discrimination is expected to be provided through Dynamic Route Information (see section 5.2.2).

If the odometry Information already provided by ETCS Odometry enables the FSTP based on VB to compute the continuous position estimation in accordance with the required performance and safety for the VBR, the kinematic sensors are not required for VB detection.

The FSTP shall provide the expected output also in absence of GNSS signal. (e.g. GNSS signal loss, SiS outage).

The FSTP shall work under harsh electromagnetic interferences for RF signal with strong multipath, spoofing and jamming scenarios (for GNSS and TS communication frequency bands).

The FSTP based on Virtual Balise can be identified with the functional inputs/outputs described in the following subsections.

The FSTP shall work under harsh environmental situations including heavy snow, rain, leaves, dust or fog.

5.2.2 Functional Inputs

5.2.2.1 GNSS-SiS - FFFIS (IS GPS-200, Galileo OS SIS ICD, etc.) (Mandatory Input)

The acquisition of the GNSS signals (by spatial segment) takes place by trackside (for navigation data) and by on-board (for raw observation data). The ability of optionally acquiring navigation data by on-board is also covered in the solution.

5.2.2.2 GNSS Augmentation Information (Safety Related, Mandatory Inputs)

The on-board subsystem, named Virtual Balise Reader (VBR), also takes advantage of the SBAS data (i.e. corrections and integrity information) coming from the trackside for the calculation of the train's position. In particular, EGNOS SiS (RTCA Do229E – ED-259) is acquired by trackside, to make available augmentation information from trackside to on board unit. It is expected that this information ensures the safety of GNSS system against global threats.

5.2.2.3 Digital Map – DM (Safety Related Mandatory Input)

It represents the complete set of trackside related information (e.g. track geometry, objects locations etc.), useful for Stream 1-FSTP functionality. Starting from this complete set, specific subsets or views can be obtained to suit different needs (e.g. from On-Board and Trackside Stream 1-FSTP constituents):

- Trackside views shall be formatted so that they can be logically linked to the usual representation of the line used by the signalling equipment (RBC).
  On board views shall be formatted (see §9.3 of X2R2 D3.2 [2]) so that they can- represent the geometry of the track and the VBs positions;
  easily and safely used by the VBR.

The Digital Map includes also the Virtual Balise representation (i.e. Balise User Bits, Virtual Location along the railway track, Virtual Balise fixed location accuracy) that is necessary by on-board to perform the Virtual Balise Detection. (see §6.1.1.3 of [2] for more details).

The Digital Map shall be available and valid on board before that the FSTP can be used in a given part of the line.

Actually, isn’t a standard representation on the digital map.

5.2.2.4 Dynamic Route Information (Safety Related Mandatory Input)

This information represents the dynamic information necessary to identify, within the DM, the track portion that the train is travelling. It is mainly related to constrained position computation performed in “Estimate Safe Train Position” and Cross talk protection (see 11.2.1.8 of [1]).

This information shall be updated in the FSTP by means of Radio Communication Channel before the train enters in the track section.

The Dynamic Route Information includes:

a) Route information,

b) initial train position (see 6.2.1.2) and

c) initial train orientation (see §6.2.5 of [2]).

Route information include the status of the switches.

Initial train position is defined from ETCS Position Report (including validated SoM PR), IXL occupancy, driver inputs, and other specific applications inputs managed by the ETCS On Board.

5.2.2.5 Odometry (Safety Related Mandatory Input)

The FSTP receives from On-Board ERTMS/ETCS kernel continuous information (i.e. Travelled Distance, Speed and Time, see § 9.6-D3.2 [2]). Related to time and space (the so-named odometer information or Odometer Data). The Odometry Data are computed by On-Board Constituent, and they are based on the information coming from the "Odometry Sensors" (e.g. Wheel Sensors mounted on the train's bogies, Radars, Accelerometers, ...).

The ETCS Odometry Subsystem Performances and Accuracy shall be compliant to the Subset-041 [12] [3] Requirements.

The Odometer Information (in particular, Time and Distance with related uncertainties) is useful to assign to the 1D Pos(t) an appropriate tag/stamp. By means of such tag/stamp, the "Detect Virtual Balise" Block shall be able to refer the Balise Info in the same Odometric Coordinates System used by ETCS Kernel. See §7.1.1 of [4].

5.2.2.6 Independent (from ETCS Odometry) Kinematic Sensors (Optional Input)

They are not required if the Odometry Information already provided by ETCS Odometry enables the FSTP to compute the continuous position estimation in accordance with the expected performance and safety. The independence shall be guaranteed by each supplier at level of used kinematic physical measures. The demonstration of this is supplier-dependent because the set of physical measures employed by ETCS Odometry is chosen differently by each supplier. Independency from ETCS odometry is necessary to avoid common cause failures.

5.2.3 Functional Outputs

The detection of the Virtual Balise by enhanced train positioning is announced to ETCS Kernel through the message representing the "**output to ETCS Kernel**"; this message includes (see §11.5.2 of [1]):

- Time and odometer stamp of the detected virtual balise centre,
- The confidence interval associated with the virtual balise detection accuracy,
- Balise information (user bits) for the detected virtual balise.

5.2.4 Assumptions

- Ast1_1: Regard to application conditions, a preliminary survey is needed to evaluate the reception characteristics of the GNSS signal, so as to allocate the VBs into the Digital Maps and to protect the FSTP against local phenomena (such as multipath, Non-line-of-sight – NLOS, no GNSS signal and interferences) by the adoption of Receiver Autonomous Integrity Monitoring –RAIM- techniques (which are based on the assumptions about the number of satellites whose signal is affected by local feared events).

  Note: It has to be noted that state of the art of satellite positioning does not allow in general to discriminate between parallel tracks; given this, Virtual "Balises Detectability" (as defined in §4.1.4 "Basic Functions" of Subset-036 [13])) can only be ensured once the FSTP has been initialized by means of additional information.

- Ast1_2: The line shall be digitised and updated. It is assumed that the digital map is always up to date. It is expected that the digital map represents the current track with high resolution and completeness. If balises are present, they need to be located too in the digital map. (Note: this is a requirement exported to the digital map procedure).
- Ast1_3: FSTP must be integrated with the current ETCS with minimal modifications.
- Ast1_4: Because the FSTP is added to the ETCS architecture the system is compatible with the line equipped with current ETCS. Since the ETCS+FSTP system maintains all the functions of the ETCS system (including those of the BTM) and adds the use of virtual balises which are configured in the line and known to the RBC, there is complete compatibility with lines which do not envisage the use virtual balises.
- Ast1_5: The driver inputs are not expected as preliminary assumption, and further investigation may lead to other conclusions.

5.3 Function of X2Rail-2 WP3 Stream 2

5.3.1 Description of the function

Fail-Safe Train Position (FSTP) in X2Rail-2 WP3 Stream 2 is aimed to provide an absolute train position, a longitudinal speed and relative distance from a reference point of the front of the active cab of the On-Board Unit (OBU) [7].

FSTP –X2RAIL-2 WP3 Stream2 is based on multiple sensors including GNSS, IMU, Speed sensors, balises and digital map information as defined in [8]. The system combines these inputs to calculate the absolute position of the train (3D), project this absolute position to the correct track (1D without orientation) and to define the distance with respect to a given reference point (1D with orientation). The reference point can either be a point from the digital map, the position of the Last Relevant Balise Group (LRBG) or since switch on. In addition, the system is responsible to calculate the train speed in order to move along the track of the map from the calculated 1D position, with orientation.

The initial position with track discrimination is expected to be handled by the FSTP On-board unit algorithm. Two options are considered depending on the use case; deterministic approach and iterative approach.

The deterministic approach requires Balise information to be read and to match with the digital map information, i.e. the digital map also requires to have Balise location information.

The iterative approach requires IMU sensor information to match with digital map information, i.e. the digital map also requires to have orientation/curvature information of the track.

Finally, once the initial position is obtained, the system is responsible to maintain the current position of the train even if a switch point is passed.

The FSTP shall work under harsh environmental situations including heavy snow, rain, leaves, dust or fog.

The FSTP shall work under harsh electromagnetic interferences for RF signal with strong multipath, spoofing and jamming scenarios (for GNSS and TS communication frequency bands).

5.3.2 Functional Inputs

Hereafter the list of functional inputs (see [8]):

5.3.2.1 GNSS-SiS – FFFIS (IS GPS-200, Galileo OS SIS ICD, etc.) (Mandatory Input)

The acquisition of the GNSS signal in space by FSTP On Board for both navigation data and raw observation data.

5.3.2.2 GNSS Augmentation Information (Safety Related Optional Input)

The on-board subsystem also takes advantage of the SBAS data (i.e. corrections and integrity information) coming from the trackside for the calculation of the train's position. In particular, EGNOS SiS (**RTCA Do229E – ED-259**) is acquired by trackside, to make available augmentation information from trackside to on board unit. It is expected that this information ensures the safety of GNSS system against global threats.

5.3.2.3 Accelerometer and Gyroscope information (Safety Related Mandatory Input)

3 Accelerometers and 3 gyroscopes information for the main three axes of the train are required. This is typically obtained by at least 6 Degrees of Freedom (DoF) IMU sensor. Notice the sensor itself is not expected to be Safe but rather the function that uses the data from the sensor should comply with the safety requirements.

5.3.2.4 Speed Sensor (Safety Related Mandatory Input)

Wheel angular speed sensor or tachometers. Speed sensors based on Radar or optical technology may be eligible. Notice the sensor itself is not expected to be Safe but rather the function that uses the data from the sensor should comply with the safety requirements.

5.3.2.5 Digital Map – DM (Safety Related Mandatory Input)

It represents the area of operation where the train is certified to run. For this area, the set of trackside related information (e.g. track geometry, objects locations etc.) needs to be available for the FSTP system at start-up. The information stored on the map it shall include GNSS related information and balise data information at least. Other information related to track geometry such as curvature, may be eligible but it is currently optional.

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 [11]) 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.

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.

5.3.2.8 Balise Data Information (Safety Related Mandatory Input)

Balise data information by means of balise group id and balise identifier read with time stamp by the ETCS-OB system (odometric stamp is not required). The balise identifier shall also be part of the Digital Map information to provide track discriminatory information to the FSTP system.

5.3.3 Functional Outputs

The following mandatory outputs from the FSTP are required (see [8]):

- **Absolute train position**: (see Table 1: Common definition)
- **Longitudinal Train Speed** see Table 1: Common definition)
- **Relative Distance**: see Table 1: Common definition)

5.3.4 Assumptions

Hereafter a preliminary list of assumptions:

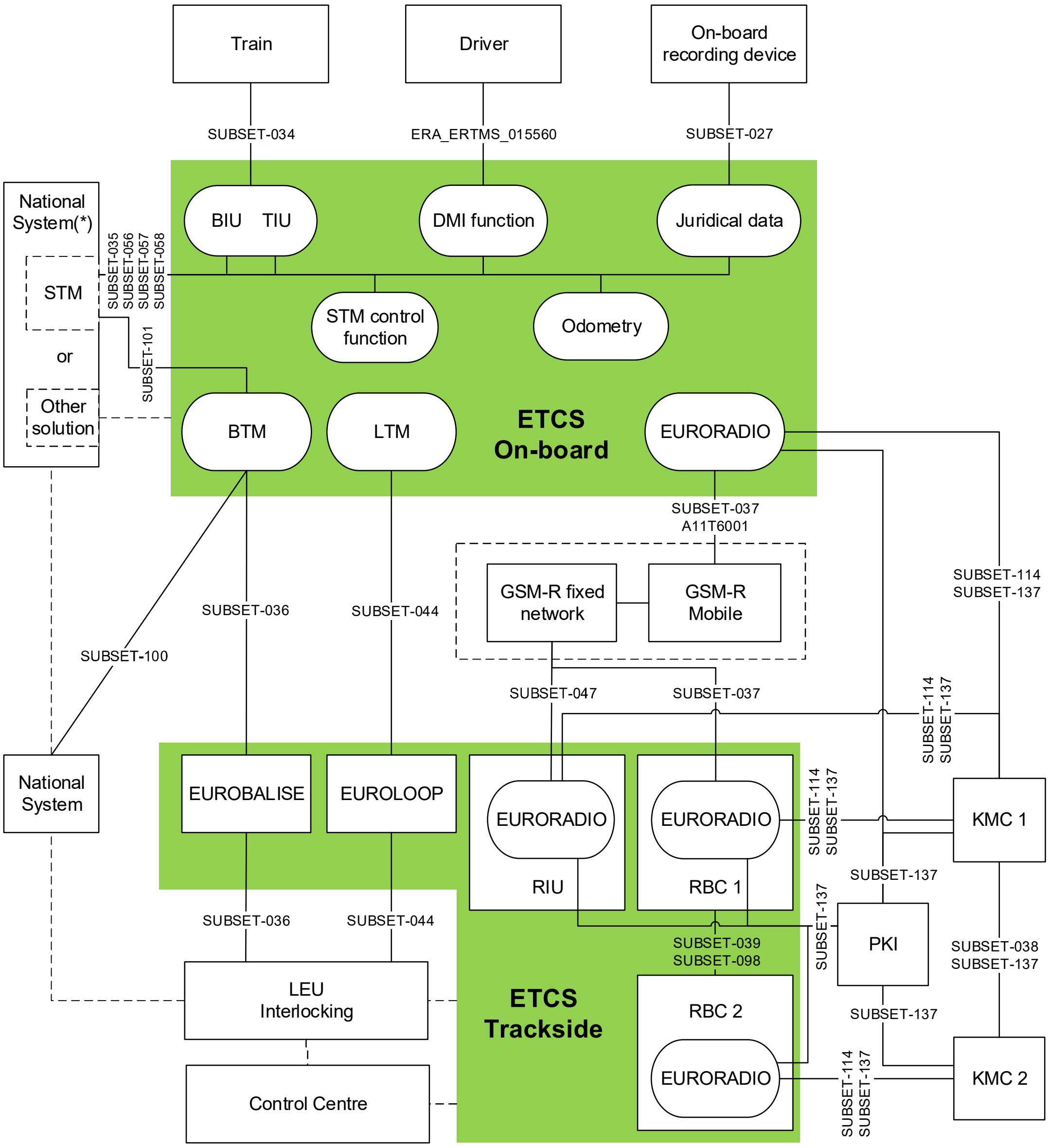
- Ast2_1: The line under which the FSTP shall run, needs to have GNSS coverage. The limitation of the GNSS coverage is not defined and the impact at which stages this coverage needs to be present during Start of Mission for instance, is to be defined too. The survey for checking the GNSS coverage could be a solution, other possibilities are not excluded.
- Ast2_2: All inputs are expected to be timestamped to avoid inaccuracies.
- Ast2_3: The track in the digital map need to be updated when railway line geometry has been changed. It is assumed that the digital map is always up to date and correct.
- Ast2_4: Train's on-board unit supporting this FSTP system may be able to run in old legacy lines. This, however, needs to be studied more thoroughly whenever the options from the FSTP are clarified.

6 Integration of FSTP and Impact on CCS

6.1 Current CCS Architecture description

This paragraph represents the evolution of the on-board architecture contained in the TSI up to the official version 2022.

The architecture present in the current version of the TSI before the 2022 issue is the one shown in the Figure 2. It represents the CCS on board interoperable architecture.

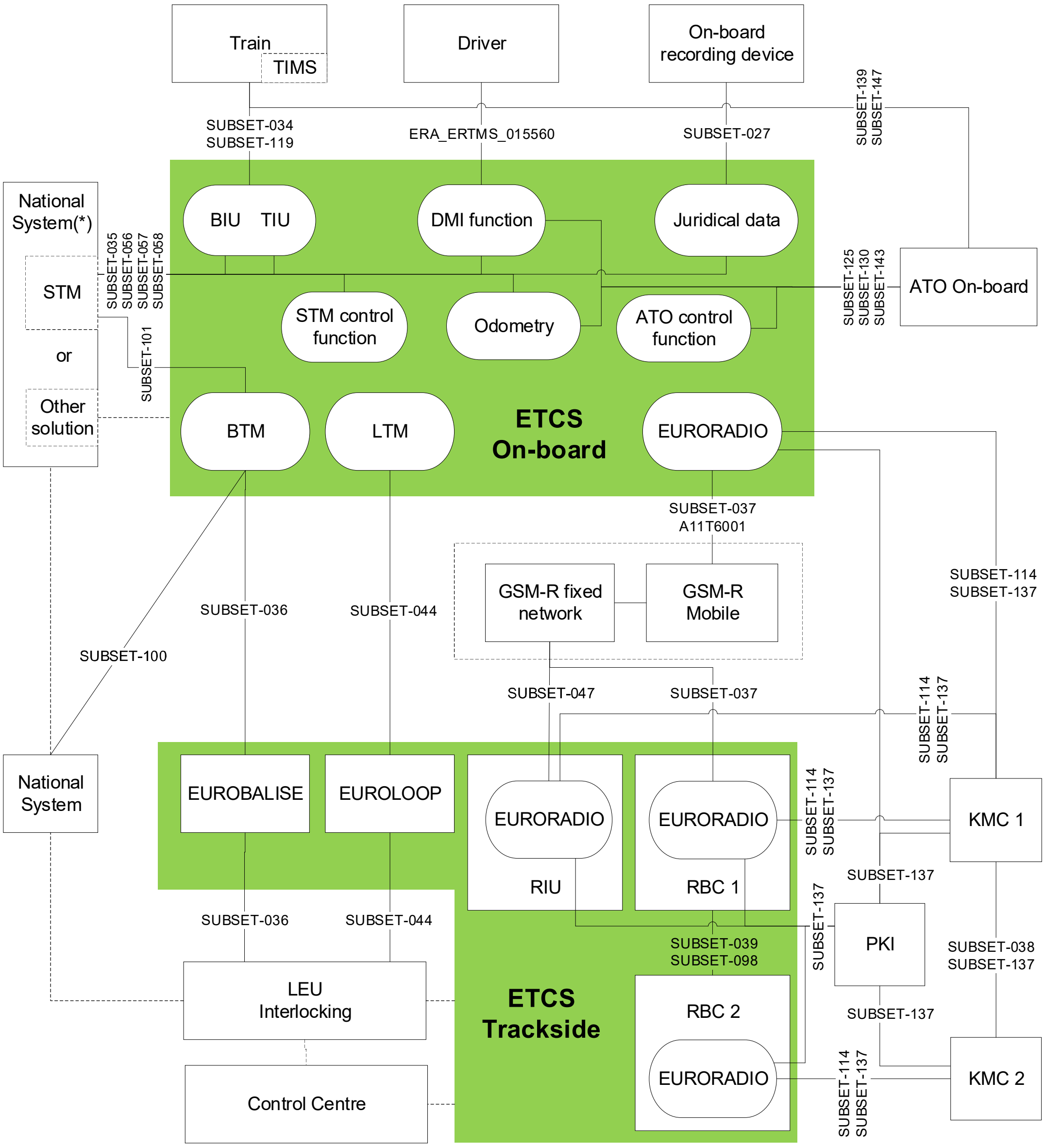


(*) Depending on its functionality and the desired configuration, the national system can be addressed either via an STM using the standard interface or via another national solution

Figure 2: ERTMS/ETCS system and its interfaces before 2022

The Figure 2 is a functional description of what is reported in the ETCS Baseline 3 [11].

The architecture of the on-board system that is present in the ETCS SRS version 4 is shown in the following Figure 3, this figure is also a functional description of what is reported in the ETCS SRS version 4.



(*) Depending on its functionality and the desired configuration, the national system can be addressed either via an STM using the standard interface or via another national solution

Figure 3: ERTMS/ETCS Architecture in Subset-026 of ETCS SRS version 4

In both do not compare any specific module for the management of virtual balise or for a dedicate advanced odometry.

The above figures (Figure 2 and Figure 3) show the subsets for managing the interfaces between the modules.

The modifications for the introduction of the FSTP solutions described in the following paragraphs refer to what is reported in Figure 3.

It should also be indicated that the new trackside and on-board CCS architecture will be designed within the Europe's Rail project.

The result of this work will be integrated into future versions of the TSI.

6.2 X2Rail-2 WP3 Stream 1

The Figure 4 shows the reference architecture for the Fail Safe Train Positioning system valid in Stream 1.

This architecture was designed during the activities carried out in the X2Rail 2 project.

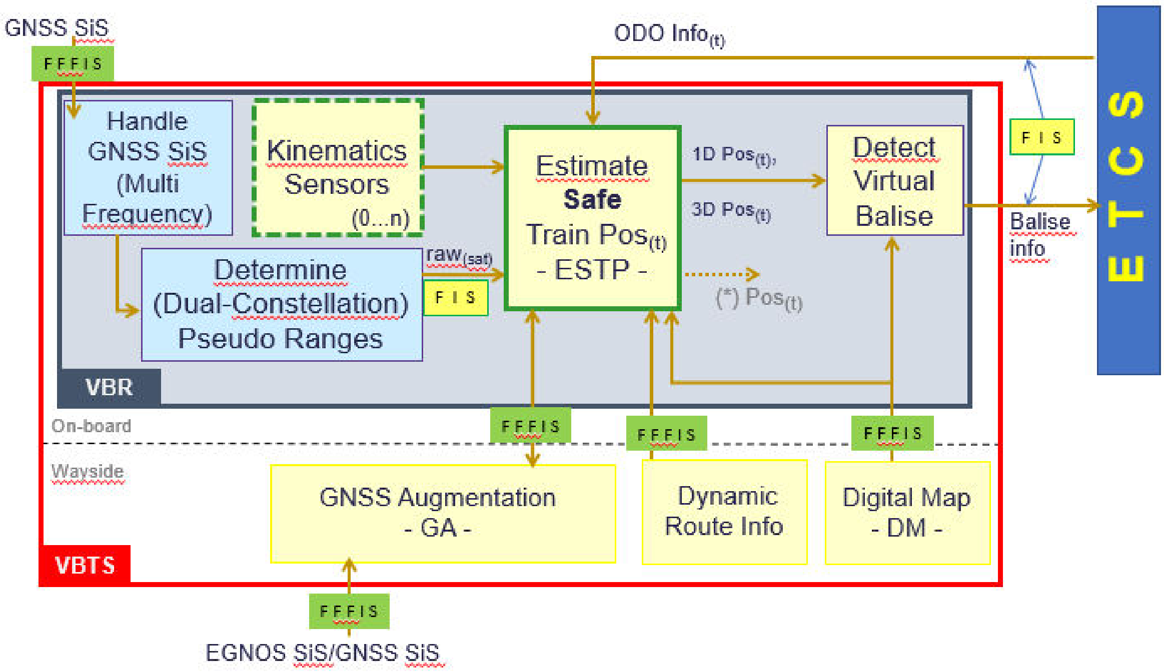


Figure 4: FSTP stream 1 Architecture.

The VBTS has the interfaces as shown in the Figure 4. The VBTS includes both the on-board and the trackside part.

The VBR which is installed On-board the train provides the interfaces with the respective trackside modules which as shown in the Figure 4.

To improve the understanding of how the system works, the main modules that make up the Stream 1 FSTP and their interfaces are showed.

6.2.1 FSTP Integration on CCS

6.2.1.1 Integration functional impact description

The ERTMS/ETCS on-board kernel currently performs train positioning based on both odometric and balise information (from BTM).

Stream 1 FSTP introduces respect the current CCS architecture an additional transmission system named Virtual Balise Transmission System (VBTS) into ERTMS/ETCS system structure. The VBTS is a safe spot information-based system, as for the EUROBALISE Transmission System (see §4.1.1 of [13]), whose purpose is the integration of VB detection function without changing the on-board ERTMS/ETCS location determination functions.

A Virtual Balise is a position on the line to which a unique telegram is associated. Therefore, the Virtual Balise is treated within the ETCS system in the same way as a Real Fixed Balise.

Therefore, when the train passes the VB position on the track, the ERTMS/ETCS on-board kernel uses the VB related information for computing the train position and for managing the related User Bits as it traditionally does.

The VB detection is accomplished by mapping the GNSS-based Safe Train Position elaborated by VBR (into the so-named “Estimate Safe Train Pos-ESTP” functional Block, see §6.2.2.4 of [2] for details) on the track and comparing it with the Virtual Balises locations referenced in the DM as well.

The output of ESTP Block is a continuous 1D position (*1D Pos(t)*), constrained to the track, with the corresponding Along the Track Protection Level (ATPL) to be used as input to detect Virtual Balises. Whenever it is necessary (for example during SoM phase), the ESTP block is also able to output the unconstrained position information (i.e. *3D Pos(t)*) with its Protection Level and THR.

The 1D Pos(t) is the estimated position of a Virtual Antenna (i.e. a virtual point below the train to preserve the analogy with the BTM antenna) along the track. The usage of ETCS - Odometry, with additional possible other sensors, supports the generation of a safe and continuous 1D position (in digital way, discrete time values) estimation along the railway track where the train is travelling. This latter is extracted by ESTP, on the basis of track geometry provided by DM and up-to-date track status information coming from trackside segment VBTS functional blocks.

The Safe Train Position is estimated in the ESTP Block. The position is based on GNSS SIS acquired by VBR and augmentation information (e.g. SBAS data) provided by trackside. On top of that, the safety requirements are also ensured with the additional information known by trackside. Both of these trackside data are used by VBR to mitigate possible feared events; besides, the adoption of any additional monitoring techniques enables the VBR to take into account different error sources that impact position uncertainty (e.g. MP, RFI) in the confidence interval evaluation.

The ATPL is dynamically evaluated by VBR and it represents an over-bound of the accuracy of Virtual Balise Group location reference; in other words, it defines the part of the rail track where the VBR virtual antenna is guaranteed to be located with a given probability (or THR) at the moment of the VB detection. In §6.5 of [2] a complete description is provided on the expected usage of this safety-related parameter by ETCS on-board kernel, in order to compute the Train Position Confidence Interval and to reset the odometry Confidence Interval.

In chapter 9 of [4] the theoretical determination of the train position Confidence Interval in ETCS Kernel (w.r.t. [11] and [12]) using VB location and the related uncertainty is analytically described.

The GNSS-based localization solution is compared with a list of absolute reference positions stored in the Digital Map Data and when it matches with a VB position, the VB is detected (by the "Detect Virtual Balise" functional Block, see §6.2.2.6 of [2] for details). In this case, the VBR delivers:

- the balise information (i.e. User Bits) associated with the detected VB (exactly as the BTM does);
- the time and odometer stamp of the VB centre in the location reference originated from the ERTMS/ETCS Kernel (exactly as the BTM does);
- the dynamically computed estimation of the safe over-bound of the virtual balise location accuracy.

The proposed approach requires the integration of new (VBTS-related) functional blocks on both on-board and tracksides constituents and it brings to a low impact towards the ERTMS/ETCS on-board kernel, preserving the logical interface. In fact, (see chapter 9 of [1]) the ERTMS/ETCS kernel logically receives the same information (i.e. user bits and the reference location) irrespective of the medium through which this information is sent: a physical or a virtual balise.

The ERTMS/ETCS kernel remains responsible for implementing all the traditional ERTMS/ETCS functions related to balises (e.g. LRBG, Linking, Expectation window, balise message consistency checks, etc.). The only remark is that the ERTMS/ETCS on-board kernel when computing the train position Confidence Interval based on LRBG composed of VBs shall take into account the VB location uncertainty, that is not anymore a static value as for physical balises but it is a dynamic value. Indeed, this uncertainty differs from Q_LOCACC information associated with a physical BG because it has a dynamic component computed by VBR and based on GNSS data (see §9.1.4 of [4]).

6.2.1.2 FSTP Functional input description

6.2.1.2.1 GNSS SiS

Starting from what has already been reported in 5.2.2.1, the GNSS Signal in Space is acquired from both FSTP on-board and trackside subsystems.

More specifically, the GNSS Radio Frequency Signals from satellites are acquired by means of suitable GNSS receivers (together with suitable antennas and amplifiers), namely compliant to a Minimum Operational Performance Standard (MOPS) for GNSS Augmentation On-board Equipment (GA-OB MOPS - see [14])

In this way a set of measurements (aimed to enable the calculation of GNSS-based train's position) can be pre-processed and provided to ESTP functional block located into VBR. Such measurements include Pseudo Ranges, Carrier Phase measurement, Doppler measurements and Carrier to Noise Ratio from on board and Navigation Data from trackside. To be noted that the ability of acquiring Navigation Data by on-board is also enabled into VBR. [14]). The management of the Navigation Data is under evaluation.

6.2.1.2.2 *SBAS SiS*

Starting from what has already been reported in 5.2.2.2, the GNSS Augmentation (GA) module is responsible of receiving Augmentation Information (EGNOS corrections and integrity data) directly from the Signal in Space (SIS) in order to provide this information to the connected on-board VBRs.

As specified in [14] "The GNSS Augmentation capability for ERTMS/ETCS has been designed as an agnostic framework supporting GNSS augmentation systems that meet an agreed set of mission requirements for Railway SoL Services and are based on compatible principles (i.e., provision of a pseudorange domain integrity service)." The principles of GNSS augmentation for ERTMS/ETCS are described in Annex A of [14].

While reception of Augmentation Information directly from SBAS-SIS by the ETCS on-board is possible, this mode of operation is not considered due to a low SiS availability related to obscuration of signals in the railway environment (EGNOS geostationary satellites are at relatively low elevation, approximately 30° above the horizon in central Europe and less in northern Europe).

The GNSS/SBAS receiver implemented within the GNSS Augumentation, needs to implement the specific requirements on GNSS signal processing provided in [14]):

- SBAS L1 Receiver Guidelines for Railway – Trackside Unit [ESSP-TN-26038] and SBAS DFMC Receiver Guidelines for Railway – Trackside Unit [ESSP-TN-26137] for SBAS service

and by

- the relevant GNSS-SIS-ICD.

To be noted that at the time of writing this document the aforementioned MOPS are under definition and that a preliminary specification of the minimum operational requirements for the VBTS is found in [5] for the SBAS L1.

6.2.1.2.3 Digital Maps

Starting from what has already been reported in 5.2.2.3, Digital Map (DM) and Dynamic Route Information are railway signalling related blocks that add further signalling functions needed in order to manage GNSS-based positioning.

The Digital Map is a complete set of trackside related information (e.g. track geometry, objects locations, fixed balises etc.) - useful for VBTS functionality- and it shall be designed and validated according to EN50126, EN50128 and EN50129. The geometric model of the track is an oriented graph. The graph orientation convention allows to define unambiguously the LEFT (L) and RIGHT (R) nodes of any given edge. (Conventional Track Orientation)

The DMs are static track data and there are present also the Virtual Balises representation (i.e. Balise User Bits, Virtual Location along the railway track, Virtual Balise fixed location accuracy) that is necessary by on-board to perform the Virtual Balise Detection. (see §6.1.1.3 of [2] for more details).

The on-board digital map must be present before the mission and it must contain at least the route on which the train will travel. Interacting with the trackside, the validity of the map must be checked through a version verification mechanism (see [1] [2]) between on-board and trackside VBTS sub-systems. The procedure to manage the verification phase must be defined. It is assumed that All On-Board and Trackside functions are using aligned and verified Digital Map Data.

To obtain valid data regarding the line, it is necessary a *Track Geometry Data Preparation*. This process is intended to classify the track area in terms of track representation and it consists of:

- a *Track Geometry Survey*, namely a procedure to collect all the measurements needed to model the real railway line with the suitable degree of precision. The output of this procedure is a digital map of the railway line, intended as the most complete set of information useful for VBTS purposes.

- A *Track Geometry Formatting*, intended to create specific subsets, named DM *views,* to meet different needs of on-board and trackside VBTS constituents. More specifically, they are:
  - Trackside views that shall be formatted so that they can be logically linked to the usual representation of the line used by the signalling equipment (RBC).
  - On-board views that shall be formatted (see §9.3 of X2R2 D3.2 [2]) so that they can easily and safely be used by the VBR.

6.2.1.2.4 Dynamic Route Information

Starting from what has already been reported in 5.2.2.4, it represents the dynamic information necessary to identify, within the DM, the track portion where the train is actually travelling. It is mainly related to constrained position computation performed in “Estimate Safe Train Position” (see Figure 4) and perform the track discrimination function.

“Dynamic Route Information” is used as input for the identification of the unique, linear oriented path (route), correlating to the DM, namely to the geometry of the railway track ([1]-[2]).

The Dynamic Route information is sent from trackside to VBR through a FFFIS interface and its information is related to:

- Route information (i.e. the switch point status) that identifies the unique oriented path in the track graph;
- Information related to the Initial Train Position. Such information is useful to allow VBR to compute (after Power On) the first 1D Pos(t), i.e. the Initial Train Position constrained to the track. The Initial Train Position is defined from ETCS Position Report (including validated SoM PR), IXL occupancy, driver inputs, and other specific applications inputs managed by the ETCS On Board In the case the VBR is unable to guarantee initial position by itself, there is the need to provide this information from Trackside. One mechanism is using Eurobalises. Another mechanism is to provide this information from trackside (by

other means depending on specific application) through this interface. The expected information is a position in the DM.
- trackside Train Orientation with respect to the conventional Track Orientation. This information is useful to allow VBR i) compute the first 1D Pos(t), ii) correctly use the odometry information to estimate safe train position.

As above mentioned, all these information are used by “Estimate Safe Train Position” block for 1D Pos(t) computation. More specifically, given the Initial Position of the train, the VBR is able to start its navigation by information from the DM and to compute 1D Pos(t) - without any route ambiguity -, namely the identification of the track segment where the train is currently located. This information could be referred to any reference point described in the DM: to preserve the analogy with a legacy Position Report, this information shall be represented as the oriented distance from the Last Relevant Balise Group – LRBG.

The information about train position and orientation, including the confidence interval, shall be provided in terms of at least the following variables included in the Position Reports [11]:

- NID_LRBG: Identity of Last Relevant Balise Group
- D_LRBG: Distance between the last relevant balise group and the estimated front end of the train
- Q_DIRLRBG: Orientation of the train in relation to the direction of the LRBG
- Q_DLRBG: Qualifier telling on which side of the LRBG the estimated front end is
- L_DOUBTOVER: Over-reading amount plus the Q_LOCACC of the LRBG
- L_DOUBTUNDER: Under-reading amount plus the Q_LOCACC of the LRBG

The Q_LOCACC is calculate on board. (see 5.2.3)

In case the VBR is not able to guarantee initial position by itself, it informs the Trackside by providing a list of possible positions (i.e., a new single packet with several iterations (N_Iter) of the set of variables listed above). (see §9.4.3.1 [2])

If Trackside is able to safely and unambiguously validate train position and orientation, this information is provided to the VBR through a single iteration of the following set of variables:

- NID_LRBG: Identity of Last Relevant Balise Group
- D_LRBG: Distance between the last relevant balise group and the <u>estimated</u> front end of the train
- Q_DIRLRBG: Orientation of the train in relation to the direction of the LRBG
- Q_DLRBG: Qualifier telling on which side of the LRBG the estimated front end is
- L_DOUBTOVER: Over-reading amount plus the Q_LOCACC of the LRBG
- L_DOUBTUNDER: Under-reading amount plus the Q_LOCACC of the LRBG

This information, if present, should help the VBR to identify the train position and the orientation in the DM.

6.2.1.2.5 Odometry

Starting from what has already been reported in 5.2.2.5, in traditional ETCS architecture, the distance travelled and current speed have been computed by the Odometry function of the on-board unit that typically integrates wheel sensors, together with other kinematic measures

(Doppler speed, acceleration, etc.). To limit the impact of the error drift (caused, for instance, by sliding and slipping phenomena) the balises (i.e. electronic beacons) are located on railway track at specific reference points.

As displayed in Figure 4, the stream 1 FSTP receives from On-Board ERTMS/ETCS kernel continuous information, i.e. Travelled Distance, Speed and Time, see § 9.6-D3.2 [2]: this is the Odometer Information or Odometer Data.

The Odometer Data is computed by ETCS On-Board constituent, it is based on the information coming from the "Odometry Sensors" (e.g. Wheel Sensors mounted on the train's bogies, Radars, Accelerometers, etc.). The ETCS Odometry Subsystem Performances and Accuracy is compliant to the Subset-041 [12] Requirements.

In specific condition (e.g. slip/slide) the nominal performances described in Subset-041 might not be achieved. But, safe confidence interval for safety condition is provided.

The Odometry Information (in particular, Time and Distance with related uncertainties) is useful to assign to the 1D Pos(t) an appropriate tag/stamp. By means of such tag/stamp, the "Detect Virtual Balise" block shall be able to refer the Balise Info in the same Odometer Coordinates System used by ETCS Kernel (See §7.1.1 of [4]).

In stream1 FSTP, there are two uses of the ETCS Odometer Information:

1. Coasting function.

   In this case, at a given instant the GNSS-based 1D Pos(t) estimates of the train location are obtained by combining the GNSS estimates at different epochs with the distance travelled by the train given by the odometer. This is the so-named Coasting function by Odometry. The utilization of ETCS Odometry to complement GNSS-based positioning by ESTP is linked to the nature of the GNSS signal that does not guarantee a continuous availability of a "fresh" PVT. For instance, there can be bridges, tunnels, hills or trees causing temporary "blindness" of the GNSS receiver, thus making impossible for ESTP to update the PVT information for a certain amount of time. In these degraded cases, ESTP shall provide a "Virtual PVT", namely a PVT based on Odometry Information, until the satellite signals are again available. In this way, ESTP continues to map the Virtual Antenna onto the DM, ensuring the VB detection function without affecting the system availability. A complete technical insight of using ETCS Odometry as Coasting function is given in [4].

2. Consistency Check between GNSS (and optionally additional Kinematic sensor) and Odometry

   The ETCS SIL 4 Odometry Information is used to evaluate any discrepancies with the PVT information based on GNSS (and optionally additional Kinematic sensor). In any case, the data produced by the VBR shall be always consistent with the Odometry Information produced by the ETCS system.

   The cross-check between PVT information based on GNSS (and optionally additional Kinematic sensor) and odometric data originated from the ERTMS/ETCS on-board kernel permits to VBR of discarding PVTs whose kinematic data are not compatible.

6.2.1.2.6 Independent Kinematic Sensors

Starting from has already been reported in 5.2.2.6, the ESTP PVT algorithm uses the Kinematic Sensors in addition to the pseudorange data produced by the GNSS receiver for the calculation of the PVT quantities. These are VBR internal independent sensors that depending on the specific implementation can improve the ESTP elaboration included the THR values (see chapter 5).

Because these sensors are managed directly by the ESTP module only, these haven't any functional impact to the introduction of the VBR into the CCS architecture.

6.2.1.3 FSTP Functional output description

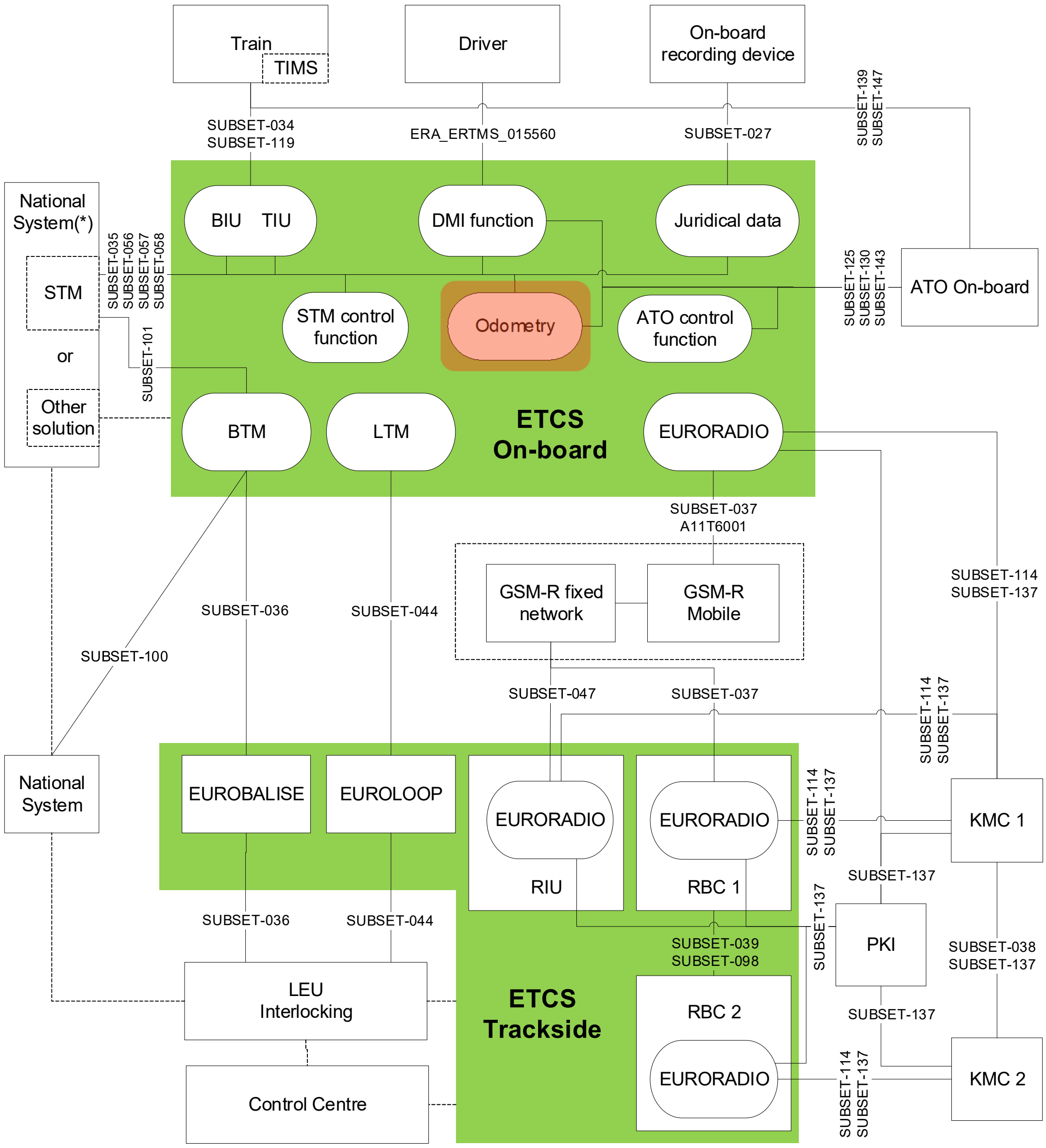
Starting from what has already been reported in 5.2.3, the stream 1 FSTP shall provide train location in terms of VB detection. This information will make available to the ERTMS/ETCS Kernel, providing the corresponding Balise Information as specified in [13].

As shown in Figure 4, the VBR block is connected to the ETCS Kernel by a functional interface of FIS type (as in analogy with the interface between BTM and ETCS kernel). Through this interface, when a virtual balise is detected, the VBR provides to ETCS Kernel the information described in section 5.2.3 .

6.2.1.4 FSTP integration into CCS

Starting from the complete architecture present in the Subset-026, shown in the Figure 5, the introduction of the stream 1 FSTP foreseen to add functional blocks both on the on-board and on the trackside system.

On the on-board system side, as shown in the Figure 6, the VBR block, part of the stream 1 FSTP solution (see Figure 4), is added at the ETCS On-Board. This block for interoperability reasons requires the FFFIS interfaces shown in Figure 6. The GNSS FFFIS interface through appropriate antennas acquires the radio signals coming from the satellites. For the other interfaces (GNSS Augmentation FFFIS, Dynamic Route info FFFIS and Digital Map FFFIS) a dedicated safe radio channel allows the trackside system to send information to the on-board system.



(*) Depending on its functionality and the desired configuration, the national system can be addressed either via an STM using the standard interface or via another national solution

Figure 5: ETCS architecture from Subset-026 version 4

The VBR is positioned within the ETCS on-board system area. The functional module will have proprietary interfaces with EVC similar to what is currently created for the BTM. Just like for the BTM, every company can choose the type of integration within the proprietary architecture of the ETCS on-board system. This approach has no backward compatibility impacts, in the sense that the new system will be able to circulate on equipped lines without the trackside FSTP system. In the Figure 5, odometry was not present in previous versions, it was made explicit in this version. It has no impact on backwards compatibility.

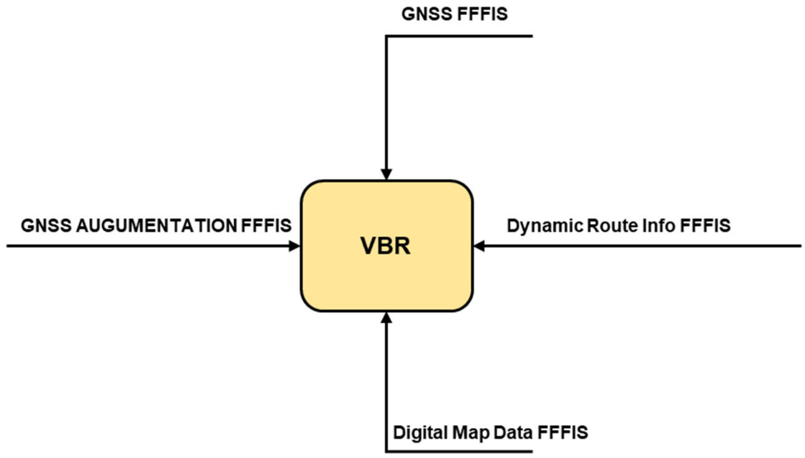


Figure 6: VBR Module with FFFIS interfaces

The functional blocks to be added in the trackside system are shown in Figure 7. These blue blocks provide the FFFIS interfaces that ensure the interoperability of the systems.

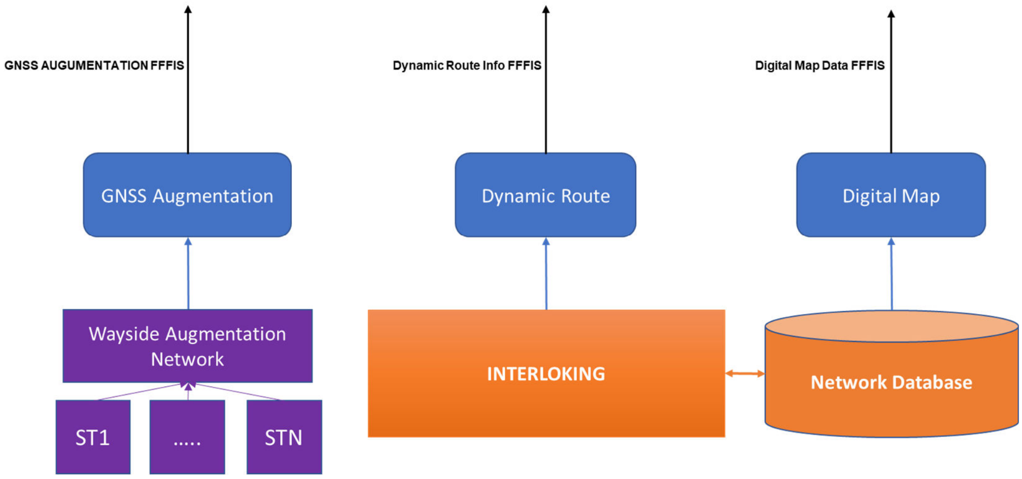


Figure 7: FSTP Trackside Modules

GNSS Augmentation brings the information coming from augmentation networks that can be built for different purposes. The Dynamic Route receive in input the rail network configuration from the interlocking that manages the rail area, and the Digital Map is coming from a Rail network Database shared with the other trackside equipment.

With reference to Figure 6 for the introduction of stream1 FSTP the activities to be carried out are as follows:

- Regarding the interface GNSS FFFIS showed in Figure 6, it's necessary the formalization of the use of the GNSS signal, MOPS for railways, this must be a valid document at least for all of Europe, it must also contain the minimum guaranteed performances and the degree of availability and safety. It is also indispensable standardization of the interface from which acquire GNSS signals. The interface with the constellations of satellites shall be specified in detail in order to ensure interoperability between different system suppliers.

- Concerning the remaining interfaces shown in the Figure 6, these will be transmitted to the VBR through a FFFIS radio connection. So, it is needed specification and standardization of the safe radio interface between the on-board and the trackside sub-systems. This interface must allow the transmission of the following information to the on-board system:
    - GNSS Augmentation
    - Dynamic Route info
    - Digital Map

In first hypothesis, the data exchanged between the trackside system and the on-board system could be contained in specific packets of the current EURORADIO protocol. This is just a hypothesis. We need to work to propose a standard to be applied.

6.2.2 FSTP Integration Impact Analysis

The integration of the Stream 1 FSTP, considering the assumption in chapter 5.2.4, leads to the reduction of the number of physical balises installed along the line. Indeed, physical balises can be replaced by virtual balises, reducing management costs while maintaining the same level of safety.

The stream 1 FSTP system is based on the ETCS system and compared to the ETCS architecture currently in use, to introduce the FSTP system what is described in paragraph 6.2.1.4 must be implemented.

The integration of the stream 1 FSTP can be done incrementally, maintaining interoperability with circulation on FSTP non-equipped lines.

One of the advantages is that the management of the balises (whether physical or virtual) does not change; different confidence intervals will be used in relation to the different type of balises. Another advantage is that with the introduction of new technologies there is an increase in the accuracy of train location.

The increase of the confidence interval against a reduction of the physical balises is implicit and justifiable in the choice of the new technology, this can have an impact in the definition of the engineering rules to be applied to the line. A big advantage is that the changes to the ETCS system as a whole are contained. This allows an easier and faster integration of the FSTP with the on-board system and with the track-side system.

6.3 X2Rail-5 WP5 Stream 2

The description of a Fails Safe Train Position on [8] does not define the integration of the positioning subsystem in the ETCS. This gap has been addressed in [15] and it is described here.

6.3.1 FSTP Integration on CCS

6.3.1.1 Integration functional impact description

To understand the proposed solution for the integration of a FSTP stream2 in the ETCS it has been necessary to define a scope, objectives and a set of definitions that are not present in paragraph 5.1 was found hereafter:

- 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).
- Objective with assumptions/decisions considered:
    - It is considered that E_ODO-OB, calculates the position of the vehicle body at a fix point and it does NOT attempt to calculate active cab's safe front end. It is assumed that the deduction of the active cab is part of the ETCS functionality and does not belong to E_ODO-OB. This also simplifies the functionalities to be carried out by E_ODO-OB and removes the dependencies on knowing which cab is active, train length and train integrity information too.
- List of Definitions:

Concept	Definition
Reference Location System	The reference coordinate system E_ODO-OB is using, is defined as a fixed point with fixed orientation in the vehicle-body. The output of E_ODO-OB has to be standard included the orientation. For instance, in [16] it is defined in this way "Positive movement direction is defined as a movement in the forward direction in relation to cab A. It shall be indicated with positive speed and increasing odometer distance values". An example of this reference system is illustrated in Figure 8 we have two trains. The active one is that one with blue Cab. The reference system is indicated in red in the Figure 8. With this set up, if the train is moving from the active train unit's Cab B to Cab A then the speed value estimated according with the coordinate system of the active train is negative. Notice that ETCS will require to know in advance as part of its configuration parameters the position and orientation of this reference system before it can use it as it is the case for instance for tachometer mounting direction parameter.

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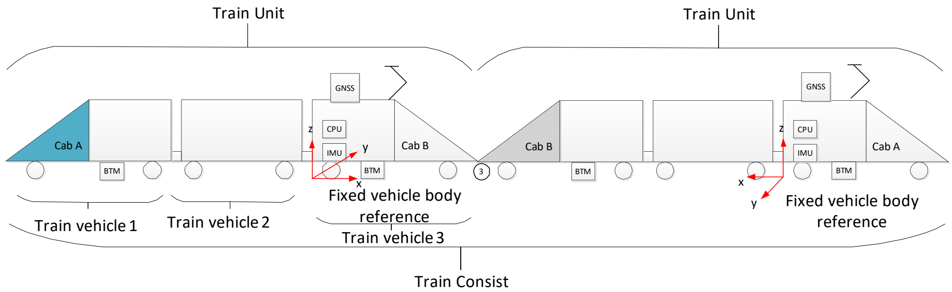

Figure 8: Coordinate reference system for E_ODO-OB with example localisation sensors.
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Table 2: Table definition for Stream 2

The current proposal requires an update on the functional architecture defined in [8]. In the following Figure 9, it is illustrated an updated architecture with two principal blocks identified in blue. On the left side E_ODO-OB as the main function to estimate position, speed and to report balise telegrams to ETCS-OB whereas on the right side the E_ODO-OB integrator is an additional functional block required on the ETCS side to integrated received data into its existing functionalities.

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.

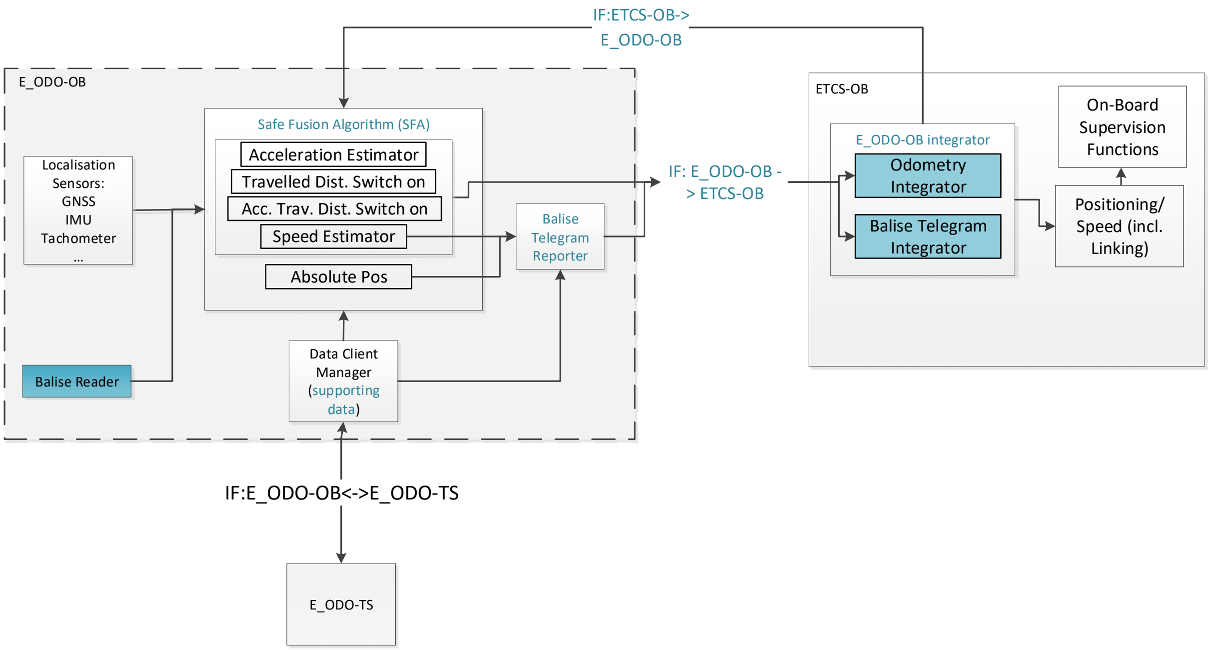

Figure 9: Architecture for Stream2 (upgrade in blue with respect to X2Rail-2)

<u>The *Safe Fusion Algorithm* (SFA)</u> 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 (see definitions on Table 2). The potential safety conflict due to the use of GNSS as source to determine the absolute position and reference location is expected to be handle by this function.

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 on GNSS does 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 (see [15] for a deeper comparison on both options) and thus every physically read balises shall be reported to ETCS-OB. This the option presented on Figure 9.

Notice that the described absolute position makes a reference to a fix point at the train vehicle in which the main sensors are installed (see [15] for further illustrations). 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 (see [15] for further discussion details on CI values).

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 §12 [16].

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 [11].

The Eurobalise Telegram Reporter functional block is responsible to possibly report a Eurobalise telegram whenever the E_ODO-OB crosses a reference location defined in the digital map. Recall that reference locations as per definition can be a common geographical point along the track, on centre line and with orientation, so it can either be a physical Eurobalise, a virtual Eurobalise or any other meaningful geographical point. The functional block uses the absolute position and speed information from SFA to decide whether E_ODO-OB shall trigger a Eurobalise telegram report or not. This Eurobalise telegram report includes Eurobalise telegram bits stored in the digital map, the dynamic confidence interval calculated at the time the Eurobalise is crossed and the corresponding time and odometer stamp information (See [13] §4.2.4.2). 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 Eurobalise 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 Eurobalise telegrams from E_ODO-OB as inputs to the current positioning functionality on ETCS as if they were physical Eurobalises. 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 Eurobalise reader can either be located at the E_ODO-OB side or ETCS-OB side so far. For this reason, if the Eurobalise reader is to stay at the ETCS-OB, then the Eurobalise reader requires odometry speed value and in turn it returns read Eurobalise telegrams to the E_ODO-OB (see bidirectional arrow from Eurobalise reader to *E_ODO-OB Integrator*). On the contrary, if the Eurobalise 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 cyclically.

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.

6.3.1.2 FSTP Functional input description

"*IF: ETCS-OB->E_ODO-OB*" defines the input information received from ETCS-OB by the E_ODO-OB to perform its functions. The following list of inputs are expected:

- Timestamp: Current time of the ETCS-OB so that any information sent from E_ODO-OB to ETCS-OB can be correctly timestamped.
- Eurobalise Telegram Information: It refers to NID_C, NID_BG and N_PIG values from a Eurobalise telegram as defined in Subset-026-8 §8.4.2. [11] and the Q_LOCACC of the received Eurobalise, see Subset-026-7 §7.5.1 [11].
    - Notice that this information is subject to the alternative presented in the architecture and may not be necessary if the Eurobalise reader is part of the E_ODO-OB.

"*IF: E_ODO-TS->E_ODO-OB*" defines the input information received from E_ODO-TS by the E_ODO-OB to perform its functions. The following list of inputs are expected:

- Digital Map: The digital map shall contain all required information to allow E_ODO-OB position the system and report a Eurobalise telegram to ETCS-OB whenever a reference location is crossed.
- Augmentation information: if required by the SFA it is possible to obtain GNSS augmentation information to provide integrity and accuracy to the GNSS signal received by GNSS sensors. In the case the augmentation is needed the starting point will be [14].

6.3.1.3 FSTP Functional output description

"*IF: E_ODO-OB->ETCS-OB*" defines the output information sent from E_ODO-OB to ETCS-OB. The following list of outputs are expected:

- Eurobalise Telegram Reported information (bits as defined in the digital map plus confidence interval) whenever necessary.
- Speed and its confidence interval with respect to the fixed body frame on the train periodically.
- Travelled distance and its confidence interval since switch on periodically.
- Accumulated Travelled distance since switch on periodically.
- Acceleration value at the fixed body frame on the train periodically.

"*IF: E_ODO-OB->E_ODO-TS*" defines the output information sent from E_ODO-OB to E_ODO-TS. In this interface two main information is expected. The first one related to establish a safe communication from on board unit to track side. The second one is the exchange of message that may be required to retrieve both the appropriate update of the digital map and/or augmentation information for sensors.

6.3.1.4 FSTP integrated into CCS

The integration of FSTP into CCS requires changes to both FSTP of stream2 and ETCS-OB. In this section a deeper look into what is expected by each side is described.

6.3.1.4.1 E_ODO-OB function description

6.3.1.4.1.1 Absolute Position Function

Absolute Position Function uses the following input information:

- E_ODO-OB localisation sensors
- Supporting data from track side
- Eurobalise Telegram Information
- Timestamp reference from ETCS-OB

The absolute position information uses all its inputs to estimate its absolute position and the corresponding Confidence Interval. The estimation shall guarantee track discriminative resolution and the provided confidence interval is possible to grow and shrink depending on the states of each of the received inputs. The *E_ODO-OB localisation sensors* refer to any sensor that aids the algorithm to estimate its position. The typical sensors used by the algorithm could be but are not limited to speed sensors, such as radars or tachometers; it could also use absolute positioning sensors, such as GNSS receivers; it could also use Inertial Measurement Units (IMUs).

The *supporting data from track side* refers to the digital map information as well as GNSS augmentation information. The former refers to the geographical/topological information used for map matching techniques whereas the latter refers to the information required to increase the tolerable hazard rate associate to GNSS based information and to improve accuracy.

The *Eurobalise Telegram Information* refers to NID_C, NID_BG and N_PIG values from a physical Eurobalise telegram as defined in Subset-026-8 §8.4.2. [11] and the Q_LOCACC of the received Eurobalise, see Subset-026-7 §7.5.1.115 [11]. Note that this information can be obtained either by an integrated Eurobalise reader included in E_ODO-OB or received by ETCS-OB. If this information is also stored in the digital map, then E_ODO-OB can determine in which track edge the train is located at.

The TimeStamp reference from ETCS-OB is required to provide an output with a time reference defined by the ETCS-OB.

6.3.1.4.1.2 Speed Estimator

The *speed estimator* function uses the following inputs:

- E_ODO-OB integrated sensors
- Supporting data from track side
- Timestamp reference from ETCS-OB

Speed estimator function is responsible to estimate E_ODO-OB speed value and its confidence interval. Speed values since they refer to a fixed point in the vehicle body, it is a value that provides positives values if the train is moving in the positive direction of the coordinate reference system and negative values if it is moving in the opposite direction. With regards to the confidence interval, it is expected that the CI value of speed can grow and shrink depending on the input's information. The *speed estimator* function shall estimate train's speed with a maximum confidence interval of +/-2km/h for speed lower than 30km/h, and then increasing linearly up to12km/h at500km/h [7].

The *speed estimator* shall timestamp its information with a timestamp referenced to the ETCS-OB.

The following performance requirements for speed information are based on [17] where the main goal is to limit the time the confidence interval exceeds the performance requirement:

- The confidence interval of the speed under "constant speed" (see Table 2 for definition) conditions shall be within the tolerable limits specified in Subset-041 at least 99.167 % of the time.
    - Notice that the 99.167% value is a first attempt value and it is subject to be adjusted.
- The confidence interval of the speed under "transition speed" (see Table 2 for definition) conditions shall be within the tolerable limits specified in Subset-041 at least 99.167 % of the time.

- Notice that the 99.167% value is a first attempt value and it is subject to be adjusted.
  - Note: since the values are subject to be changed, only speed transition is defined. If finally they provide % for each transition is different

The TimeStamp reference from ETCS-OB is required to provide an output with a time reference defined by the ETCS-OB

6.3.1.4.1.3 Eurobalise Telegram Reporter

Eurobalise Telegram Reporter uses the following inputs:

- Absolute Position information
- Timestamp reference from ETCS-OB.
- Speed Estimator function.

Eurobalise Telegram Reporter uses the absolute position to estimate its position within a digital map. This estimated position is then matched with explicitly stored reference locations in the digital map to report a Eurobalise telegram to the ETCS-OB. The Eurobalise Telegram Reporter shall transmit a Eurobalise telegram every time an absolute position estimate is on a reference location defined in the digital map.

The function shall output the following information:

- The Eurobalise telegram stored in the digital map shall be matched with a reference location on the digital map.
- The reported confidence interval within the Eurobalise Telegram report shall bound not only the uncertainty of the estimated position but also the uncertainty of the reference location defined in the digital map.
- Time and odometer stamping

Eurobalise Telegram Reporter shall use *Data Client Manager* to ensure it has an up-to-date digital map.

- The digital map update process is part of the Data Client Manager function block, and it is considered as part of supporting data used by Eurobalise Telegram Reporter function.
- The digital map shall have for each telegram location the bits associated to it.

Eurobalise Telegram Reporter shall time and odometer stamping its Eurobalise telegram report with a time stamp and odometer stamp inside the same reference system of the ETCS-OB.

The TimeStamp reference from ETCS-OB is required to provide an output with a time reference defined by the ETCS-OB

6.3.1.4.1.4 Travelled Distance since Switch on Estimator

The *travelled distance since switch on estimator* function uses the following inputs:

- E_ODO-OB integrated sensors
- Supporting data from track side

- Speed Estimator function
- Timestamp reference from ETCS-OB

The *travelled distance since switch on estimator* is responsible to provide estimated travelled distance and its confidence interval since switch on. This function's objective is to provide ETCS-OB with the required information to comply with its current position and supervision functions, mainly all sections related to Subset-026 [11] §3.6 and §3.13. The travelled distance since switch on estimator provides a signed travelled distance referred to a fixed body frame, where its values increase when moving in favour of the fixed body frame reference and decreases in the opposite direction. The signed value of travelled distance since switch on is necessary for ETCS-OB to perform train protection functions such as roll-away functions. Notice that this behaviour mirrors the current behaviour of the tachometers where the sign of the tachometer is a configuration parameter for ETCS-OB.

The confidence interval related to travelled distance since switch on refers to the absolute value that represent the uncertainty of the estimated travelled distance. The CI value for travelled distance since switch on is thus always a non-shrinking value which shall be added and subtracted to the travelled distance since switch on in order to estimate the worst-case scenario. This mirrors the current state of the art of ETCS-OB behaviour where no absolute information is integrated in the algorithms to estimate the confidence interval. Consequently, the expected performance is predictable. In Figure 10 it is illustrated an example of the behaviour of the CI and the travelled distance since switch on values to facilitate the comprehension. The figure represents the "travelled distance since switch on", the CI value of the travelled distance since switch on plus the travelled distance itself and the performance value required to the system as a 2% value (see further in this section for this requirement). Note that in reality CI value shall be added and subtracted to the travelled distance since switch on but for simplicity of this figure only the positive value is shown. The train starts from cold and imagine that at the beginning there is a slip and slide phenomena leading to a position of a travelled distance of 500 meters and a CI value of 50 meters. This is currently not meeting the requirements of 2%. However, imagine that in the next section the train runs smoothly the next kilometres with an average error of 1%, that is in the next 4500 meters has an accumulative error of 45 meters in the CI, reaching to the end of the graph at 5000 meters at travel distance value with a CI of 95 m, from which 50m of errors refer to the initial section whereas the 45 meters errors refer to the last section of the remaining 4500 meters.

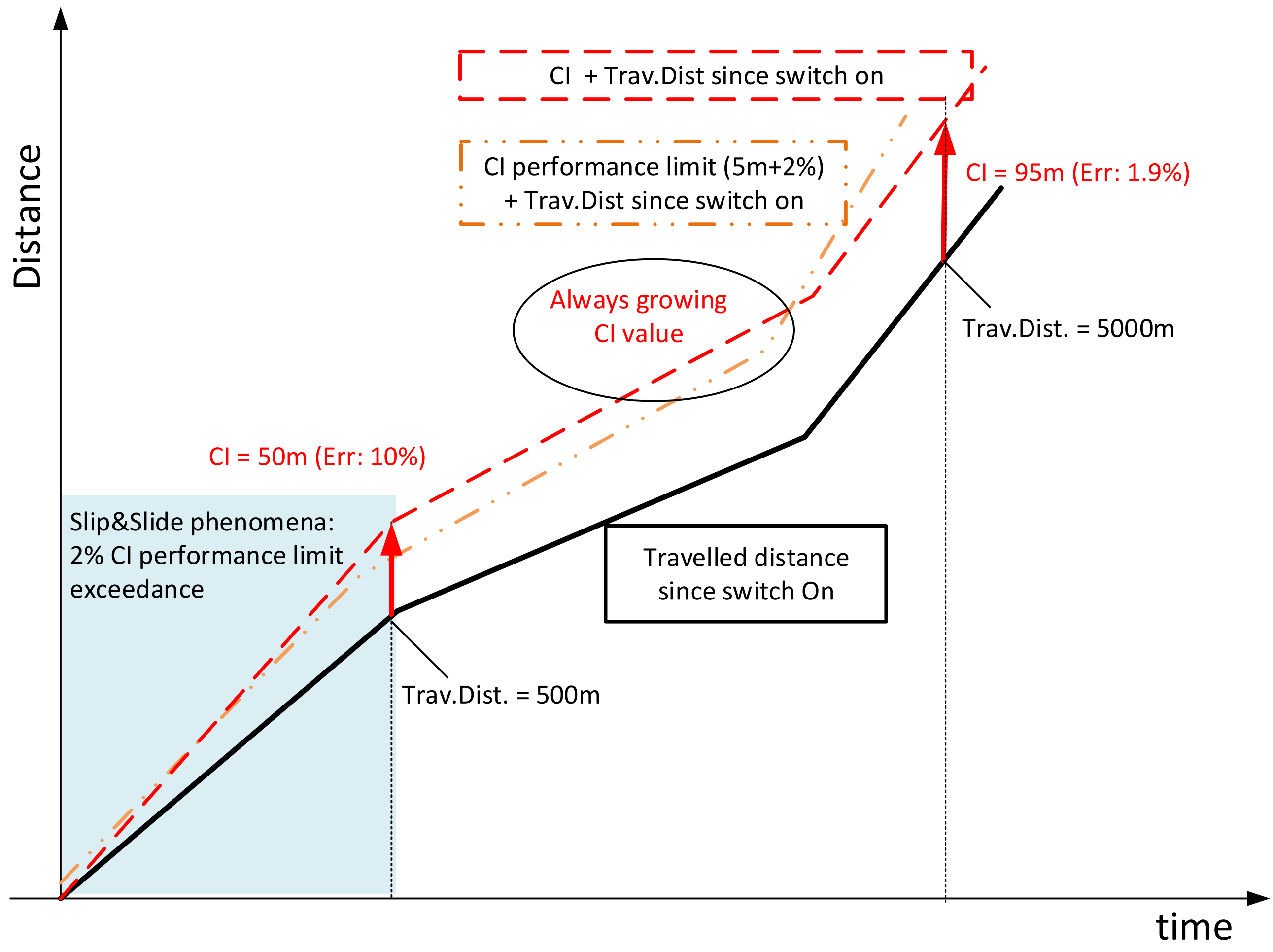

Figure 10: Confidence Interval example for Travelled distance since switch on

The TimeStamp reference from ETCS-OB is required to provide an output with a time reference defined by the ETCS-OB

6.3.1.4.1.5 Accumulative Travelled Distance since Switch on Estimator

The accumulative *travelled distance since switch on estimator* function uses the following inputs:

- Travelled distance since switch on Estimator function;
- Timestamp reference from ETCS-OB.

To be able to define performance requirements, it is necessary to define the “accumulative travelled distance since switch on” value. The “accumulative travelled distance since switch on” value refers to 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. In the following Figure 11 it is depicted the case where the train runs in the same direction of the body fixed frame of E_ODO-OB and then changes direction. The travelled distance since switch on decreases, the CI value keeps increasing positive. However, since the travelled distance is decreased, the overall figure shows values that keep track of the travelled distance. However, for performance requirements it is of interest to investigate the accumulative values that could directly be compared to a percentage value such as 5m + 2%. The accumulative travelled distance value is shown as an always increasing value and the corresponding CI is simply adding the same value as it is for the travelled distance since switch on.

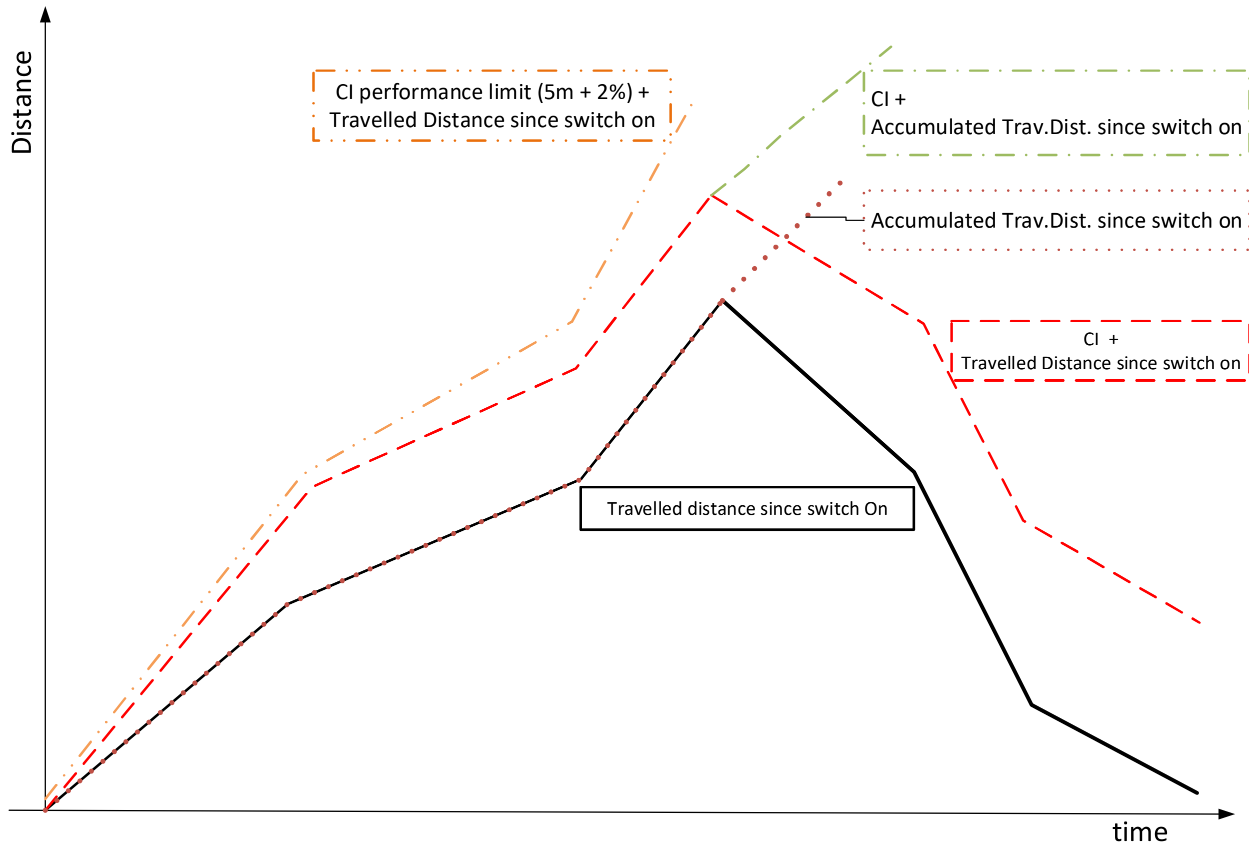

Figure 11: Accumulated travelled distance since switch on

The CI of the accumulative travelled distance since switch on shall be lower or equal to ± (5 m + 2% s), where ‘s’ is the accumulative travelled distance since switch on.

The following performance requirements for “accumulative travelled distance since switch on” information is based on [17] where the main goal is to limit the time the confidence interval exceeds the performance requirement:

- It is defined as “*Accumulative Travelled distance since switch on Maximum Limit 1*” as 100 meters maximum increase of confidence interval over a 5 km travelled distance (0.02*5km). (This is based on [17] with 2% instead of 5%)
- It is defined as “*Accumulative Travelled distance since switch on Maximum Limit 2*” as 1500 meters maximum increase of confidence interval over a 5 km travelled distance (0.3*5km).
- The “*Accumulative Travelled Distance since switch on Reliability*” limit 1 shall be better than 8*10^3 hours (see Table 2 for reliability definition).
    - Rationale, this value is taken from the application guideline RAMS [18] section 2.2.2.2.
    - Notice that the proposed reliability value is defined at the level of the overall onboard ETCS, the allocation to the E-ODO-OB has to be derived.
- The “*Accumulative Travelled Distance since switch on Reliability*” limit 2 shall be better than 2.7* 10^6 hours (see Table 2 for reliability definition).
    - Rationale, this value is taken from the application guideline [18] section 2.2.2.2.
    - Notice that the proposed reliability value is defined at the level of the overall onboard ETCS, the allocation to the E-ODO-OB has to be derived.

The *travelled distance* since switch on is required by ETCS-OB to fulfil the STM requirements, see Subset-035 §8.3 [16].

The *travel distance since switch on* shall timestamp its information with a timestamp referenced to the ETCS-OB.In other words, the TimeStamp reference from ETCS-OB is required to provide an output with a time reference defined by the ETCS-OB.

6.3.1.4.1.6 Acceleration Estimator

The *acceleration estimator* function uses the following inputs:

- E_ODO-OB integrated sensors
- Supporting data from track side
- Speed Estimator function
- Timestamp reference from ETCS-OB

The *acceleration estimator* is responsible to provide estimated acceleration value. The value is both positive and negative as it represents the acceleration defined in the fix body frame of the vehicle. No confidence interval is required by this function.

The *acceleration estimator* is required by ETCS-OB to comply with the A_traction value for the braking curves, Subset-026-3 §3.13.2.2.2 [11].

The *acceleration estimator* shall timestamp its information with a timestamp referenced to the ETCS-OB. In other words, the TimeStamp reference from ETCS-OB is required to provide an output with a time reference defined by the ETCS-OB.

6.3.1.4.1.7 Data Client Manager

The *Data Client Manager* function shall retrieve all supporting data required by the SFA from E_ODO-TS.

The *Data Client Manager* needs to guarantee a safe communication channel between E_ODO-OB and E_ODO-TS.

The *Data Client Manager* shall ensure the SFA has an up-to-date digital map.

The *Data Client Manager* shall allow receiving augmentation information from track side if SFA requires it.

6.3.1.4.2 ***ETCS-OB function description***

6.3.1.4.2.1 E_ODO-OB Integrator

The *E_ODO-OB Integrator* function uses the following inputs:

- Eurobalise Telegram and its confidence interval as reported by E_ODO-OB
- Speed value and confidence interval
- Travel distance since switch on and its confidence interval.
- Accumulative Travelled distance since switch on
- Acceleration values

The *E_ODO-OB Integrator* has the objective to integrate these inputs into the ETCS kernel. Integrate means that these values may potentially have an impact in multiple ETCS functions and its impact cannot be determined at this stage, as each supplier will need to estimate the real effort behind this integration.

The *E_ODO-OB Integrator* function shall integrate any new Eurobalise telegram transmitted by the E_ODO-OB into ETCS kernel.

The *E_ODO-OB Integrator* function shall integrate the dynamically computed confidence interval for the new Eurobalise telegram as part of the confidence interval of the read Eurobalise.

The *E_ODO-OB Integrator* shall integrate speed value and its confidence interval into ETCS kernel.

The *E_ODO-OB Integrator* shall integrate travelled distance value into ETCS kernel.

The *E_ODO-OB Integrator* shall integrate the Acceleration value into ETCS kernel.

The *E_ODO-OB Integrator* shall provide current ETCS time refence to E_ODO_OB.

The Accumulative Travelled distance since switch on value is used for performance evaluation only so far.

In the case where the Eurobalise reader is kept within the ETCS-OB, the *E_ODO-OB Integrator* is responsible to send the physical Eurobalise telegram read by the Eurobalise reader to E_ODO-OB.

To clarify the integration of these functions into ETCS-OB, in

Figure 12 it is depicted an example with the change of travelled distance since switch on value with respect to the travelled distance from Last Read Eurobalise Group as it is done today by ETCS-OB. In this case, ETCS-OB may receive a Eurobalise group of two Eurobalise telegrams at any point in time, for instance a travelled distance since switch on of 600 meters. Since the slip and slide behaviour is finished, the CI value of the travelled distance now grows at a rate of, for instance, 0.5 percent, which means that between 500 meters and 600 meters it has only grown 0.5m. At this point the first Eurobalise telegram is read, BT1/2 but ETCS determines its LRBG when BT2/2 is read [11]. Then, if the Eurobalise telegram comply with all the ETCS checks to become an LRBG the ETCS can compute the travelled distance since LRBG1. This computation occurs in time after BT2/2 is read but the illustration shows all backwards computation too. So, when the LRBG is accepted ETCS travelled distance from LRBG is set to zero at the time BT1/2 is read. For the ETCS_CI value the following mathematical formula is followed:

ETCS_CI = 2×Eurobalise Read Error + 2×Q_LOCACC + Trav.Dist.SwitchOnCI(t) –

Trav.DistSwitchOnCI(T_LRBG).

Where Eurobalise Read Error has a maximum error of 1 meter (from [13]), Q_locacc value is included in the linking information related to the Eurobalise location accuracy, Trav.Dist.SwitchOnCI(t) is defined as the Travelled distance since switch on CI value at time t and Trav.DistSwitchOnCI(T_LRBG) refers to the travelled distance since switch on CI value at the time the Eurobalise telegram BT1/2 is read. In the example below, assuming Eurobalise Read error as 1 m, Q_locacc as zero, then the ETCS_CI value at the time BT1/2 is read is equal to d1=2×1+2×0+650.5-650.5 =2 m. Consequently, the values shown in the illustration reflect that by the time ETCS reaches travelled distance since switch on of 5000, the ETCS_CI value is equal to 2×1+2×0+5095-650.5=4,446.5, which is about 1.057% of error from LRBG.

Figure 12 is an illustration of a possible case scenario that should be considered for comprehension purposes only. The illustration shows on one hand the travelled distance since switch on and its confidence interval. Notice that on the one hand the CI needs to be an always growing value. On the other hand, it is also depicted the requirement value of 2%.

Whenever the train crosses a Eurobalise group it reads its first Eurobalise telegram (BT1/2) and then the second Eurobalise telegram (BT2/2). It is at the time of reading BT2/2 that the ETCS determines its LRBG, assuming no errors occur, when reading Eurobalises for the sake of this example. ETCS-OB then shall consider the difference of the travelled distance between BT2/2 and BT1/2 to define the new 'd2' value for the ETCS_CI value at the time BT2/2 is read.

As seen in Figure 12; the CI value at the instance the second Eurobalise is read, is determined as the confidence interval difference of the travelled distance between BT1/2 and BT2/2 plus twice the 1 metre Eurobalise Read Error (in case of a physical Eurobalise) plus twice the Q_LOCACC value.

From this moment on, the new travelled distance from LRBG will be the travelled distance from BT1/2 (reference Eurobalise of the LRBG). In parallel, the confidence interval difference of the travelled distance from BT1/2 plus twice the 1 meter Eurobalise Read Error (in case of a physical Eurobalise) plus twice the Q_LOCACC value will determine the ETCS CI value of the absolute position with reference to the new LRBG.

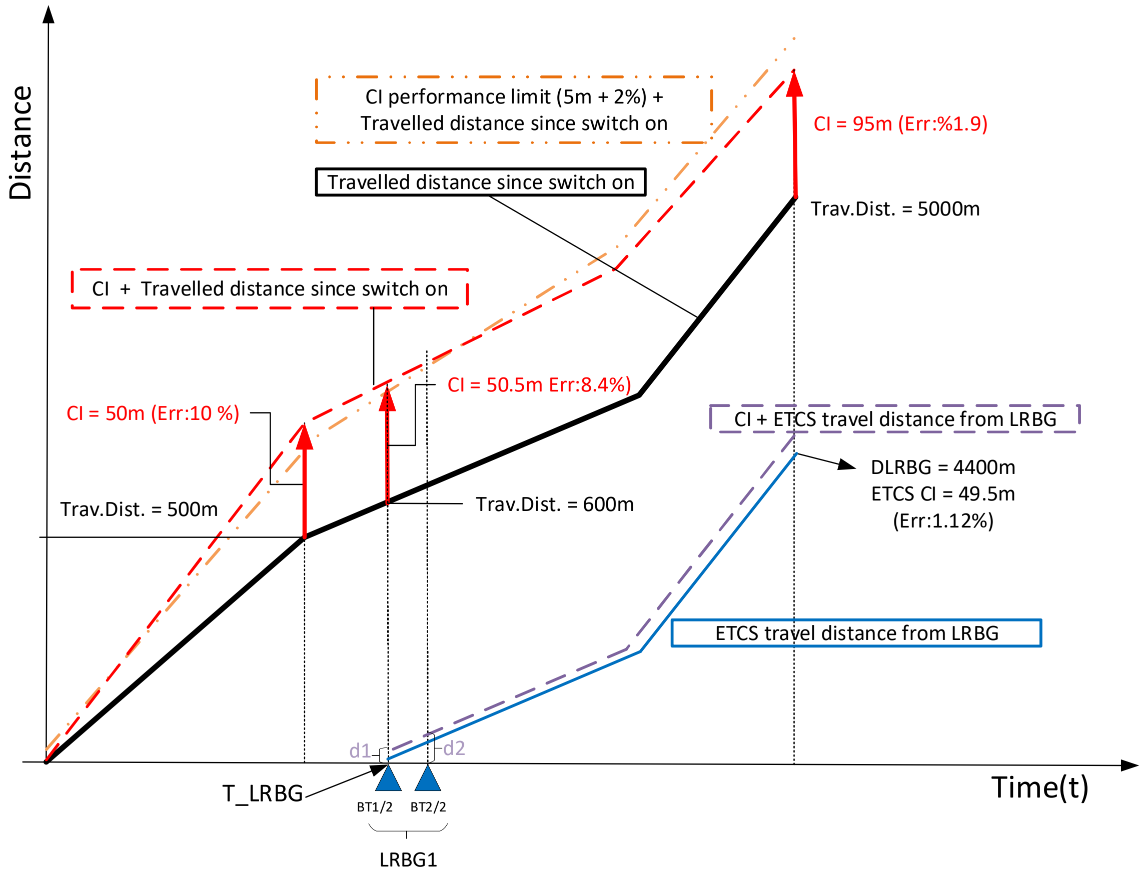

Figure 12: Confidence Interval integration illustration

6.3.2 FSTP Impact Analysis

The impact analysis is divided into two main parts, migration strategy and impact on current TSI.

6.3.2.1.1 Migration Strategy Proposal for Stream 2

The integration of an Enhanced Odometry system as defined by stream 2 Fail Safe Train Position, could foresee a two-step approach to the final target. The first step could be associated to the performance enhancement values of the travel distance confidence interval and speed confidence interval. If the current E_ODO-OB could perform these values without track side support, i.e., with E_ODO-TS not fitted, then the system would already improve. The second step would consider that both track side and on board are fitted with E_ODO 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 new E_ODO-OB system and already take benefits from it. And on a second step to obtain full integration. The matrix that represents all possible case scenarios for a migration strategy is shown hereafter.

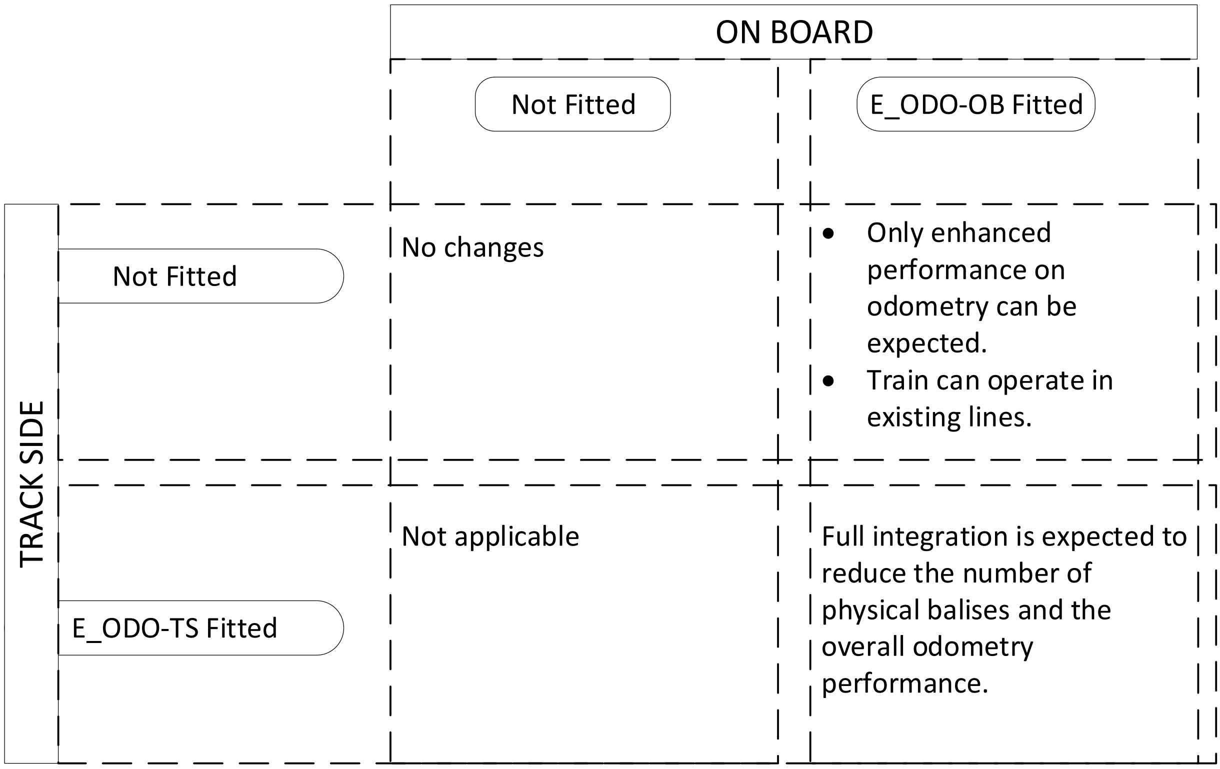

Figure 13: Migration Matrix definition for E_ODO into ETCS.

6.3.2.1.2 Impact on ETCS TSI

The new E_ODO system shall have its own system requirement specification standardised. In addition, the current proposal defines two interfaces, E_ODO-OB with ETCS-OB and E_ODO-OB with E_ODO-TS. It is expected that for these two interfaces dedicated subsets should be defined as illustrated in Figure 14. For instance, it could be expected to have a set of 3 specifications:

An overall functional specification as Subset–XX1, and two interface specifications. Subset–XX2 would define the interface between E_ODO-OB and ETCS-OB and Subset–XX3 the interface between E_ODO-OB and E_ODO-TS.

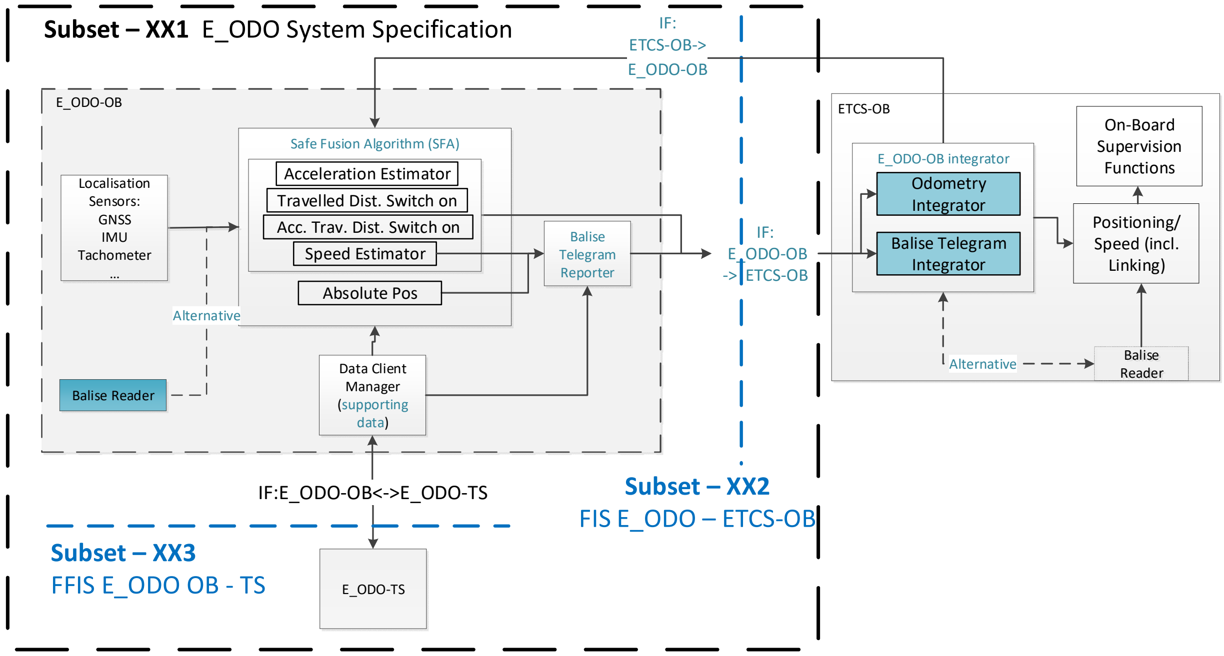

Figure 14: E_ODO to ETCS-OB interface specification.

With regards to the impact on existing subset, the following non-exhaustive list is expected:

Subset	Modification Reason
Subset-026	The new E_ODO-OB requires at the ETCS-OB to introduce a new function that integrates read Eurobalises from E_ODO-OB into the positioning functionality. The changes here also depend whether the Eurobalise reader is kept on ETCS-OB side or not.
Subset-041	The new performance values for travel distance confidence interval shall be integrated within this subset. In addition, the new performance values related to the accumulative travel distance value should also be integrated.
Subset-035	Definitions of D_Max and D_Min needs to be investigated
Subset-076	Test specification would need to be updated consequently with the Subset-026 modifications.
Subset-088	An update on Functional Fault trees shall be expected as a new safety related subsystem is integrated.

Subset-091	An update on external entities may be expected due to the integration of a new subsystem.
Subset-036	Analyse the impact from 4.2.4.2 (From subset-036 “The instant in time or position on which the location reference is based shall originate from the ERTMS/ETCS Kernel.”)

Table 3: Impact analysis

7 Comparison between the two Streams

The work done in the previous chapters (chapter 5 and chapter 6) has produced as a result the two architectures shown in the Figure 15.

In this chapter the goal is to identify common functions and also the differences.

The analysis conducted led to the highlighting of four areas that have a lot in common. These four areas are clearly indicated in the Figure 15 with different colours.

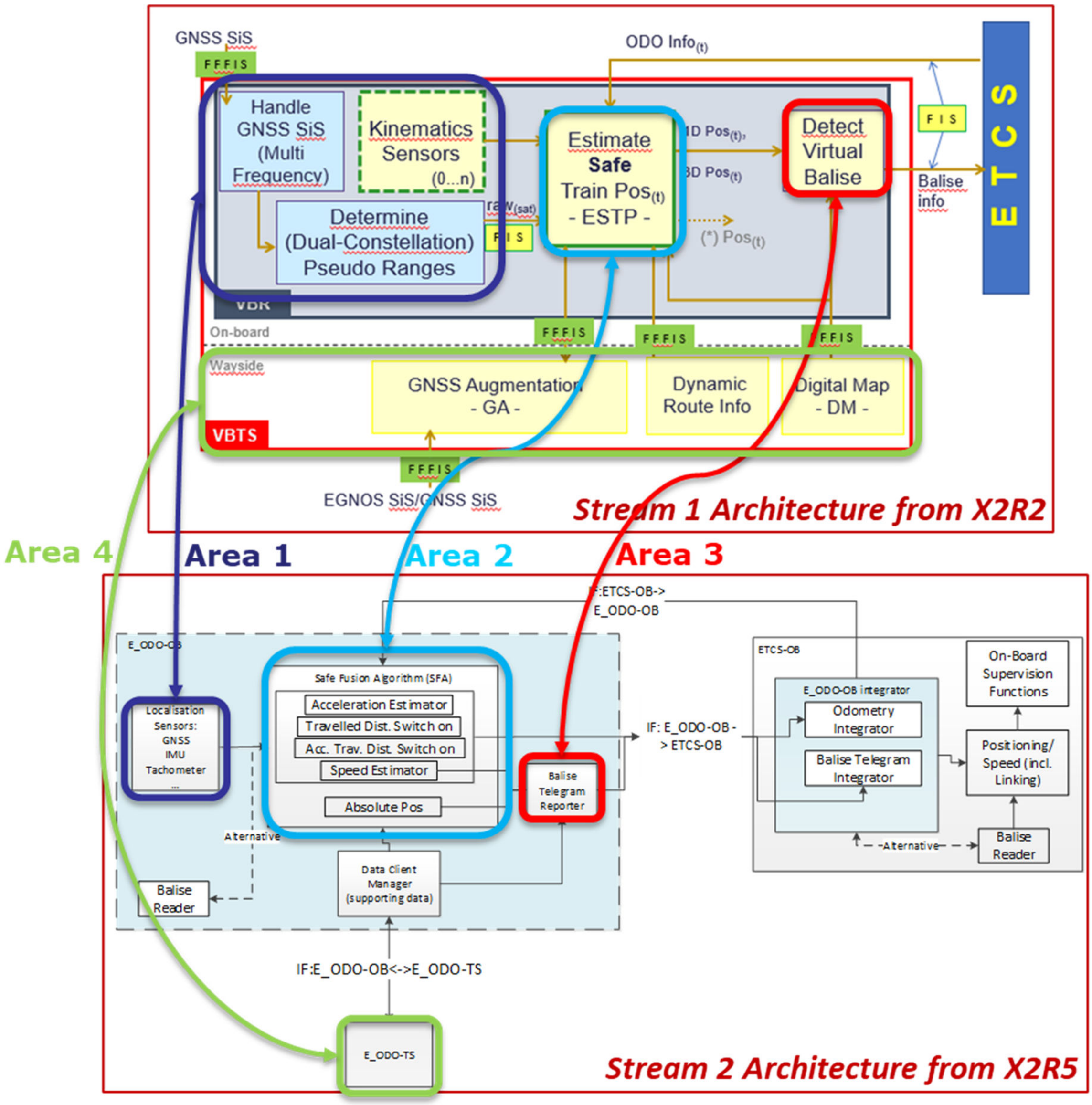

Figure 15: Comparison between Architectures

In Figure 15 the Data Client Manager in the Stream 2 architecture performs the communication with trackside. In Stream 1 this block is implicitly present (managed by different functions) but not displayed due to higher level of architecture drawing in Figure 15.

The 4 areas have been extracted from Figure 15 to clarify which of these is being studied in order to facilitate reading.

Four paragraphs are made, find the list below, and in each one the communalities are described. The paragraphs are:

1. Area 1: Information acquisition from sensors
2. Area 2: Fusion algorithms and definition of the train position
3. Area 3: Virtual Eurobalise Detection
4. Area 4: FSTP trackside.

After them there is a chapter that shows the differences between the two streams that will be part of the activities in the chapter 8.

7.1 Area 1: Data acquisition from sensors

The Area 1 described in this paragraph has the task of collecting the input data coming from the GNSS and from sensors mounted on board the train. See Figure 16.

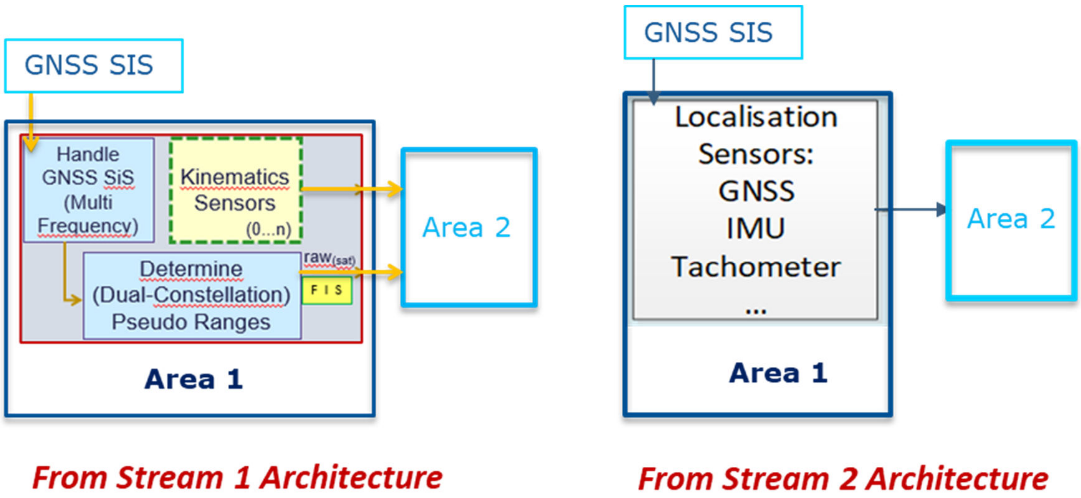

Figure 16: Communality Area 1

- **AREA 1 INPUTS**
  - ✓ For the Stream 1 the inputs of Area 1 are described in paragraph 5.2.2.1.
  - ✓ For the Stream 2 the external input of Area 1 is described in paragraph 5.3.2.1.

- **AREA 1 OUTPUTS**
  - ✓ The Area 1 outputs, that are internal at the FSTP, provide the raw data of the sensors that are installed to Area 2 for their elaboration.
  - ✓ For the Stream 1 the Kinematic Sensors are optional.

7.2 Area 2: Fusion algorithms and definition of the train position

Area 2 is the heart of the FSTP System. Area 2 has the task of processing the position of the train in real time using the inputs coming from (See Figure 17):

(i) Area 1;
(ii) Area 4;
(iii) From ETCS information.

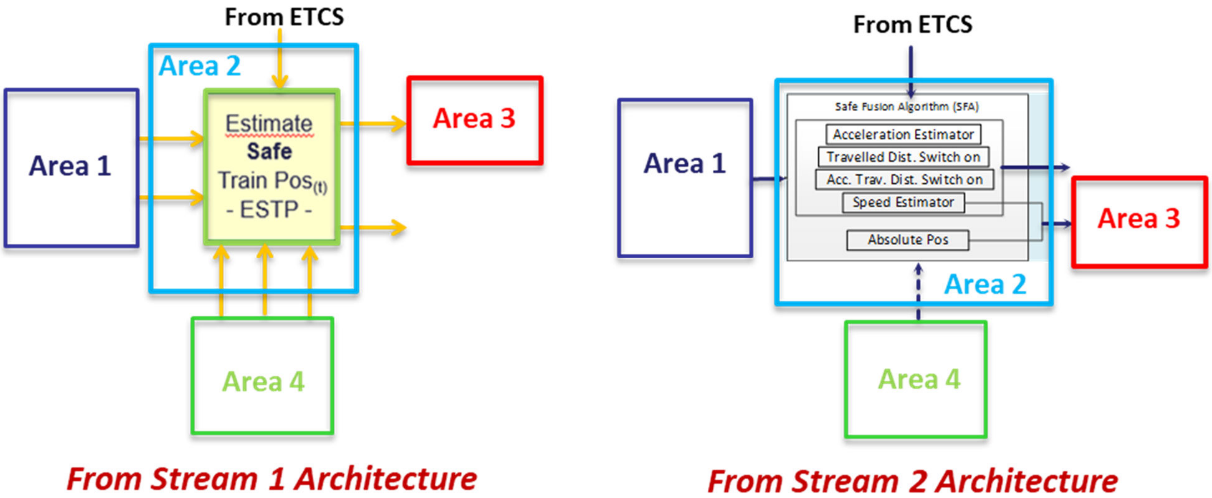

Figure 17: Communality Area 2

- **AREA 2 INPUTS**

  ✓ Area 1 provides to Area 2 what is described in the paragraph 7.1.

  a) The Area 1 provides the raw data of the sensors that are installed in the FSTP to Area 2 for their elaboration (see Figure 16).
  b) For the Stream 1 the Kinematic Sensors are optional see 5.2.2.6 above.

  ✓ Area 4 provides to Area 2:

  c) GNSS Augmentation information see 5.2.2.2 for Stream 1 and 5.3.2.2 for Stream 2
  d) Digital Map described in 5.2.2.3 for Stream 1 and 5.3.2.5 & 6.3.1.2 for Stream 2
  e) Dynamic Route Information see 5.2.2.4 for Stream 1
  f) Train Dynamic Information see 5.3.2.6 & 6.3.1.2 for Stream 2

  For the Stream 2 there is and additional step between Area 4 and Area 2 as in Figure 15.

  ✓ ETCS provides to Area 2:

  a) For Stream 1: "**From ETCS**" information is described in 5.2.2.5 and it is an odometric value calculate inside the ETCS system, it is composed by Travelled Distance, Speed and Time.
  b) For Stream 2: "**From ETCS**" information is the time stamp produced by the ETCS system for the synchronization purpose, and the Eurobalise information.

- **AREA 2 OUTPUTS**
  - ✓ The outputs of Area 2 for Stream 1 are:
    a. The estimate position along the track, i.e.1D Pos(t), with its confidence interval, that is input for Area 3.
    b. The unconstrained position, i.e. 3D Pos(t), with its confidence interval and eventually the related speed information, that are auxiliary information potentially available for on board applications.
  - ✓ The outputs of Area 2 for Stream 2 are:
    a) Area 2 provides to Area 3 the absolute position and speed information.
       (i) Confidence interval for absolute position.
       (ii) The speed information to determine the time of Eurobalise detection.
    b) Area 2 provide to ETCS OB:
       (i) Speed and its confidence interval with respect to the fixed body frame on the train periodically;
       (ii) Absolute position and its confidence interval with respect to the fixed body frame on the train periodically;
       (iii) Travelled distance and its confidence interval since switch on periodically;
       (iv) Accumulated Travelled distance since switch on periodically;
       (v) Acceleration value at the fixed body frame on the train periodically.

7.3 Area 3: Virtual Balise Detection

Area 3 is responsible to provide the information relate to a Virtual Eurobalise linked to a specific position along the track. See Figure 18.

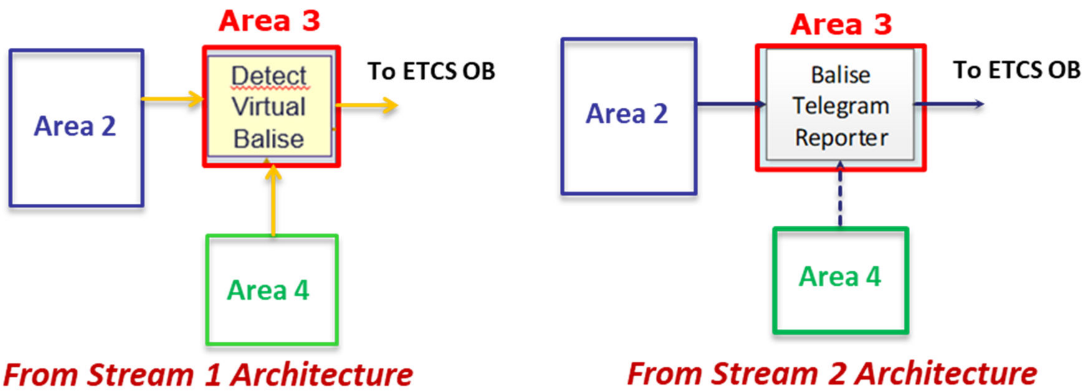

Figure 18: Communality Area 3

Area 3 has inputs coming from Area 2 and Area 4 as in the Figure 18. To be more precise for the Stream 2 there is and additional step between Area 4 and Area 3 as in Figure 15.

- **AREA 3 INPUTS**
  - ✓ Inputs of Area 3 for the Stream 1 are:
    a) the 1D position of the train with the associated confidence interval.

b) Location of the Virtual Eurobalises in the digital map included the telegram (user bit)

✓ Inputs of Area 3 for the Stream 2 are:

a) the absolute position and speed information.
b) Location of the Virtual Eurobalises in the digital map included the telegram (user bits).

- **AREA 3 OUTPUTS**

The Area 3 output is sent to the ETCS On Board system.

✓ The outputs of Area 3 for the Stream 1 are (see 5.2.3):

- Time and Odometer stamp of the detected virtual Eurobalise centre,
- The confidence interval associated with the virtual Eurobalise detection accuracy,
- Eurobalise information (telegram user bits) for the detected virtual Eurobalise.

✓ The outputs of the Area 3 for Stream 2 are (see 6.3.1.1),

- Time Stamp of the detected virtual Eurobalise centre (optionally for physical Eurobalise too)
- The dynamic confidence interval calculated at the time the virtual Eurobalise is crossed.
- Eurobalise information (telegram user bits) of the virtual Eurobalise (optionally for physical Eurobalise too)

7.4 Area 4 FSTP trackside

Area 4 is the trackside counterpart of the FSTP system. It provides the complementary information necessary for on-board processing. Its architecture has not been defined in detail, but from a functional point of view it must produce its own outputs towards the on-board part.

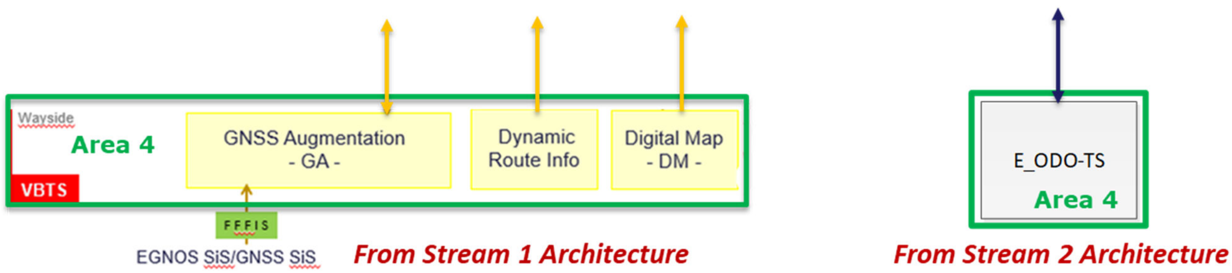

Figure 19: Communality Area 4

- **AREA 4 INPUTS**

For Stream 1:

a. The augmentation and SiS data coming from EGNOS or in general from GNSS networks. These can also be dedicated private networks that collect data from the satellite constellation and produce the correction factors to be applied to the calculations. See [22] and [23].

b. Digital Maps collected for the lines managed by the OB system.
c. All the input for identify the Dynamic Route Information.

For Stream 2:

a. Digital Maps collected for the lines managed by the OB system.
b. Optionally the Augmentation information for the GNSS.

- **AREA 4 OUTPUTS**

  ✓ The output of Area 4 for the Stream 1 are:

  a) GNSS Augmentation information see 5.2.2.2
  b) Digital Map described in 5.2.2.3
  c) Dynamic Route Information see 5.2.2.4

  ✓ The output of Area 4 for the Stream 2 are:

  a) GNSS Augmentation information see 5.3.2.2 (optional)
  b) Digital Map described in 5.3.2.5 & 6.3.1.2

7.5 Difference between the two architectures.

The basic difference between the two streams is that:

➢ Stream 1 introduces the concept of virtual Eurobalise and leaves the functions of the ETCS on-board system unchanged (odometry is basically calculated by the on-board system). The Eurobalise Reader remains inside of the ETCS On Board architecture.

Stream 2 introduces the concept that system odometry is produced within the FSTP and provided to the ETCS on-board system. The FSTP module also provides train position and odometry for other systems on board the train. The Eurobalise Reader can be part of the FSTP.

The Stream 2 needs a ETCS On Board function modification for Odometry Integrator and Eurobalise Telegram Integrator function blocks in the red square in the Figure 20.

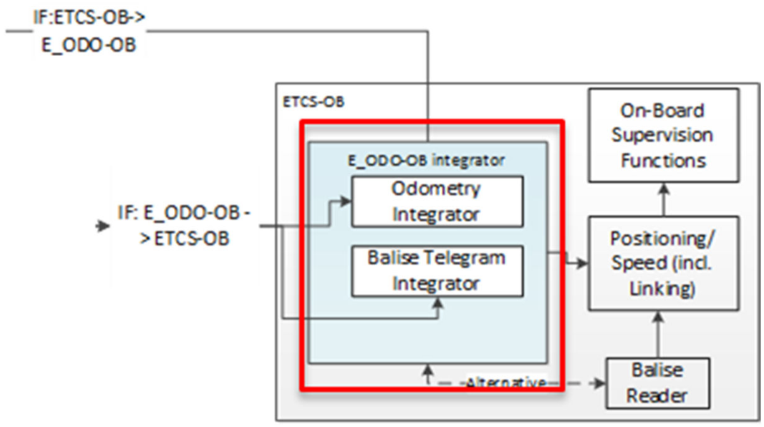

Figure 20: Stream 2 ETCS modification

Follows the description done for the communalities some differences can be highlighted for the four areas.

7.5.1 Area 1 Differences

Stream 1 using the existing GNSS standards accepts all the GNSS SiS and internally to Area 1 has as optional additional Kinematic Sensors. If necessary, the additional sensors can help to fill the condition when the GNSS coverage isn’t enough.

Stream 2 always adopts all the sensors included the GNSS for internal elaboration.

Stream 1 and Stream 2 haven’t a big difference in Area 1.

7.5.2 Area 2 Differences

For **Odometry output:**

For Area 2 there is core difference. The output of Stream 1 is determined by the ETCS odometry (ODO Info), Stream 2 produce the odometry itself and deliver it to the On-Board modules.

This is the main difference between the two streams. Regarding better performances respect to the current ones specified in the TSI, this affect the odometry in ETCS for Stream 1 and the FSTP for Stream 2.

For the performances (e.g. accuracy of speed and position) the two streams are on the same plane depending on the quality of the sensors used.

For **implement the solution in the On-Board system:**

Stream 2 may require further changes in existing ETCS than Stream 1 due to the fact that the odometry is taken out from the EVC.

7.5.3 Area 3 Differences

As indicated in the paragraph 7.3, there is a difference in the Eurobalise centre passing report, in the Stream 1 there are time and distance, in the Stream 2 only time. This can have an impact to the current ETCS On Board Kernel for the Stream 2.

7.5.4 Area 4 Differences

For Stream1, Area 4 shall provide GNSS augmentation, Dynamic route info and Digital Maps.

For Stream2, Area 4 shall provide Digital Map and optionally GNSS augmentation.

For **Dynamic Route information**:

Stream 1 defines this as an input whereas in Stream 2 it does not. Identify the safety case and SOM procedures for each of the streams to define how it could work.

For **GNSS augmentation:**

Stream 1 asks to have it when it is available for increasing GNSS precision; Stream 2 defines this input as mandatory except by a partner that considers it as optional.

7.6 Commonalities between the two architectures.

This paragraph reports the summary of the communalities in the following table.

INPUTS				
	Ref.	STREAM 1	STREAM 2	COMMENT
GNSS-SiS - FFFIS	AREA1	Mandatory	Mandatory	
Other Sensors	AREA1	Optional	Mandatory	The kind and amount of the sensors (e.g. IMU, other) can be different depending on supplier's solution choice
GNSS Augmentation information	AREA 2	Mandatory	Optional	This input is used for increasing the precision of the GNSS info and for increase the GNSS safety integrity level
Digital Map	AREA 2	Mandatory	Mandatory	The digital Map contains the position of all the relevant points (included fixed and virtual Eurobalises)
On Board Input from ETCS	AREA 2	Mandatory	Mandatory	For Stream 1 is the On Board odometric data that include the On-Board Time. For Stream 2 is the On-Board time for synchronization purpose and Eurobalise information
Dynamic Route Info	AREA 2	Mandatory	Optional	
OUTPUTS				
	Ref.	STREAM 1	STREAM 2	COMMENT
Virtual Eurobalises	AREA3	Mandatory	Mandatory	For Stream 1 • Time and Odometer stamp of the detected virtual Eurobalise centre, • The confidence interval associated with the virtual Eurobalise detection accuracy,

				• Eurobalise information (telegram user bits) for the detected virtual Eurobalise. For Stream 2 • Time Stamp of the detected virtual Eurobalise centre (optionally for physical Eurobalise too) • The dynamic confidence interval calculated at the time the virtual Eurobalise is crossed. • Eurobalise information (telegram user bits) of the virtual Eurobalise (optionally for physical Eurobalise too)

Table 4: communalities highlighted in chapter 7

The optional parts can be seen as potential increases in performance depending on the end customer's requests. The fact that additional systems are applied will certainly increase the cost. It will be the responsibility of each supplier to find the trade-off between performance and costs.

8 Future FSTP

Starting from what is described in the previous chapter 7, this chapter represents a solution that tries to harmonize the solutions of the two working streams by making some parts optional. Then the solution gets “common” and compatible with what is foreseen in each stream.

To do this the activities carried out in chapter 7 and in particular in paragraph 7.6 indicate the functions that are certainly overlapping in the two streams, while the others are considered optional.

In line with what is reported in chapter 7 where the FSTP was divided into areas, we proceed with a description of the solution that could be considered harmonized, as mentioned, highlighting the parts that are considered “fixed” with those that can be considered optional in function of the solution selected.

If the FSTP is considered as a black box that must be integrated within the ETCS on-board and trackside system in line with what is reported in chapter 6, it is possible to state that the following Figure 21 represents the envelope of the solutions coming from the two streams.

As indicated in chapter 6, various sensors and functional modules may be present inside the FSTP, but in conclusion the interfaces towards the trackside system and the ETCS On-Board may be those indicated in Figure 21.

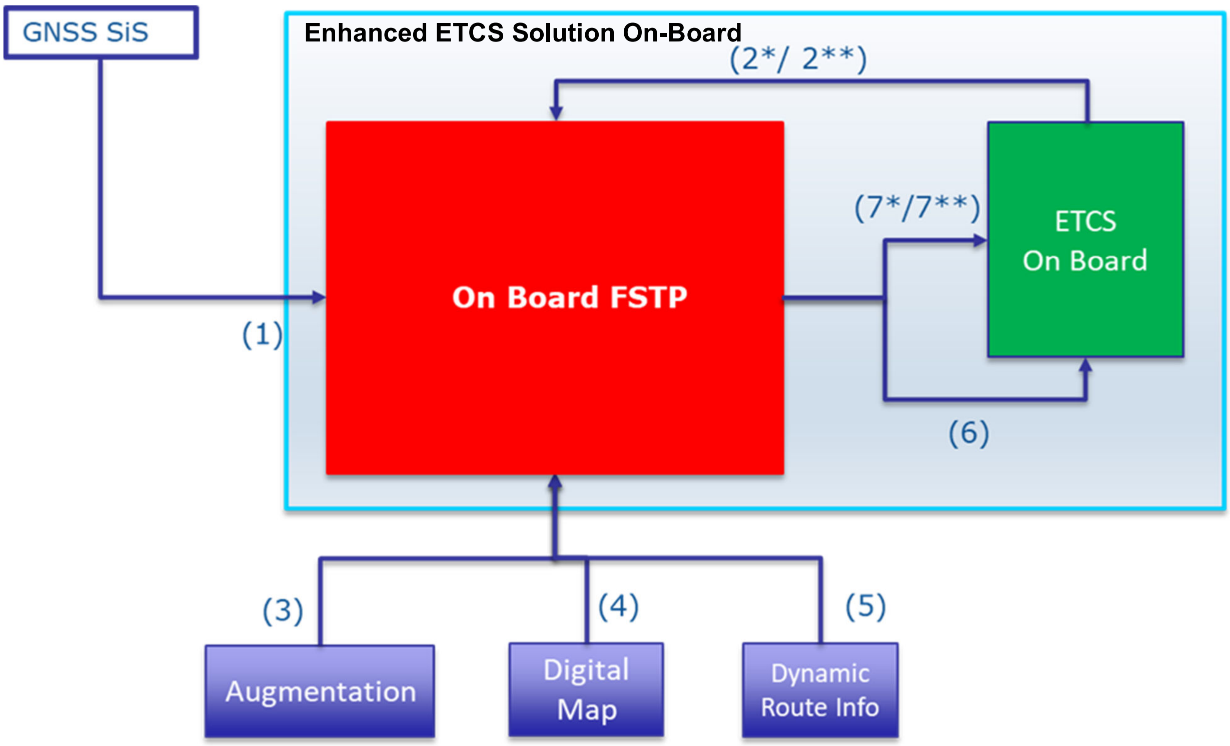

Figure 21: Interoperable FSTP Solution integrated with ETCS On-Board

If the on-board system is considered as a single functional block, then the FSTP solution could be inserted within Enhanced ETCS Solution On-Board. This can be represented by Figure 21.

In Figure 21, a blue box has been identified which only considers interoperable interfaces. For clarity, internal interfaces 2, 6 and 7 do not have an impact on interoperability but certainly on the creation of interfacing with the EVC system.

To then explore the interoperability aspects, the task concentrated only on the interfaces shown in Table 5.

The external interfaces of the Enhanced ETCS Solution On-Board relevant for FSTP integration (with trackside system and satellites) represent the interoperability aspects to be described in a TSI.

To then explore the interoperability aspects, the task concentrated only on the interfaces shown in Table 5.

Interface	Interoperable FFFIS	Mandatory Optional	Description
(1)	YES	M	GNSS SiS
(3)	YES	M (*)	GNSS Augmentation information by FFFIS Radio Link (GSMR or FRMCS)
(4)	YES	M	Digital Map transmission by FFFIS Radio Link (GSM-R or FRMCS)
(5)	YES	O	Dynamic Route Information by FFFIS Radio Link (GSM-R or FRMCS)

Table 5: Enhanced ETCS solution On-Board interfaces

Note: (*) only a company on Stream 2 wants to classify the GNSS augmentation from trackside 5.3.2.2.as optional, because it is confident that the SiS information is enough to reach the performance requirements.

The new FSTP system is obtained by taking the optional and mandatory outputs.

The mandatory interfaces are those that are common to the two solutions, while the optional are those that are valid for one of the solutions.

In this way all needs are covered.

To implement the solution different changes are necessary within the ETCS on-board (see 6.2.2 for Stream 1 and 6.3.2 for Stream 2).

Regarding the internal interfaces shown in Figure 21 variants were under discussion. A decision on a dedicated common solution could be a task for the subsequent design work beyond WP5 on the refinement of the architecture.

The IF variants proposed, are marked by one star (*) for stream 1 and by two stars (**) for stream 2 in Table 6. The internal IF (6) is already agreed in WP5.

Internal Interface	Interoperable FFFIS	Mandatory Optional	Description
(2**)	TBD	M	On Board Time
(2*)	TBD	O	On Board Time, Distance and Speed
(6)	TBD	M	Virtual Eurobalise report • Time and Odometer stamp of the detected virtual Eurobalise centre, • The confidence interval associated with the virtual Eurobalise detection accuracy, Eurobalise information (telegram user bits) for the detected virtual Eurobalise.
(7*)	TBD	M	1D train positioning + confidence interval
(7**)	TBD	O	(i) Speed and its confidence interval with respect to the fixed body frame on the train periodically; (ii) Absolute position and its confidence interval with respect to the fixed body frame on the train periodically; (iii) Travelled distance and its confidence interval since switch on periodically; (iv) Accumulated Travelled distance since switch on periodically; (v) Acceleration value at the fixed body frame on the train periodically.

Table 6: Discussed Internal Interface variants for Enhanced ETCS solution On-Board

9 Cost Benefits and Impact Analysis

For what concerns the Cost Benefit Analysis, WP5 took into consideration the outcomes of X2R2 WP3, which produced a dedicated document on the subject, namely D3.3 [3]. Such document describes and documents the wider activity carried out by GSA, which deeply analysed the Cost Benefits of the FSTP by considering several operative scenarios and by investigating the economic benefits over a line of 100km; the analysis takes in charge the perspective of three different railways stakeholders: Infrastructure Managers, Railway undertakings and Industrial Suppliers. D3.3 [3] complements the analysis by deepening the ERTMS business model and analysing the impact of the Virtual Balise solution on it.

The sources of the above-mentioned analysis include the STARS deliverables, which also enclose a well-defined analysis on the operative scenarios and economic target to be applied. In particular, STARS document D6.2 [24] exploits the case studies, while D6.3 [25] focuses on the related impact analysis.

As per the section 11.2.39, the X2R2 Document [3] (including the attachment related to the GSA deliverables) beyond the description of the scenarios and contexts for the CBA, depicts the economic analysis from the perspective of Infrastructure Managers, Railway Undertakings and Industrial Suppliers by describing the computation of costs (€ per 100km) and benefit, as well as the calibration of the model used. At completion of the description also the alongside sensitivity analysis and final conclusion are present.

X2R5 WP5 evaluated those findings and integrated them with the analysis of the impact of the introduction of the FSTP concept into the ETCS system. Referring to the evaluations performed in section 6.2.2 for Stream 1 and in section 6.3.2 for Stream 2, and combining the analysis of the impact of each solution to build the future FSTP, WP5 came to the solution described in chapter 8, which is interoperable and adaptable through the use of the optional components and interfaces in order to reach the desired trade-off between the costs, benefits and impact, taking into account the incremental introduction of the system into existing lines.

In all cases, the overall impact of the solution consists in the reduction of physical Eurobalises, which can be achieved both with the replacement of physical Eurobalises with virtual balises, and with the enhancement of the odometry performance. This will reduce management costs while maintaining the same level of safety.

One of the advantages is that, while different confidence intervals may be used in relation to the different type of balises, the management of the balises (whether physical or virtual), does not change. Another advantage is that with the introduction of new technologies there is an increase in the accuracy of train location.

Moreover, in the framework of the standardization activities carried out in the X2Rail-5 WP5 Task 5.2.3 (see document [21]), the evaluation of some specification-related aspects linked to interfaces relevant for interoperability (i.e. GNSS Augmentation and Digital Map) has been provided, to estimate the impact of the proposed solutions with respect to the possible benefits deriving.

As example, a comparison between the two candidates for representing the railway track (namely, point-based versus vectorial-based track axis representation) was developed, basing the cost-benefit analysis on a common set of features (such as accuracy, amount of data to storage, impact on on-board to process DM data, scalability, etc.).

The system, described in chapter 8, relies mainly on existing interoperable interfacese, with minimal requirements for creation of new interfaces with the EVC system. Based on these considerations, the steps for reaching a common FSTP solution to optimize the cost, benefits and impact trade-off are described in the following Chapter 10.

10 Migration Strategy and Roadmap

Starting from the current TSI (no newer than TSI 2023) this chapter describes the migration strategy to introduce the FSTP described in chapter 8 into a future CCS.

Since we will not have the precise definition of how the future CCS will be, it will be important to highlight the constraints and limits that the FSTP introduces, and it will be indicated whether it will be a backwards compatible solution.

Since what is described in chapter 8 has an impact on both the on-board and trackside systems, the suggested approach is to follow what is normally done for the introduction of a new ETCS version described in the CCM process. This is an established accepted procedure in use in all European countries.

Backward and forward compatibilities are analysed in the following 2 sub-chapters.

10.1 backward compatibility

It should be considered that solution described in chapter 8 provides that, from a functional point of view, there are no changes to the principle of the ETCS system, i.e. onboard backward compatibility is guaranteed with respect to the ETCS version in use at the time of the update.

The moment in which this D5.5 is drawn up is therefore considered as the moment of evaluation of the Migration process.

Given these premises expressed chapter 8, the process must include the following steps:

1. Consolidation of functional and non-functional specifications and execution of tests in order to consider the FSTP system requirements suitable for inclusion in the TSI. This path is partly included in the Europe's Rail project which continues the activities carried out in Shift2Rail.
2. Inclusion of the solution in the official TSIs. As known, when the solution is included in the TSI can it be taken as a reference and used for tenders involving lines that have interoperability implications. Actually art. 11 of new Regulation 2023/1695 opens additionally the possibility to also use an ERA Opinion as long as the upgrade of the TSI is pending.
3. implementation of the solution on lines in commercial service. This is the last step but extremely important because European Signalling Stakeholders move on to the intensive application of the proposed solution.

From a preliminary analysis done in this project (X2Rail-5 WP5) on how the system described in chapter 8 is designed, the introduction of the new version of the system will have to be done first on the entire fleet of trains that will have to interact with the lines that will be upgraded.

This event can be deferred over time, in the sense that it is not necessary to update the fleet at a specific time because backward compatibility with the ETCS version in use on the line is guaranteed and therefore the functions that are foreseen/described in chapter 8 and in the rest of the document are additional and do not prevent vehicles to continue to run on existing infrastructures. It is assumed (the task did not go into this detail) for example that communication messages and packets will be added to the EURORADIO protocol, but these will only be operated by the trackside system (basic communication system) when it is updated. In the meantime, these packets (track to train and vice versa) a will not produce any exceptions for the new on-board system when running on lines not using them.

Following the approach described, which is in line with the ETCS upgrade strategy for new backward compatible versions, the migration should not have a particular impact on the system consistently in use.

10.2 forward compatibility

For the introduction of FSTP a solution similar to that one adopted for the new SM mode, can be adopted, in which can be implemented trackside with SV 2.3 (therefore not excluding vehicle SV 2.1 and 2.2 to continue to circulate) and, when decided that vehicles without SM cannot run anymore (because IM is going to remove shunting signals), trackside SV is increase to 3.0.

If we allow trackside to start implementing FSTP interfaces while keeping physical Eurobalises, we can deploy FSTP in parallel on OB and trackside (allowing FSTP trains to start getting some benefit in terms of performances) and then, when it is agreed between IM and RUs that vehicles not equipped with FSTP shall not run anymore on that line, physical Eurobalises are removed and trackside SV X incremented in order to impede operation of vehicle without FSTP (and therefore with lower SV).

10.3 Roadmap to a common FSTP

For reaching a common FSTP solution by the WP5, the following steps are identified:

1. Define common functionalities.
2. Obtain interoperable IFs (airgap) (On-Board and trackside)
3. Identify On-board IF standardisation (internal On-Board interfaces (see Subset-119)) Functional Interface maybe not for standardisation. Just provide the interface between the different functional blocks (to provide an overview of them)

The first two steps are reached within WP5 in particular:

1) identification of the communalities between the streams
2) the specification of the interface which have impact on the interoperability see [21].

The third step should be solved after the clarification regarding the On-Board architecture and when the interfaces are investigated more.

The future activities for the introduction of common FSTP are:

- Interoperable IFs (Complete list of the interfaces) Track side DM, EuroEurobalise (no impact - no modification), (Dynamic Route Info), GNSS Augmentation
- Functional blocks for the future architecture.
- The on-board interfaces: ODO, Eurobalise Reader, Virtual Eurobalise Reader, GNSS receiver

11 Conclusion

This document reports the results of the activities carried out in sub-task 5.3.2 of the X2Rail-5 WP5 to analyse the possible commonalities and synergies between Stream 1 and Stream 2, in order to provide an overall concept of how Satellite-Based Fail-Safe Train Positioning systems could be integrated in CCS systems.

In particular, big effort has been spent in consolidating an effective proposal for the integration of a Stream 2 FSTP (i.e., Stand-Alone FSTP) in the ERTMS/ETCS system (see section 6.3). The resulting solution foresees the introduction of a new “Eurobalise Telegram Reporter” functional block whose functional outputs are analogous to those provided by the “Detect Virtual Eurobalise” functional block of the Stream 1 FSTP in the ERTMS/ETCS (see section 6.2).

Given this, both Streams foresee the presence of following location related functional blocks in the framework of the overall ERTMS/ETCS on-board:

- **Odometry**, for computing and providing at regular intervals measures related with the train’s movement along the track, at least in terms of current time, speed and travelled distance, together with their confidence intervals ([20]);
- **Eurobalise Transmission Module**, for processing data from the Eurobalises passed over and providing their telegrams, associated to the location information of the Eurobalise reference mark in the time and odometer reference system originated from the ERTMS/ETCS Kernel ([13]);
- **Virtual Eurobalise Reporter**, for providing a Eurobalise telegram, associated to the location information of the Eurobalise reference mark, whenever the train crosses a reference location defined in the Digital Map (see sections 7.6 and 8).

Moreover, in order to enable the Virtual Eurobalise Reporter functionality, both Streams foresee to estimate at regular intervals absolute position of the train along the track defined in the Digital Map. This functionality may eventually be used also in the framework of the ERTMS/ETCS, in case absolute location principles based on reference points other than the Eurobalises (Eurobalises and/or Virtual Eurobalises) would be considered to be convenient in future CCS systems.

Given this, at this level, the two Streams converged to an aligned functional architecture for the location related functional blocks of the future ERTMS/ETCS on-board. Some architectural differences between the two Streams come out when a physical architecture is defined.

In Stream 1, even if a physical architecture is not in the scope of the specification, ERTMS/ETCS Odometry and BTM functions are not supposed to be modified due to the introduction of the Virtual Eurobalise Reporter.

On the other hand, Stream 2 proposes to integrate the Odometry in the FSTP, together with the Virtual Eurobalise Reporter (and eventually the Eurobalise Transmission Module). This approach would allow to improve modularity but has a bigger impact on the ERTMS/ETCS on-board, where a new “Integrator” function is supposed to be implemented to properly manage the FSTP (see 6.3.1).

As for the interoperability, the following interfaces have been identified (see section 8):

- GNSS SiS;
- GNSS Augmentation;
- Digital Map;
- Dynamic Route Information.

Detail on the activities performed and reached results, as well as further actions/decisions needed to include Satellite-Based Fail-Safe Train Positioning systems in the CCS system, are deeply investigated in D5.3: Contribution to the standardisation activities [21]).

In particular, GNSS SiS/Augmentation and Digital Map have been confirmed to be fundamental information to implement Satellite-Based Fail-Safe Train Positioning, whereas Dynamic Route Information is currently considered mandatory only for Steam 1.

Finally, high level description of a possible migration strategy, based on the same criteria consolidated in the ERTMS/ETCS framework, has been proposed in section 9.

12 References

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[7] X2R2 D3.8 Stand Alone System Requirements Specification for Fail-Safe Train Positioning V 06

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[21] X2R5 D5.3 Contribution to the standardization activities V1

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[23] SBAS DFMC Receiver Guidelines for Railway–Trackside Unit, ESSP-TN-26137, Iss.01-00, 08/07/2020

[24] STARS D6.2 - Cost-Benefit Analysis: Case studies V 08

[25] STARS D6.3 - Impact analysis V 05

Appendix A: Ownership of results

The following Table 7 lists the ownership of results for this deliverable.

Ownership of results			
Company	Percentage	Short Description of share/ of delivered input	Concrete Result (where applicable)
ALS			
AZD			
BT			
CAF			
EUG			
HITACHI			
THALES			

Table 7: Ownership of results

This deliverable is jointly owned by the organisations listed above. The last three columns in the table are intentionally left empty.

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