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1 Executive Summary

This document reports the activity related to subtask 5.2.3 “Contribution to the standardisation activities – Application definition and Specifications” as part of Task 5.2 “Train Positioning Specification” of WP5 “Fail-Safe Train Positioning Specification”.

Starting from ERTMS Change Request CR1368 [1], the deliverable focuses on the interoperability relevant elements of the GNSS-based Fail Safe Train Positioning -FSTP- that need of a standardisation effort, including Digital Map –DM- and GNSS Augmentation – GA-.

During the execution of the first phase of subtask 5.2.3, the members of the X2R5 WP5 faced on preliminary evaluation of inputs coming from MoU [2] and Concept Paper [3] provided by JWG, besides the feedback received by other WP5 tasks (e.g. T5.3.1) and WPs (i.e. WP6 and WP7). The resultant comments were discussed and shared within JWG with the aim of consolidating/refining the Concept Paper.

In a subsequent phase, the effort was aimed to critically analyse the EUG/ESSP/ESA/GSA documentary package on the GA for ERTMS/ETCS in support of CR1368. The package is comprised of the following documents:

- GNSS Augmentation for ERTMS/ETCS – System Requirement Specification [4]
- GNSS Augmentation for ERTMS/ETCS – Interface Control Document for GA-OB/GA-TS (Airgap) [5]
- SBAS L1 Receiver Guidelines – On-board [6]
- SBAS L1 Receiver Guidelines – Trackside [7]
- SBAS DFMC Receiver Guidelines – On-board [8]
- SBAS DFMC Receiver Guidelines – Trackside [8]
- GNSS Augmentation for ERTMS/ETCS – System Functional Hazard Analysis [9]

To evaluate the specifications and their applicability for satellite-based FSTP, technical discussions started firstly in WP5 and then followed by ad-hoc meetings with EUG and space sector (namely with ESA e EUSPA experts) to present the point of view of the rail sector on a set of technical key concepts.

This process of continuous comparison held among WP5 partners, WP5/JWG and WP5/ESA/EUSPA brought the identification of the strategic issues to provide a framework to support the use of GNSS Augmentation System such as EGNOS (the European Geostationary Navigation Overlay Service), with the consequent evaluation of responsibility and commitment to be assumed by rail and space sectors to accommodate CR1368.

The resulting document D5.3 collects the main issues related to the technical key concepts dealing with EGNOS services integration for rail safe applications, providing the rail point of view and the linked ESA/ESSP or GSA feedback or action.

In the last phase of X2R5 project, the WP5 members investigated another topic considered crucial for future TSI. It is the DM, intended as "*a set of functionalities providing track and trackside infrastructure information in the form of structured Map Data, including quality criteria for the data. In addition, it also ensures map management functionalities like map versioning, and download of Map Data*." [11].

As done for the analysis on GA systems and the related data to be managed, WP5 technical discussions on DM started on basis of the investigation of its state of the art concerning, extensively described by the following RCA documents:

- Documentation focused on the Overall Map Data process/structure (data preparation, publishing to trackside, publishing to on-board):
    - Solution Concept MAP [12]: Overall concept regarding Digital Map goals and high-level process/requirements.
    - Digital Map Object Catalogue [13]: Unified data model to be used for the data provisioning to all subsystems;
    - Digital Map Evaluation Reference Model [14]: Reasoning about the used data model approach;
    - Digital Map Quality Framework [15] and Annex A [16]: definition of data quality, discussed process to maintain data quality.

- Documentation focused on the airgap part (providing Map Data from trackside to on-board):
    - Digital Map System Definition [17];
    - Digital Map Evaluation Publish On-board Map Approaches [18]: reasoning for decisions within system definition;
    - Digital Map Concept [12]: Initial Concept focused on airgap as input for system definition.

Given the context under evaluation, the focus was on localization functionality, in the actual architecture which is based on the existing ERTMS/ETCS along with the introduced game changers of GNSS-based FSTP. The attention was on both the structure and content of DM, as well as its distribution mechanisms for making available the DM data to on-board localization from trackside.

The initial version (i.e. 00) of the document, was focused on the first topic of GNSS Augmentation. In the subsequent release of D5.3 (i.e. 01 version) the focus– and therefore its revision – is shifted towards the completion of the description of activities undertaken in T5.2.3 task. This includes evaluations related to the second topic of interest, namely DM, as well as concluding chapters (from chapter 9 onwards, as indicated in the table of contents).

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3 Abbreviations and acronyms

Abbreviation / Acronyms	Description
CED	Clock and Ephemeris Data
CR	Change Request
CRC	Cyclic Redundancy Check
CT	Cooperation Tool
DFMC	Dual Frequency Multiple Constellation
DFRE	Dual Frequency Range Error (dual frequency UDRE)
DM	Digital Map
EGNOS	European Geostationary Navigation Overlay Service (SBAS developed by the European Union)
ERTMS	European Rail Traffic Management System
ESA	European Space Agency
ESSP	European Satellite Services Provider
ETCS	European Train Control System
EUSPA	European Union Agency for the Space Programme (formerly European GNSS Agency)
EVLF	Enhanced Vehicle Localisation Function
FRMCS	Future Railway Mobile Communication System
FSTP	Fail-Safe Train Positioning
GA	GNSS Augmentation
GAC	GNSS Augmentation Channel
GADF	GNSS Augmentation Dissemination Function
GAM	GNSS Augmentation Message
GA-OB	GNSS Augmentation On-board
GAS	GNSS Augmentation System
GATF	GNSS Augmentation Trackside Function
GA -TS	GNSS Augmentation Trackside
GEO	Geostationary Earth Orbit
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICD	Interface Control Document
IP	Innovation Pillar
JWG	Joint Working Group
MOPS	Minimum Operational Performance Standard
NLES	Navigation Land Earth Station
NPA	Non-Precision Approach
PDM	Position Domain Monitoring
PRIR	Pseudorange Integrity Risk
PRN	Pseudo-Random Noise
RTCA	Radio Technical Commission for Aeronautics
SBAS	Satellite-Based Augmentation System
SiS	Signal in Space
SFHA	System Functional Hazard Analysis
SNT	SBAS Network Time
SoL	Safety of Life

SP	System Pillar
SRS	System Requirement Specification
THR	Tolerable Hazard Rate
TSI	Technical Specification for Interoperability
TTA	Time To Alert
UDRE	User Differential Range Error
UTC	Universal Time Coordinate

4 Background

GNSS-based localization is a standard approach in several domains, including aerial, maritime, and automotive transportations. The use of Differential augmentation GNSS (DGNSS) and augmentation systems (e.g. SBAS) allows improving the localization performance by reducing local errors in the PVT (Position, Velocity, Time) estimation.

In the aforementioned application context, the Minimum Operational Performance Standards (MOPS) are well known and specified. The related GNSS receivers must be compliant with such requirements. For instance, the RTCA DO-229 MOPS regulates the airborne navigation equipment using the Global Positioning System (GPS) augmented by Satellite-Based Augmentation Systems (SBAS).

The use of SBAS corrections for train positioning has brought the attention of railway stakeholders that are interested to complement and enhance the DGPS-based positioning solution. EGNOS, as SBAS, delivers an integrity monitoring service and could improve the availability and preserve the accuracy for safety critical applications such as railway signalling.

The lack of standards for the use of SBAS and GNSS in the railway context is a current problem. This means that there are no specific guidelines or regulations that establish how to properly use these systems for the navigation and monitoring of trains. Furthermore, the way in which GNSS-related information should be integrated and managed into the DM is not defined or standardized. This can create difficulties in understanding the information provided by GNSS and using it to make decisions about train localization. This lack of standardization can result in a lack of consistency and uniformity in how railway operators use and interpret GNSS, with possible implications for the safety and reliability of the railway system.

As a result, it is necessary to develop specific standards and guidelines for the use of SBAS and GNSS in the railway context in order to ensure the safety and efficiency of these systems in the railway industry. Document D5.3 is aimed in this direction, providing a contribution to the standardization activities related to GA and DM.

The document includes: 1) Report on the collaboration and contributions to the EUG-S2R Joint Working Group (JWG) with the focus on GA and DM; 2) Initial draft inputs to the future TSIs.

It constitutes the issue of WP5 Deliverable D5.3 in the framework of the Project titled “Completion of activities for Adaptable Communication, Moving Block, Fail safe Train Localisation (including satellite), Zero on site Testing, Formal Methods and Cyber Security” (Project Acronym: X2Rail-5; Grant Agreement No. 101014520).

5 Objective/Aim

This document is a deliverable of the work performed in X2RAIL5 WP5 (Fail-Safe Train Positioning Specification) and it describes the analysis, revision and consolidation process followed within the subtask 5.2.3 on the more critical issues to close technological gaps and to easy the progress towards the integration of EGNOS service for safe train localization within ERTMS.

6 Introduction

The use of GNSS technology for railway signalling is promoted by ERA, working together with rail and space industry stakeholders, as a Game Changer in the ERTMS context and it is to be included in the TSI CCS [19].

In principle, both current proposed solutions (named Stream 1 and Stream 2 to indicate the introduction of Virtual Balise – VB- concept and the stand-alone solution, respectively) integrate the GNSS/SBAS data into current ERTMS/ETCS functional architecture for computing the safe train position.

The impact of the proposed solutions has been investigated in the past in different R&D initiatives performed under Shift2Rail and EU-Rail.

This deliverable is inserted in this evaluation, focusing on the following topics, relevant for the interoperability:

- **GNSS Augmentation**, namely a new GNSS data category provided by GA systems - such as EGNOS- consisting of ground stations at known positions that receive and process navigation signals from core GNSS constellations, with the objective of protecting users from feared events, estimating common errors and providing differential corrections and integrity information to improve accuracy of enhanced on-board localization functionality.

- **Digital Map**, namely on-board map needs to translate a GNSS referenced position into an “along the track” position and possible further related information.

Section 5 of this document states the objectives and aims of the document.

Section 6 (i.e., this section) provides an introduction and overview of topics explored in the following chapters.

Section 7 describes the preliminary investigation conducted by WP5, with the aim of becoming fully aware of the principles and needs to promote progress in the specifications concerning GA e DM.

Section 8 contains detailed report of the contribution provided by WP5 on GA topic, with an in-depth analysis whenever possible to share the main considerations derived by technical discussions.

Section 9 will report the considerations resultant from DM-related discussions.

Section 10 highlights the steps taken in view of the inclusion of GNSS technology and Digital Map data into ERTMS/ETCS localization functionality with reference to next TSI.

7 MoU and Concept Paper: WP5 Analysis

Considering the need to identify the boundaries and the constraints for the standardization of GA and DM, the first evaluations among the rail suppliers represented within WP5 started with a focus on [2] and [3]. As direct result of this evaluation process, through strict interactions with the JWG and using CR 1368 as the starting point, a consolidation was reached on the principles to be adopted and the activities to be performed concerning digital map and augmentation to easy the inclusion in medium/long term of satellite technology in the CCS TSI.

The first evaluation phase of the topics under analysis has shown the need to specify the informational content of the SBAS and essential GNSS services to benefit from this new technology for train positioning. After consolidating how this information flow should be managed (for example, transferring information between trackside and on board through appropriate interfaces), the related functions/sub functions have been consolidated. This has led to the identification of functional context and potential functional interfaces for GNSS augmentation system based on EGNOS, and therefore to the definition of the functional architecture (see Figure 6) to consider as reference for subsequent activities.

At the end, the need to integrate the management of key information into the relevant data structures, primarily in the DM, was highlighted. This brought to plan within WP5 discussions mainly aimed to consolidate and specify the dataset necessary for localization functionality, and as consequence how this should be lowered into the current formalism used for the DM and how it should be represented on the railway line.

All the above considerations have led to the activation of the activities on GA and DM that are reported in the following chapters.

8 Focus on "GNSS Augmentation": Report on the collaboration and contributions to EUG-S2R JWG

In the following sections, the used approach to investigate the GA related topic is shown; then, a detailed report of the contribution provided by WP5 members on this is provided, with an in-depth analysis whenever possible to share the main considerations derived by technical discussions.

8.1 WP5 Review process on ESA/GSA/ESSP Documents on Augmentation

The investigation of the GA services and their integration impact on the satellite-based FSTP solution was focused on a review process of a document pack shared by the JWG on GNSS Augmentation ([4] to [10]). This revision process consisted of two steps:

a) in March 2021, WP5 performed a high-level evaluation of the documents, in order to provide initial feedback to JWG and define if dedicated meetings have to be organized with ESA (for technical comments/questions) or with EUG (for conceptual comments or questions about the CR process, TSI, etc.).

b) by May 2021 until the end of 2022, WP5 performed a deeper analysis of the documents, and defined on which inputs focus the T5.2.3 activities.

The comments were provided in review sheets with the following new categorization:

- [Understanding]: Requests for clarification, misunderstandings.
- [Mistake]: Mistakes
- [Low-level/technical issues]: Lower-level technical comments
- [Assumptions/principles]: High-level aspects, which have an impact on the mechanisms to be analysed.
- [Mechanisms/Approaches]: Issues about proposed mechanisms and/or approaches

The comments closed through exhaustive answers of the authors in the review sheets can be consulted in the CT at the following links:

- For GNSS Augmentation for ERTMS/ETCS – SRS [4] and ICD [5] and SBAS L1/DFMC receiver Guidelines [6][7][8][9]:

  https://www.cooperationtool.eu/projects/goto.aspx?p=X2RAIL-5&doc=51fe07bb-ee50-46c2-8a18-69ac9a40d95c

  and

  https://www.cooperationtool.eu/projects/goto.aspx?p=X2RAIL-5&doc=b7a6a3a7-a07b-4a66-859b-14ee0ff49197

- For SFHA [10] document: *https://www.cooperationtool.eu/projects/goto.aspx?p=X2RAIL-5&doc=bb9a06f4-9159-4571-ad2d-3530cea0b34e*

and

https://www.cooperationtool.eu/projects/goto.aspx?p=X2RAIL-5&doc=ca4288db-1195-45bb-91fd-d403f97af67d

On the other side, the discussions on “Assumptions/Principles” and “Mechanisms/Approaches” comments brought to identify a set of key concepts by WP5 members to be investigated in more detail with ESA/ESSP/GSA. In the next section, these topics are exhaustively described, providing also the final notes derived from technical discussion.

The consequence of this review process was an iterative update of the GA-related package to keep into account the main comments.

To be noted that at the time of writing this document, the most updated versions of this documentary set are under investigation in other contexts, for example becoming an input of the System Pillar and R2DATO project.

8.2 Receiver Guidelines for Railway: in depth analysis

8.2.1 Document Overview

Four different receiver guideline documents have been drafted by ESSP as follows:

- SBAS L1 Receiver Guidelines for Railway – On-Board Unit [6]
- SBAS L1 Receiver Guidelines for Railway – Trackside Unit [7]
- SBAS DFMC Receiver Guidelines for Railway – On-Board Unit [8]
- SBAS DFMC Receiver Guidelines for Railway – Trackside Unit [9]

Their purpose is to provide preliminary receiver requirements for the On-board and Trackside units that will be used to support safe train positioning in ERTMS, assuming the use of EGNOS.

8.2.2 Technical Key Concepts

8.2.2.1 GNSS RX Design and Constraints

The X2R5 WP5’s review of the receiver guidelines for railway focused on the impact of design constraints that have been inherited from the civil aviation MOPS, questioning whether they are appropriate in the rail case.

8.2.2.1.1 Smoothing filter

The approach taken by ESA/EUSPA/ESSP in the on-board receiver guidelines has been to state the assumptions made at system side concerning the smoothing filter, including reference to an acceptable implementation, and make it the responsibility of the supplier to justify that any deviation from this is safe.

The X2R5 WP5 team questioned whether further commitments should be made, or minimum performance levels defined for the use of alternative filters.

ESA and EUSPA explained that there are two aspects to address:

1) An inflation factor may be applied to the UDRE/DFRE in case a shorter weighting function time constant is used.
2) If a time-varying filter is used, then the transient function of the error must be addressed during convergence time.

They also discussed the possibility of defining test sequences for verification of a specific implementation and providing guidelines in an annex of the documents.

8.2.2.1.2 EL correlator

The X2R5 WP5 team asked for further clarification on the guidelines concerning the Early-Late correlator, including how COTS receivers may be utilised/chosen.

ESA/EUSPA explained that the constraints in the guidelines, inherited from aviation MOPS, relate to assumptions for protecting the user against signal distortion feared events. As an alternative, the supplier may implement Signal Quality Monitoring (SQM) in the receiver as a barrier, if it can be justified with relevant allocations in their safety case.

ESSP stated that the possibility of a relaxation may be discussed. In the DFMC on-board guidelines [8], a new requirement should be included to ensure that the receiver considers/complies with Section 2.3.1.1.2, with the design constraints in Section 2.3.1.1.3 being possible solutions to this.

8.2.3 Next Steps: Open Points to be addressed in Future Iterations of the Specification

As described in Section 8.4.3, the updated SRS includes a list of open points. Some of these are applicable to the receiver guidelines documents, namely:

- Validation of tropospheric model for railway (see Section 8.4.2.2).
- Development of guidance on how to deviate from prescribed critical user receiver parameters in a controlled manner to ensure integrity requirements are met.
- Update of EGNOS railway receiver guidelines (MOPS) for GA-OB and GA-TS (see Section 8.2).
- Requirement for at least 2 available SBAS GEO signals for selection of GAC (see Section 0)
    - Applicable to Trackside guidelines.

- Support for reception of SBAS SIS directly by EVLF (see Section 8.4.2.1.2).
    - Applicable to on-board guidelines.

8.3 SFHA: in depth analysis

8.3.1 Document Overview

A System Functional Hazard Analysis (SFHA) has been drafted[23], its scope being to define generic high-level quantitative safety requirements that must be fulfilled to provide interoperable GA for ERTMS/ETCS and addressing the specificities of GA based on an EGNOS railway SoL service. This document has already been updated based on the review performed by the X2R5 WP5 members. A description is provided below of the topics covered in this review process.

8.3.2 Technical Key Concepts

8.3.2.1 THR Apportionment PRIR: Pseudorange integrity risk

The X2R5 WP5 requested an explanation of the proposed THR apportionment indicating that the proposed THR seems too stringent, and whether there were considerations to possibly relax the THR apportionment, given the augmentation system THR. ESA clarified by providing the following explanations and definitions on THR apportionment for PRIR (Pseudorange Integrity Risk). At the conclusion of the meeting the explanation provided was accepted by WP5 and ESA took an action to update the SFHA accordingly.

The safety target for the GA transmission channel (end-to-end, non-trusted parts) is allocated as 4% of the safety target for the GA top-level level hazard, such that:

i. THR_PRIR = 5.0E-6 / hour
ii. THR_TRANS-HAZ = 2.0E-7 / hour
iii. (Transmission channel hazard TRANS-HAZ is apportioned between trusted and untrusted parts as per EN50159).

An initial PRIR THR apportionment is detailed below:

ID	Gate / Event	Description	Allocation (THR)
PRIR	**Pseudorange integrity risk (correction residual or ionospheric residual error bout bound and TTA > T_NVGAMAXTTA**	**Top level GA hazard and THR allocation**	**5.0E-6 / hour**
PLIR	Protection level integrity risk (fault-free conditions)	Performance supported by SBAS	2.4E-6 / hour
SGIR	Integrity risk due to SIS / ground fault conditions	Performance supported by SBAS	2.4E-6 / hour
GA-TS	Integrity risk due to GA trackside (including trusted part of the GA transmission channel)	Preliminary allocation	1.1E-8 / hour
GA-OB	Integrity risk due to GA on-board (including trusted part of the GA transmission channel)	Preliminary allocation	1.0E-8 / hour
TRANS-HAZ	Integrity risk due to hazards from GA transmission channel (non-trusted part)	Preliminary allocation	2.0E-7 / hour

Table 1: Initial PRIR THR apportionment from SFHA Annex B.2 [10]

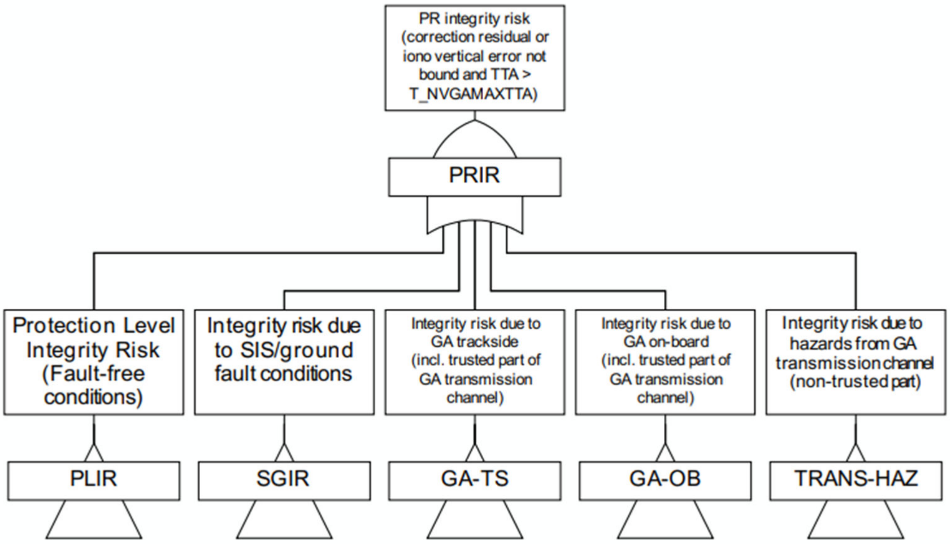

Figure 1: Example Fault Tree for PRIR from SFHA Annex B.2 [10]

The term TRANS-HAZ is used for the integrity risk due to hazards from GA transmission channel (non-trusted part).

TRANS-HAZ is apportioned between:

a. CH/SBAS-GATF: SBAS SIS to GATF transmission channel
b. CH/GNSS-GATF: GNSS to GATF transmission channel
c. CH/GADF-EVLF: GADF to EVLF transmission channel
    i. The TRANS-EVLF/RADIO-1 and TRANS-GADF/RADIO-1 allocations reflect the bi-directional nature of the radio link and that the potential for corruption is present in either direction (GADF to EVLF or EVLF to GADF).
    ii. Assumption of performance of EURORADIO protocol – from SUBSET-091:
        a. The requirement for the non-trusted part of OB-EUR-H4 is that the non-trusted ETCS on-board radio transmission equipment shall respect the definition of non-trusted as given in paragraph 5.1.1.6 and the THR of 1.0E-11 dangerous failures / hour
        b. The requirement for the non-trusted part of TR-EUR-H4 is that the non-trusted ETCS trackside radio transmission equipment shall respect the definition of non-trusted given in paragraph 5.1.1.6 and the THR of 1.0E-11 dangerous failures / hour
d. CH/GNSS-EVLF: GNSS to EVLF transmission channel

ID	Gate / Event	Description	Allocation (THR)	Estimated HR
CH/SBAS-GATF	SBAS SIS to GATF transmission channel	Preliminary allocation	7.4E-8 / hour	7.36E-8 / hour
CH/GNSS-GATF	GNSS to GATF transmission channel	Preliminary allocation	2.5E-8 / hour	2.35E-8 / hour
CH/GADF-EVLF	GADF to EVLF transmission channel (bi-directional)	Preliminary allocation	2.0E-11 / hour	2.0E-11 / hour
CH/GNSS-EVLF	GNSS to EVLF transmission channel	Preliminary allocation	9.1E-8 / hour	9.07E-8 / hour
		Margin	1.0E-8 / hour	
TRANS-HAZ	Total estimated HR for GA transmission channel (non-trusted part)		2.00E-7 / hour	1.88E-7 / hour

Table 2: Initial TRANS-HAZ THR apportionment from SFHA Annex B.2 [10]

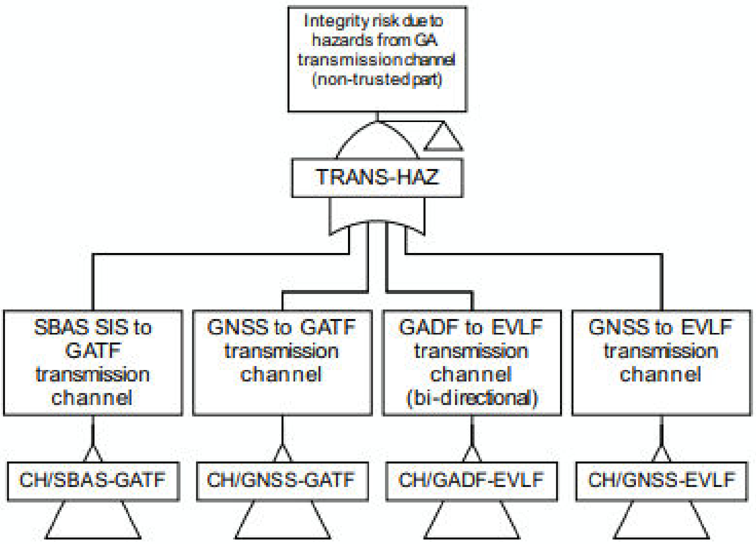

Figure 2: Example Fault Tree for TRANS-HAZ from SFHA Annex B.2 [10]

However, if required, the THR can be relaxed:

a. Based on THR allocation, margin could be utilised, allowing a target of 1E-8 / hour for corruption of radio messages
   i. Allocation of 5.0E-9/h to TRANS-EVLF/RADIO-1
   ii. Allocation of 5.0E-9/h to TRANS-GADF/RADIO-1

b. Based on estimated hazard rate, up to 1.2E-8 / hour could be utilised.

Assumptions seemed reasonable; however, if required, there is scope to relax THR based on results of the initial apportionment exercise: a) Based on THR allocation, margin could be utilised, allowing a target of 1E-8 / hour for corruption of radio messages i. Allocation of 5.0E-9/h to TRANS-

EVLF/RADIO-1 ii. Allocation of 5.0E-9/h to TRANS-GADF/RADIO-1 b) Based on estimated hazard rate, up to 1.2E-8 / hour could be utilised.

8.3.2.2 Justification on PRIR

The X2R5 WP5 requested additional reference material on the PRIR parameters. ESA provided the following explanations and definitions for the justification on PRIR. At the conclusion the explanation was accepted, and it was suggested that depending on the acceptance process, it is conceivable that a safety manual would be developed - e.g., considering “use of pre-existing items developed in accordance with other safety standards” in EN 50129 and IEC 61508 (safety manual is defined in IEC 61508).

The justification on PRIR is as follows:

A structured hierarchical approach is taken for the identification of hazards at different boundaries:

a) Boundary of the ERTMS/ETCS system.
b) Boundary of the enhanced vehicle localisation function (EVLF); and
c) Boundary of the GA framework for ERTMS/ETCS.

There is currently no defined architecture for ERTMS/ETCS with the EVLF

a) EVLF only defined to the extent needed for supporting GA-OB functions.
b) Hazards identified at boundary of GA framework for ERTMS/ETCS are linked to relevant hazards at the ERTMS subsystem level considering an EVLF using GNSS and the GA framework for ERTMS/ETCS for determination of the train position.
    i. ERTMS safety analyses (Subset-088-2 part 1) used to establish link between relevant ERTMS/ETCS subsystem hazards and system hazards (ETCS Core Hazard).
c) Scope is not to build completely fault free, rather support preliminary analyses.

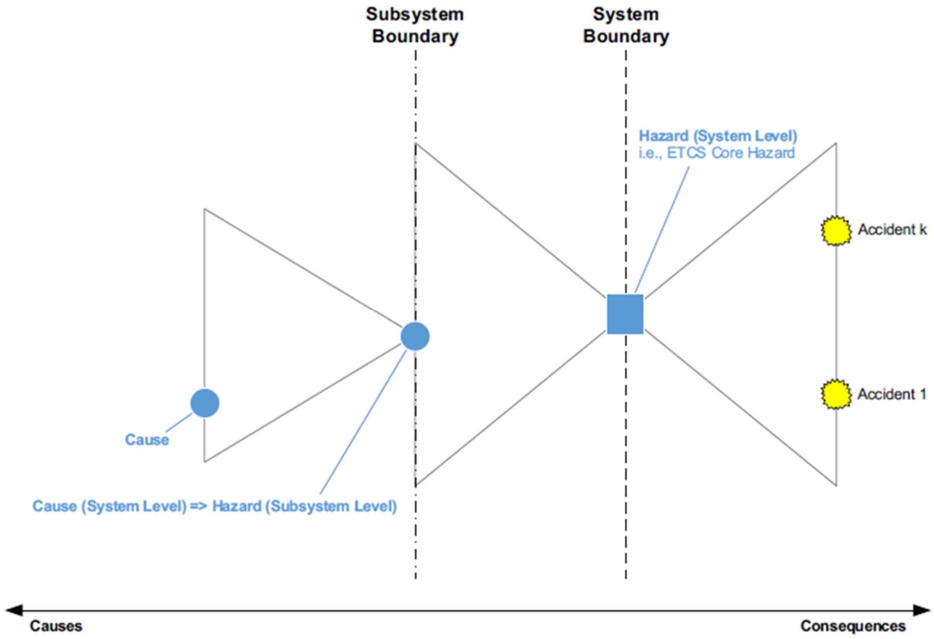

Figure 3: Identification of hazards at different boundaries [10]

The intermediate EVLF hazard IDPT (Incorrect Determination of Train Position), is considered equivalent to GATE58 in the ERTMS/ETCS functional fault tree:

a) Considered sufficiently abstracted from the specificities of ETCS train positioning based on odometry and BTS, thus providing link from EVLF-based train position determination to the ETCS Core Hazard.
b) Link of EVLF/IDPT with GATE58 is limited to supporting the FMEA and assessment of the severity of failure effects.
c) Link between GATE58 and the ETCS Core Hazard is illustrated in the trace of the GATE58 minimal cut set from ERTMS/ETCS functional fault tree provided in Annex D of SFHA.

The identified hazards are described in the tables below:

ID	ETCS Core Hazard
Hazard	Failure to provide on-board supervision and protection according to the information advised to the ETCS on-board from external entities (ETCS Core Hazard)
System boundary	System level hazard at the boundary of the ERTMS/ETCS system
Remarks	ETCS system hazard is defined in [SS091]

ID	EVLF/IDTP
	Incorrect determination of train position
System boundary	Top-level hazard at the boundary of the enhanced vehicle localisation function (Interface F1:OUT<TBC>)
Remarks	Incorrect determination of train position includes train confidence interval not including the real position of the train.

ID	PRIR
Hazard	Pseudorange integrity risk (correction residual or ionospheric vertical error not bound and TTA > T_NVGAMAXTTA)
System boundary	Top-level hazard at the boundary of the GA for ERTMS/ETCS
Remarks	GA for ERTMS/ETCS is comprised of GA-OB and GA-TS

Figure 4: Identified Hazard Tables

It is assumed that the GA hazard PRIR (correction residual or ionospheric vertical error not bound and TTA > T_NVGAMAXTTA) is a cause for the hazard EVLF/IDPT.

a) The very conservative assumption is made that a violation of integrity in the pseudorange domain would result in a violation of integrity in the position domain with a probability of 1.
b) It should be emphasized that improvements to integrity performance at user level using sensor fusion, digital map integration (i.e., reducing to along-track errors only), etc. have not been taken into consideration in this analysis.

Regarding Annex B.8 of the SFHA (Example Fault Tree and Allocations for a single GNSS Channel using GA for ERTMS/ETCS), the following was stated:

a) It considers events related to GA for ERTMS/ETCS and events outside the scope of GA but that contribute to the GNSS positioning system hazard (GNSS-HAZ)
    i. GNSS positioning system hazard (xPE > xPL and TTA > T_NVGAMAXTTA seconds),
    ii. Allocated a THR of 7.5E-6 / h based on allocations from B.2 and additional allocations to USER-SEG-HAZ and TRACK-HAZ
    iii. Events outside the scope of GA are shaded grey in the fault-tree below (Figure 5)
b) It is assumed GNSS would be used with other sensors in an enhanced vehicle localisation function that is capable of meeting application-specific safety and performance targets.
    i. e.g., safety targets in the order of 0.33E-9 / hour for hazard related to real vehicle front-end position being outside the train confidence interval.

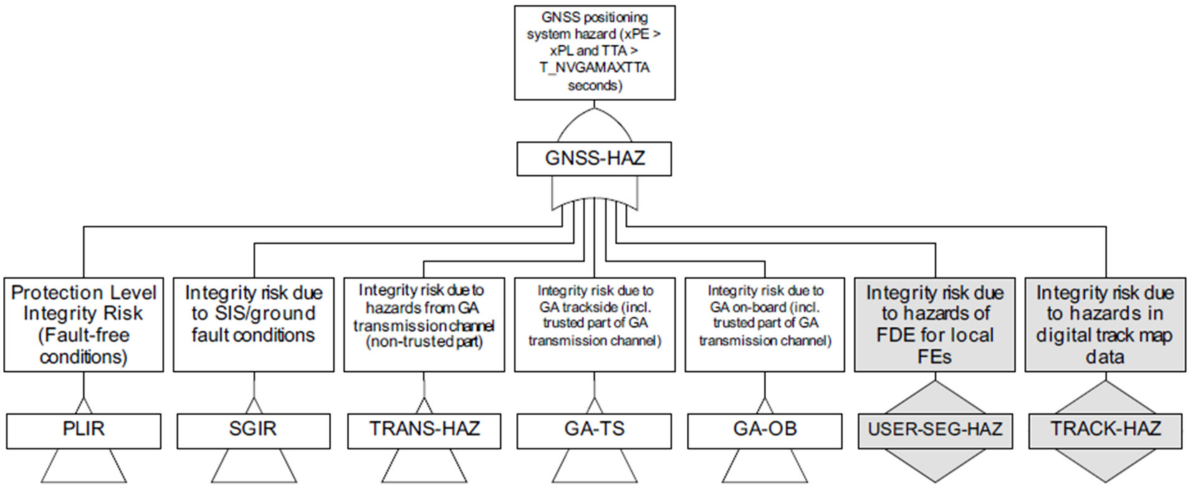

Figure 5: Example fault tree for GNSS-HAZ from SFHA Annex B.8 [10]

ID	Gate / Event	Description	Allocation (THR)
PLIR	Protection level integrity risk (fault-free conditions)		2.4E-6 / hour
SGIR	Integrity risk due to SIS / ground fault conditions		2.4E-6 / hour
TRANS-HAZ	Integrity risk due to hazards from the GA transmission channel (non-trusted part)		2.0E-7 / hour
GA-TS	Integrity risk due to GA trackside (including trusted part of the GA transmission channel)		1.1E-8 / hour
GA-OB	Integrity risk due to GA on-board (including trusted part of the GA transmission channel)		1.0E-8 / hour
USER-SEG-HAZ	Integrity risk due to hazards of FDE for local feared events		2.4E-6 / hour
TRACK-HAZ	Integrity risk due to hazards in digital track map data	Allocation of SIL4	1.0E-9 / hour
		Margin	7.8E-8 / hour
GNSS-HAZ	Total allocation for GNSS positioning system hazard (xPE > xPL and TTA > T_NVGAMAXTTA seconds)		7.5E-6 / hour

Table 3: Example THR allocations for GNSS-HAZ example fault tree from SFHA Annex B.8 [10]

8.3.2.3 THR Apportionment of GATF/GADF

The WP5 members questioned the apportionment of separate THR values to the GATF and GADF functions, stating that there should be a single THR apportionment given to the GA-TS functional block. It was agreed that the individual allocation of THR to the GATF and GADF can be removed. ESA took the action to update the SFHA [10].

8.3.3 Next Steps: Open Points to be Addressed in Future Iterations of the Specification

ESA agreed to update the SFHA [10] according to the discussions summarised above (i.e., reviewing the functional distribution and the THRs allocation).

Besides, cyber-attacks related to GNSS signals received by the GATF will be addressed in a future issue of the SFHA (e.g., detection using PDM).

8.4 SRS and ICD: In-Depth Analysis

8.4.1 Document Overview

8.4.1.1 SRS

Scope: to define the system functional requirements for GA in ERTMS/ETCS, focusing on interoperability-relevant requirements that enable the use of GNSS augmentation in a technology-neutral manner.

Purpose: to define the system requirements that must be fulfilled to provide interoperable GA. The document defines the following:

- GA functional architecture and interfaces (defined to the level required to support interoperability and safety analyses).
- GA-related functions; and
- GA operational states.

This document has already been updated based on the review performed by the X2R5 WP5 members. A description is provided below of the topics covered in this review process.

8.4.1.2 ICD

Scope and Purpose: provides the ICD for the interface between GNSS Augmentation On-board (GA-OB) and GNSS Augmentation Trackside (GA-TS). The scope of the document is to define interoperability-relevant messages, packets and variables exchanged over the airgap for GNSS augmentation, enabling the use of GNSS within enhanced on-board localisation equipment in ETCS/ERTMS.

This document has already been updated based on the review performed by the X2R5 WP5 members. A description is provided below of the topics covered in this review process.

8.4.2 Technical Key Concepts

During the review process, by a strict interaction with the authors of the documents, the rail suppliers had the opportunity to stress their point of view respect the GA data use, the related constraints to be considered by trackside and on-board subsystems, in terms of system specifications and interfaces in line with what are rail needs for having an EGNOS Railway SoL service. The main resultant actions are reported in the Annex C of the SRS [4], provided by the authors for summarizing the aspects that will be included in the future versions of the SRS.

8.4.2.1 Reference Functional Architecture

The following topics were discussed in the context of the reference functional architecture:

- The GNSS Augmentation Trackside Function (GATF) and GNSS Augmentation Dissemination Function (GADF) functional blocks, which reside within the GNSS Augmentation Trackside (GA-TS);

- The OB:IN(SBAS) interface

8.4.2.1.1 GATF and GADF

The X2R5 WP5 members requested clarification on the functionality of the GADF and GATF considered for GNSS augmentation. ESA clarified by providing the following explanations and definition of GADF and GATF functional blocks.

GNSS Augmentation Trackside Function (GATF) and GNSS Augmentation Dissemination Function (GADF), these two functions are allocated to GNSS Augmentation Trackside (GA-TS).

The GADF is a functional block that is responsible for the dissemination of GA messages containing correction and integrity information to the Enhanced Vehicle Localisation Function (EVLF). The GADF can also provide GNSS navigation data to the EVLF to support faster start-up time, especially in difficult start-up environments (e.g., where there is significant obscuration of GNSS satellites).

The (GATF) is responsible for the interface between the GA-TS and the GNSS Augmentation System (GAS). The GATF timestamps and condenses GA messages in GAM packets, leaving the in-built message protections (e.g., CRC) intact. While the GA-TS performs some message processing (e.g., in support of maintaining active data sets), by condensing GA messages, the complexity of the function is greatly reduced, and assumptions related to inbuilt defences against message-level hazards that are assumed by the GNSS augmentation service and its respective integrity commitments are maintained.

In addition, the GATF is responsible for obtaining navigation data from the Global Navigation Satellite System (GNSS), which is repackaged in packets optimised to provide essential CED parameters to the EVLF. This includes GNSS navigation data for constellations supported by the GAS (e.g., for EGNOS: GPS L1, L5; Galileo E1-B/C, E5a).

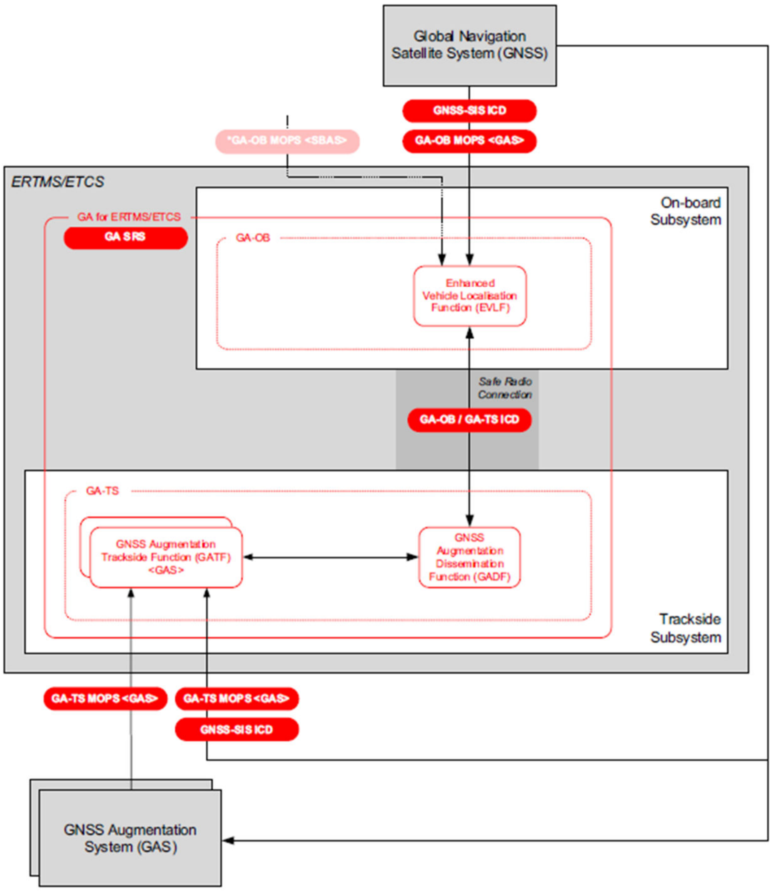

Figure 6: GNSS Augmentation Reference Functional Architecture for ERTMS/ETCS

After being questioned by WP5, it was clarified by ESA that the interface between GATF and GADF does not need to be defined since it is not considered relevant for interoperability (it can be left to the GA-TS supplier to define it). ESA took the action to modify the associated figure (repeated in Figure 6 above) in order to clarify this with possible input from HSTS.

8.4.2.1.2 OB:IN(SBAS)

The OB:IN(SBAS) interface was discussed. It represents the reception of the SBAS GEO SIS directly by the on-board subsystem. As discussed with ESA, the availability of this interface would generally be low in the railway environment due to obscuration of signals, apart from low-density lines in rural environments. There is also a dependency on latitude, with visibility reducing towards the poles.

Most of the suppliers in the WP5 questioned the necessity of OB:IN(SBAS), believing that it increases the complexity of the on-board unnecessarily. TS:IN(SBAS), the interface between the Trackside and the SBAS GEO SIS, should be the primary means of accessing the GA data. CAF however believe that OB:IN(SBAS) may be necessary and took the action to provide justification by the end of the project. This will subsequently enable a decision to be made regarding whether it will be retained.

8.4.2.2 Tropospheric Model and residual error

The X2R5 WP5 members raised the topic of the application of the tropospheric model and the over bounding of the associated residual error, requesting clarity and justification for where the responsibility should be for this. The SRS states that the DO-229/ED-259A model should be used. A model for the tropospheric residual error should be included in the overall fault-free measurement error term.

ESA explained that they assume no commitment on the model and the residual error within the scope of the hypothetical EGNOS railway service. On the other hand, the X2R5 WP5 members explained their view that as non-experts on this topic, they are not well suited to taking responsibility for it. As a result, the need for validation of the tropospheric model for railway application was recorded as an open point in Annex C of the revised SRS [4], stating that it is currently being investigated by ESA/EUSPA, with them awaiting access to data from the validation of the Galileo model and comparison with the DO-229/ED-259A model. Their investigations should validate the model- that is a "blind model" in the railway environment. Trackside Data Processing

Discussions were held concerning the role of the GA-TS (GATF), and any processing of the GNSS and GA data that it might perform. This focused on two areas:

i) Pre-processing of GA data.
ii) Potential additional techniques: e.g., Position Domain Monitor (PDM).

Concerning pre-processing of GA data, in [20] ESA and EUSPA evaluated the possibility of the GA-TS performing some of the ionospheric data processing. This could reduce the volume of data to be sent to the on-board, e.g., by only providing information for the ionospheric grid points of relevance to the trains in question (note that this would necessitate that the GA-TS has sufficiently accurate knowledge of the train locations). Some ideas were also proposed by X2R5 WP5 members, including:

- GA-TS performing the management of which navigation message set and corresponding SBAS message set are provided to the on-board.
- GA-TS generating dedicated message types to communicate events that it has detected to the on-board.

The concept of PDM was also discussed. This is based on the GA-TS equipment, with precisely known antenna locations, being able to monitor the performance of the GA data in the position domain. This would provide an independent railway assessment of performance levels.

ESA/EUSPA agreed in principle that some processing could be performed by the Trackside. However, it was explained that at this stage of the specification, the approach used was a simplification from the perspective of safety assumptions related to SBAS, considering that processing by GA-TS could have a safety impact e.g. on timeouts and degradation factors. They also agreed that PDM could have benefits, providing a barrier against cybersecurity attacks e.g. spoofing. This and other diagnostic functions are mentioned in the FIS [21].

8.4.2.3 GNSS Acquisition

In terms of GNSS acquisition, the feedback provided by WP5 focused on the need to support two or more SBAS streams.

The X2R5 WP5 requested clarification on the rationale for providing two (or more) SBAS streams to the on-board. ESA clarified by providing the explanations summarised below.

The requirement is only for the trackside; it does not mean that the on-board must process two streams. Requiring tracking of at least 2 SBAS signals (for Legacy and DFMC) ensures trackside can support two parallel message streams.

Although it was previously agreed that implementing EVLF capable of processing 2 channels should not be mandatory, confirmation is needed as to whether support should be provided for more than two parallel message streams.

a) Currently 2 streams are supported, but not required.
b) For SBAS, processing of two PRNs is specified in the aviation MOPS and is linked to unavailability of the GEO itself as well as the unavailability of the Navigation Land Earth Stations (NLES).
    i. The NLES switching may lead to a GEO SIS outage.
    ii. Having a parallel processing of at least two SBAS GEOs avoids a service outage if the on-board receiver has two channels capable of processing SBAS message streams from two PRNs with fast switching between channels in case of an unexpected service outage.

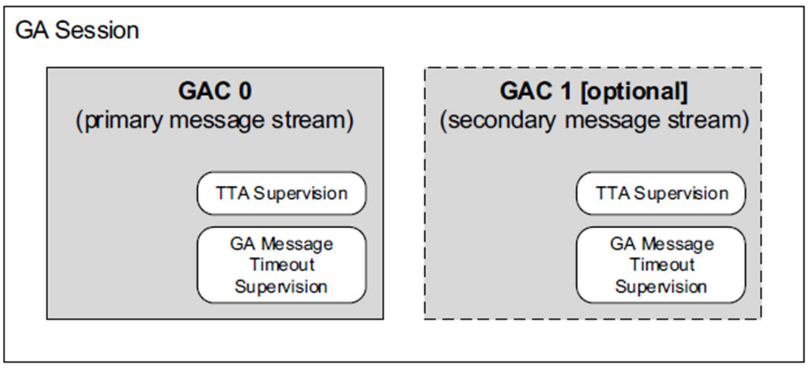

Figure 7: EVLF GA Session and GA Message Streams, where GNSS augmentation channel (GAC) [4]

The general principle taken has been that complexity should be handled in the Trackside as much as possible, enabling the On-board to be as simple as possible.

As a result of the discussion, ESA took the action to perform further analysis on the unavailability (time to recovery) that would be caused by switching from one GEO to another (for both legacy and DFMC modes). This will provide an input to a costs-benefits analysis, enabling a final decision to be taken on whether multiple streams should be supported. Different cases will be considered:

a. Switch considering a multi-lane GNSS receiver (i.e., processing two streams)

1. Receiver switches to lane processing other GEO

b. Switch with active data from trackside for single-lane GNSS receiver (i.e., processing one stream):

1. Receiver ceases using and discards any ranging data and all message types associated with current GEO
2. Receiver requests active data set for other GEO from trackside

c. Switch for single-lane GNSS receiver (i.e., processing one stream) – baseline case:

1. Receiver ceases using and discards any ranging data and all message types associated with current GEO
2. Receiver receives SBAS messages at 1Hz

8.4.2.4 Time Synchronisation

The X2R5 WP5 requested an explanation on the synchronization between the two timescales SBAS Network Time (SNT) and ETCS time. ESA clarified by providing the following explanations and definition of time synchronization and the main issues to be considered. Additionally, ESA has taken the action to include the SNT offset requirement with respect to GPS or Galileo System Time also for DFMC.

8.4.2.4.1 EVLF Supervision; Management of Alerts and Time to Alert (TTA)

Under nominal conditions, the GAS shall guarantee integrity for any valid combination of active data. Resilience against message loss is provided through timeouts for message content and the application of degradation parameters.

In the case of an alert condition, integrity is ensured with a reactive fail-safe design, where the TTA is the time elapsed from the onset of the alert condition to its detection and negation in the EVLF. An alert condition occurs when the GAS has erroneously broadcast integrity data not bounding the residuals (i.e., orbit and clock correction and ionosphere residual errors) at the required confidence level.

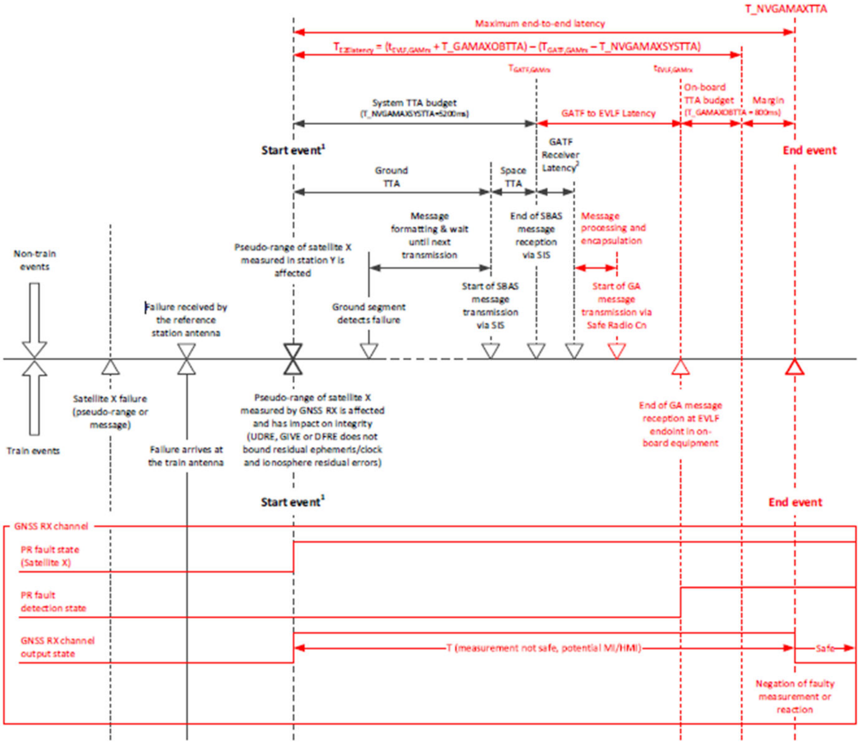

Figure 8: SBAS TTA considering reception of SIS at trackside and dissemination via Euroradio [4]

Figure 8 illustrates the SBAS TTA for the proposed railway GA approach, where:

a) GA Maximum On-board Equipment TTA Budget (T_GAMAXOBTTA) is a fixed value for the on-board equipment TTA budget allocation for processing latency from end of reception of SBAS message at endpoint in the on-board to raising an alert (negation of fault).

b) Endpoint refers to the enhanced localisation function within the on-board e.g., GA communication channel could include reception of GA messages by the ETCS kernel and forwarding on the internal bus (e.g., Profibus) to the enhanced localisation function, the endpoint.

c) Proposed value for the max TTA (T_NVGAMAXTTA), with the dimensioning taking into consideration the following:
   i. GA System TTA budget (e.g., for SBAS, T_ NVGAMAXSYSTTA = 5200 ms)
   ii. Latency of GATF/GADF processing (including encapsulation of GA message)
   iii. GA-TS to GA-OB transfer delay over Safe Radio Connection
   iv. On-board equipment maximum TTA budget (fixed value T_GAMAXOBTTA = 800 ms [TBC])
   v. Margin to cope with variations in safe radio connection performance taking into consideration track to train radio communication system (e.g., GSM-R CSD, GSM-R GPRS, FRMCS) availability, configuration, and coverage.

d) T_NVGAMAXTTA is used by the on-board equipment to determine T_GATIMEOUT for supervision of the GNSS augmentation message stream and to ensure correct assumptions are made within the enhanced localisation function regarding time to detect and negate faulty measurements caused by GNSS errors or anomalies detected by the GNSS augmentation system.

The current proposal for timestamping and management of time references is:

a) T_GAM (GA Message Timestamp) is in reference time indicated by Q_GAT
   i. For SBAS, Q_GAT (GA reference time qualifier) = 0 (SBAS Network Time)
b) T_TRAIN (time according to trainborne clock at which message is sent)

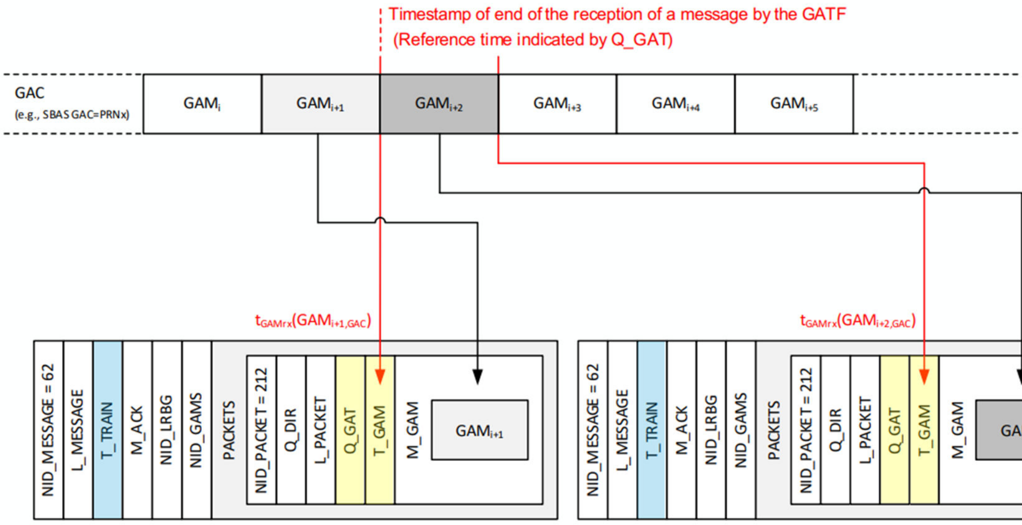

Figure 9: Timestamping of GA Messages by GATF (adapted from [4])

8.4.2.4.2 GATF Timestamping Reception of Messages from GAS

When using GA corrections, the EVLF's solution for time will be with respect to the GA Network Time.

a) For SBAS, EVLF's solution will be with respect to SBAS Network Time SNT (i.e., EGNOS, ENT).
b) $T_{GATF,GAMrx}$ is the timestamp of the end of GA message reception by the GATF (T_GAM in Packet 212) a. The reference time of T_GAM is indicated by the qualifier Q_GAT.
c) SBAS Network Time (SNT) is defined as that which is maintained, after corrections, to GPS system time, within the overall SBAS performance requirements.
   When using corrections, the EVLF's solution for time (tEVLF,now) will be with respect to SNT, and not with respect to GPS System Time. SNT will be within 50 nanoseconds of GPS system time.
d) Time of applicability for differential information in the SBAS SIS is the start of transmission from the SBAS GEO of the 1-second message block containing that information.
   The start of transmission is synchronized to the beginning of the corresponding SNT second.
e) Timeout interval for SBAS message content supervision is the end of the reception of a message by the SBAS/GNSS receiver in the GATF. This timestamp is provided in GA

messages (T_GAM) to allow the EVLF to supervise message content timeouts with respect to its current time $t_{EVLF,now}$.

Regarding on-board clock synchronisation, T_TRAIN is the time according to the train borne clock at which message is sent, and the following was stated:

a) It is provided in messages exchanged between GA-OB and GA-TS, where T_TRAIN is used for consistency checks (i.e., supervision of sequence) and acknowledgements, according to SUBSET-026 [22]:
   - The trackside shall always transmit its information with reference to the train time (Sec. 3.16.3.2.1 of [22]).
   - To timestamp its messages, the trackside shall make a safe estimation of the on-board time, based on the time-stamp of the received messages and the internal processing times. The estimation shall be made in such a way that the on-board time estimated by the trackside shall not be in advance of the real on-board time (, Sec. 3.16.3.2.2 of [22]).

b) Synchronization between the two timescales (SNT and ETCS time):
   a. There isn't a synchronisation mechanism defined for this case as there isn't an issue foreseen for ETCS on-board clock synchronisation by EVLF (not safety-related), and this would be the responsibility of supplier to implement (out of scope).
   b. It is understood that as the RBC makes safe estimation of on-board time, synchronisation to UTC or another, this is not safety-related for ETCS functions. GNSS navigation messages could be used to synchronise to UTC.
   c. For GA, timestamping with the correct reference time is safety related.

ESA took the action to include an SNT offset requirement with respect to GPS or Galileo System Time also for DFMC (only Legacy provided currently).

8.4.2.5 Version Management

The X2R5 WP5 members requested an explanation of the versioning paradigm impact. The documentation describes how the On-board (EVLF) should initiate a GA session to the GADF with Packet 50, which includes the GA versions that the On-board supports. In contrast, in ETCS the On-board unit receives the system version from the Trackside. ESA clarified by providing the following explanations and definitions of version management.

a) **GA Version**: version of the GA for ERTMS/ETCS framework supports the dissemination of GNSS augmentation information to the EVLF (GA-OB / GA-TS)
   i. GA for ERTMS/ETCS framework shall have a version number (M_GAVER) to support backwards compatibility. The version has a major and minor version number, where major versions increase in the case of non-compatible changes and minor versions increase in the case of compatible changes.
   ii. GA-OB and GA-TS with the same major version are compatible.

b) **GA Service Version**: version of a GNSS augmentation service

i. Each GA service shall have a version number (M_GASVER) to support backwards compatibility. The version has a major and minor version number, where major versions increase in the case of non-compatible changes and minor versions increase in the case of compatible changes.
ii. GA services with the same major version are compatible.

The proposed paradigm in the SRS is the following:

a) **GA Version**
   i. EVLF, when initiating a GA session, sends major GA versions with the highest supported minor version.
   ii. GADF responds with highest major version supported by both GA-OB and GA-TS. If no major version is supported by both, it responds with an error.
b) **GA Service Version**
   iii. EVLF, when requesting allocation of a GA message stream, shall send major versions with the highest supported minor version for each supported GA service.
   iv. The GADF selects a service to allocate from the GA services that are compatible. If no major version is supported by both, it responds with an error.

It was noted that the proposed paradigm is opposite to that of ETCS, but the same as that of ATO.

WP5 members decided that the augmentation system version should be embedded into the ETCS system version and therefore follow ETCS rules. It was noted that there is no need for GA to define a version management paradigm. Also, specifications will be updated removing version management mechanism and providing a note on version management, similar to the following: the baseline should be linked to mandatory augmentation (i.e., EGNOS for Europe) – this is relevant to European member states under the interoperability directive; markets outside Europe are not constrained.

8.4.2.6 Integrity Performance of Future Railway SoL Service

A question was raised by WP5 members, regarding the pseudorange domain integrity performance of a future railway EGNOS service and whether this could be improved if based on the EGNOS SoL NPA service level which provides an integrity performance of $1\text{-}10^{-7}$/hour. The precision approach (APV-I and LPV200) service levels on the other hand provide integrity of $1\text{-}2\text{x}10^{-7}$/approach.

During discussions with ESA, it was explained that the precision approach service levels are associated with the most stringent level of performance that is provided by EGNOS (current and next generation). Even though the NPA service level meets a higher level of integrity in the position domain (with TTA = 10s and Alert Limit = 556m), this integrity is not committed in the pseudorange domain. The key point is that all barriers employed within the EGNOS system are based on the precision approach service level.

It was agreed by all parties that the pseudorange domain commitments for a future railway service must therefore be based on the precision approach service level. A future railway SoL pseudorange domain integrity service would only be able to make commitments on integrity in the pseudorange domain, as aspects including the following are the responsibility of the on-board equipment perimeter:

a) Protecting user from local feared events;

b) Bounding of residual errors due to receiver and local environment.

c) Translation of pseudorange domain error bounds to position domain error bounds (i.e., equation for computing along-track protection level)

d) Along-track train position, velocity, etc. (considering different approaches including hybridisation with other sensors, etc.)

It would be the supplier that would need to provide evidence demonstrating whether the margin in translation of pseudorange domain error bounds to track-constrained position domain error bounds can be reliably quantified and taken into consideration in integrity budget.

8.4.3 Next Steps: Open Points to be addressed in Future Iterations of the Specification

As result of the discussions among WP5 members and ESA, an appendix (see Appendix C of the updated SRS [4]) was included in the new version of SRS specifications to list a series of open points to be addressed in future activities on EGNOS for Rail specifications in continuity with the activities carried out in task 5.2.3 of WP5. For sake of clarity, the open points derived from SRS and ICD documents are listed:

- Validation of tropospheric model for railway (see Section 8.4.2.2).
- GATF specification for EGNOS (see Section 0)
- Development of guidance on how to deviate from prescribed critical user receiver parameters in a controlled manner to ensure integrity requirements are met.
- Development of guidance on the computation of protection levels (along-track and horizontal).
- Update of EGNOS railway receiver guidelines (MOPS) for GA-OB and GA-TS (see Section 8.2).
- GA and GAS versioning (see Section 8.4.2.5)
- Degraded modes.
- GATF processing time.
- Requirement for at least 2 available SBAS GEO signals for selection of GAC (see Section 0)

- Support for more than 2 GA message streams.
- Support for reception of SBAS SIS directly by EVLF (see Section 8.4.2.1.2).

As can be seen, some above points require a direct contribute and feedback by space sector, while other topics are more linked to CCS.

9 Focus on "Digital Map - DM": Report on the collaboration and contributions to EUG-S2R JWG

9.1 WP5 Review Process on RCA Documentation on DM

The review process followed by WP5 on RCA documentation - representative of the state of the art of the DM theme - was completely analogous to the one adopted to investigate the GA theme. Essentially, starting from the available document set, attention was focused on a subset of documents (namely [13], [17] and [18]), containing the topics of interest by the various railway stakeholders and which led to targeted technical discussions.

The comments raised by WP5 partners, closed through answers of the authors in the review sheets can be consulted in the CT at the following link:

https://www.cooperationtool.eu/projects/goto.aspx?p=X2RAIL-5&doc=1e1656a1-29d9-4034-85c6-33f699dfbfc6

The discussions on "Assumptions/Principles" and "Mechanisms/Approaches" comments brought to identify a set of key concepts by WP5 members to be investigated in more detail with SP and IP representatives. In the next sections, these topics are exhaustively described, providing also the final notes derived from technical discussions.

9.2 WP5 Feedbacks

9.2.1 DM Data: Minimum Information Set to be used for LOC Functionality

The data model formalized in [13] covers different needs, as it is aimed at the main user consumers of the DM. Focusing on the functionality of interest in the context of X2R5-WP5, which is localization, WP5 has made efforts to identify the minimum informational content required to support the LOC functionality. More specifically, here the list of information set agreed by WP5 members:

1. Whole telegram (Mandatory), to support the detection of balises, whether physical or virtual. To be noted that for positioning function just the telegram header is enough.

2. Length Info (Optional): This is the length of the track edge section. To be clarified if it has been intended as length of arch rather than length of chord.

3. Heading of the track (Optional)

4. Addition tier to provide technology related characteristic (Optional): The integration of an additional level to integrate information related to GNSS technology, for example information regarding GNSS reception (i.e., "a priori reception information").

This data set involves some modifications of the object Catalogue of the RCA documentation [13] be lowered into the current formalism used for the DM. Lastly, it includes information indicated as “optional” data, in the sense that their use is optional and need to be consolidated and formalized in other contexts. Some preliminary evaluations are reported in the following sections.

9.2.1.1 Length Info: Insight

WP5 analysed the aspects related to the impact of considering the geometric distance versus the true distance along the path. The analysis conducted based on the contributions received (all conceptually based on the Chord Theorem) are reported here, highlighting:

- the importance of the dependence between point density and curvature of the path (curvature radius).
- The need to consider the systematic error.

9.2.1.1.1 Context: Error on curves for a point-based map

To evaluate the differences between a point-based map and a real curve description, let’s note:

- *R* the curve radius of the track,
- *dmap* the distance between two map points,
- *lcurve* the real length of the curve arc,
- α the angle between the median of the straight segment between the map points and each of those points,

and finally

- ϵ the maximum lateral distance (i.e., the lateral error) between the curve and the straight segment.

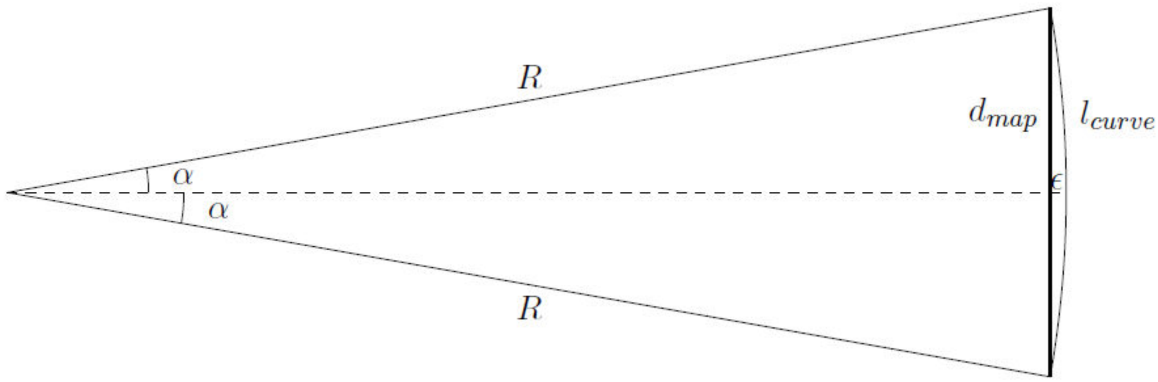

Figure 10: Representation of Chord Theorem

Let's evaluate the lateral error, i.e. ϵ.

$$\epsilon = R - \sqrt{R^2 - \frac{d_{map}^2}{4}}$$

$$\epsilon \approx \frac{d_{map}^2}{8R} \text{ if } d_{map} << 4R$$

With *dmap* << *4R*, the error grows as the distance between the map points squared.

Conversely, to respect a given ϵ, dmap must fulfil:

$$d_{map} < 2\sqrt{2R\,\epsilon - \epsilon^2} \approx \sqrt{8R\,\epsilon}$$

The maximum lateral error allowed for the track selectivity is 1.64m. Let's allocate 10cm to the map inaccuracy; For a curve with a radius of 300m, this gives dmap < 15.5m.

Let's evaluate the length error, comparing the *lcurve* and *dmap*.

$$
\begin{aligned}
l_{curve} &= 2\alpha\, R \\
d_{map} &= 2R \sin\alpha \\
&\approx 2R\left(\alpha - \frac{\alpha^3}{6}\right) \text{ if } d_{map} << 2R \\
\alpha &\approx \frac{d_{map}}{2R} \text{ if } d_{map} << 2R \\
l_{curve} - d_{map} &\approx R\frac{\alpha^3}{3} \\
&\approx \frac{d_{map}^3}{24\, R^2} = \frac{d_{map}}{3R}\frac{d_{map}^2}{8R}
\end{aligned}
$$

The error grows as the distance between the map points cubed, but with an order of magnitude less than the lateral error.

Here are some values and the required point density for curves with a radius R equal to 300m and given *dmap* values:

$d_{map}\,(m)$	10	15	20	25	30	35	40	45	50
$\epsilon\,(cm)$	4.2	9.4	16.7	26.1	37.6	51.1	66.7	84.5	104
$l_{curve} - d_{map}\,(mm)$	0.5	1.6	3.7	7.2	12.5	19.9	29.7	42.3	58.1
points$/km$	100	67	50	40	34	29	25	23	20

Table 4: Points density (#point/km) at given *dmap (*with R=300m)

And then, *dmap* values allocating only 10cm to the lateral error ϵ (leaving 1.5m to the GNSS uncertainty) for given radius of curvature R:

$R\,(m)$	300	500	1000	1500	2000	3000	5000	10000	12500
$d_{map}\,(m)$	15.5	20.0	28.3	34.6	40.0	49.0	63.2	89.4	100.0
$l_{curve} - d_{map}\,(mm)$	1.7	1.3	0.9	0.8	0.7	0.5	0.4	0.3	0.3
points$/km$	65	50	36	29	25	21	16	12	10

Table 5: Points density (#point/km) at given *R (*with ϵ=10cm)

The following figures show that the difference between Length of arc versus length of chord truly small for reasonable arc radius R (from 150m to 300m) and distances between successive points, i.e. the length of chord c (from 1m to 30m).

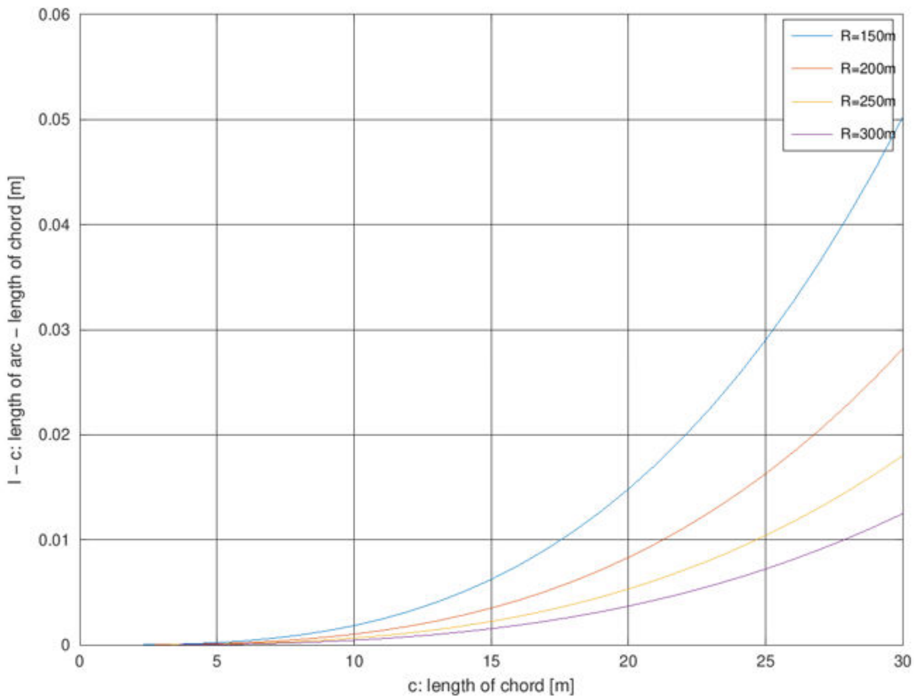

Figure 11: Representation of Chord Theorem (Linear scale)

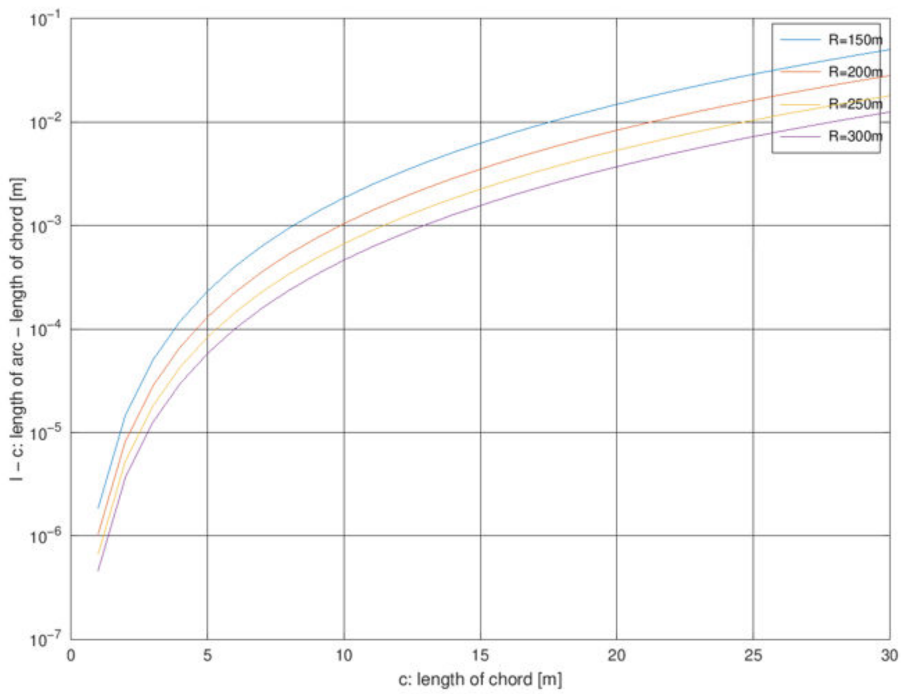

Figure 12: Representation of Chord Theorem (Semi-logarithmic scale)

9.2.1.2 Heading Info: Insight

In RCA object catalogue [13] no mention of the heading information is made.

Heading information added to *Track Edge Point* or as a specific domain object like speed profiles or gradient can be a valuable information to improve the accuracy of the localisation system and the track determination. In point area, thanks to IMU sensor heading can help to determine which leg of the point the train is running on.

9.2.2 Point-based vs Vectorial-based Track Axis Representation: PRO/CONS Analysis

Once the dataset necessary for localization functionality is identified and specified, WP5 addressed the topological aspect, that is, how to represent the line. The RCA documentation presents both point-based and vector-based representations, without an explicit or declared preference. Starting the technical discussions on the preferable way to represent the track geometry, WP5 members compiled a list of pros and cons, to allow a comparison between the two representations based on a common set of features – that are categorized in the following subsections. Most rail suppliers are in favour of the point-based representation, while at least one partner expressed the preference to use vector-based representation.

9.2.2.1 Point-Based Track Axis Representation

9.2.2.1.1 Accuracy

The accuracy of the track axis description is closely linked to the survey procedure conducted: points are surveyed in the required distance; accuracy of individual points is issued during the survey.

Both types of representations are impacted by the accuracy of individual points; vector-based representation, in addition, is impacted with the correctness of selected models (arc, clothoid and straight section) for the specific section of the track. Therefore, with point-based approach, the quality (i.e. accuracy) of the track axis is better controlled and known.

The analysis reported in 9.2.1.1 section reinforces the principle of good accuracy with good survey through the following highlights:

- a track edge, namely a track segment limited by two track edge points, can be considered straight with a given, well specified, amount of error.
- the distance among two track edge points belonging to a given track edge shall be carefully evaluated accordingly on curvature radius of the track (i.e. lower radius requires higher density of points).

9.2.2.1.2 *Amount of Data to Storage*

Point-based representations require less data storage compared to other complex representations, optimizing storage efficiency and reducing requirements. Amount of data remains dependent on line characteristics.

Regard to amount of data to be managed, in D3.2 of X2R2 (see section 9.3.3.3 of [25]) an analysis is provided on typical VBTS DM data size and expected performances for the case of point-based track axis representation, considering that VBTS applies to a variety of railway lines based on ERTMS signalling system, namely High Speed, Regional and Low Traffic lines.

See section 9.2.2.3 for details on numerical evaluation of required Data payload.

9.2.2.1.3 *Source of Information (Survey)*

The point-based approach ensures a direct representation of the surveyed data. Geodetic survey naturally provides the track axis representation in points; no additional processing (parameters finding for arcs, clothoids, and straight sections) is needed and no additional uncertainty is included. In fact, the expected output of a survey procedure is a DM of the railway line, intended as the most complete set of track-related data useful for LOC functionality.

Therefore, a proper survey procedure, that takes place in a punctual manner (i.e. point by point on the rail track), shall efficiently represent track geometry and VBs positions by 3D-points based description, namely a sequence of:

- 3D points, defined in RCA documentation as *TrackEdgePoints* (see section 7.1.2.1 of [13] and table 6 of [18])
- and linear oriented segments connecting them, defined in RCA documentation as *TrackEdge* (see [13])

9.2.2.1.4 *Impact on on-board (to process DM Data)*

Regard to the impact respect to related elaboration time by on-board subsystem for DM data process, WP5 members highlights that:

- The reduced dataset used to represent the line (i.e. without any additional vectorial information) brings to minimize the elaboration effort need to process them by on-board subsystem. Fundamentally, the on-board subsystem will only select a given route (i.e. a path on which the train is running), without a pre-processing step of further (vectorial-related) information.
- From the position algorithm implementation perspective, the point-based representation should be more suitable since the algorithm works only with one type of object (with line segment) and this object type is used for the entire track axis representation.

- The utilization of vector-based maps leads to a more complicated algorithm which has to work properly with three different objects (and two of them are less “friendly” for operations such as intersection with an ellipsoid).

9.2.2.1.5 Scalability

The use of point-based representation allows for scalability, accommodating large amounts of track data without significant impact on performance or functionality. This means that as the track expands or new tracks are added, it becomes easier to accommodate these changes in the system. Adding more points to represent an extended track or additional tracks can be done in a straightforward manner without the need for extensive modifications in the existing structure. This scalability in point representation allows for a flexible and efficient management of railway systems, enabling the seamless integration of future expansions and improvements.

9.2.2.1.6 Fault Detection information

A point-based representation allows for accurate detection of faults or defects along the railway track. By capturing various data points, such as track irregularities or abnormalities, it becomes easier to identify potential issues before they become major problems.

9.2.2.1.7 Consistency

A point-based representation ensures consistency throughout the entire railway track. Each point serves as a reference, providing a standardized and uniform representation of the track's features, allowing computation of characteristics such as elevation and slopes. This consistency allows for better planning and maintenance activities.

It has to be noted that currently ETCS defines characteristics such as the Gradient Profile as a sequence of gradient values, constant between two defined locations each, that is consistent with point-based representation of the line.

9.2.2.1.8 Geographic Analysis

With a point-based representation, geographical analysis and spatial referencing become much easier. By having specific points along the track, it becomes effortless to analyse the track's location in relation to other geographical features, such as rivers, bridges, or tunnels. This analysis can significantly aid in decision-making processes or route planning.

In fact, point based representation can be easily imported in several commercial and open tools (e.g., Google Earth, OpenStreetMap).

9.2.2.1.9 Flexibility

A point representation offers flexibility in terms of scalability and adaptability. Adding or removing points along the track can be done without impacting the overall representation. This flexibility allows for adjustments and modifications to accommodate changes or expansions in the railway network over time.

9.2.2.1.10 Interactivity

A point-based representation provides a clear and concise visual depiction of the railroad track, making it easier to understand and analyse the overall layout.

Using this representation enables interactive features and user-friendly interfaces. Users can interact with the representation to access specific information about each point, such as maintenance history, inspection records, or signal status. This interactivity enhances user experience and facilitates efficient decision-making.

It has to be noted that several commercial and open tools (e.g., Google Earth, OpenStreetMap) use point -based representation.

9.2.2.2 Vector-Based Track Axis Representation

9.2.2.2.1 Accuracy

Vector-based maps are highly accurate and versatile representations of geographic information. Unlike raster maps that rely on pixel-based images, vector maps use precise mathematical points, lines, and polygons to define geographic features. This approach allows for the preservation of detailed information, enabling accurate rendering of intricate geographic elements such as coastlines, roads, and boundaries. Vector maps also support scalable zoom levels without loss of clarity, ensuring accuracy at various levels of magnification. Additionally, vector maps can incorporate real-world coordinates and measurements, making them invaluable for precise navigation, spatial analysis, and geographic data visualization. Their accuracy and adaptability make vector-based maps indispensable tools in fields like GIS (Geographic Information Systems), cartography, urban planning, and location-based services.

9.2.2.2.2 Amount of Data to Storage

Vector-based maps generally require less storage space compared to raster or point-based maps. The data is represented as geometric shapes and attributes, resulting in smaller file sizes. This efficiency is particularly advantageous when dealing with large datasets or when transmitting map data over networks with limited bandwidth.

See section 9.2.2.3 for details on numerical evaluation of required Data payload.

9.2.2.2.3 Source of Information (Survey)

Vector based maps can be generated from civil engineering tools to survey-based data bases. In fact for a safety related information, it is believed that pure civil engineering data should be double checked with on sight information.

The survey-based data is typically based on a combination on IMU, GNSS and Lidar based information which then gathered all together can determine the geographical information required for a vector-based maps, such as Mapbox, Novatel Waypoint, etc.

9.2.2.2.4 Impact on on-board (to process DM Data)

In a vector-based map there are 3 types of interpolation expected: straight line interpolation, curve interpolation and clothoid interpolation. For straight line and curves the interpolation computation is a straightforward line that can be computed in a single computer run time cycle. For clothoids though approximations are required. There are several papers that define approximation of clothoids that can be solved without loose of precision in a single computer run time cycle. These are based typically on G1 Hermite interpolation [24].

9.2.2.2.5 Scalability

Vector-based maps can be scaled without loss of detail or quality. The information is stored as mathematical descriptions of lines, clothoids, and points, allowing the map to be zoomed in or out smoothly.

9.2.2.2.6 Fault Detection information

Fault Detection Information: whenever a positioning algorithm is based on a vector-based map, it is suitable for Fault Detection mechanism on sensor misalignment or malfunctioning. For instance, IMU information could be checked at straight lines or curves. Furthermore, the gradient value taken out of the vector-based map could be used to remove the gravity aspect from the sensor.

9.2.2.2.7 Consistency

Vector based maps intrinsically imply data consistency because the information included in vector-based maps includes for 2D at least true ground distance, the curvature and absolute position.

9.2.2.2.8 Geographic Analysis

Vector-based maps are well-suited for geographic analysis and spatial operations. The individual objects in the map can be used to perform spatial queries, measurements, and analyses.

9.2.2.2.9 Flexibility

Vector maps offer greater flexibility in terms of customization. As the map data is represented as individual objects with attributes, you can easily modify the different map elements. This flexibility is valuable when creating maps for specific purposes or when you want to present data.

9.2.2.2.10 Interactivity

Vector maps support interactive features such as panning, zooming, and querying. Users can explore the map by interacting directly with the objects on the map, selecting and querying specific elements, and obtaining additional information.

9.2.2.3 Evaluation of Data Payload for Point-based and Vector-based Track Axis Representation

To perform a quantitative evaluation on the actual data payload required by the two track representation approaches, the OpenStreetMap (OSM) database (with 415474 number of points as data size) was taken as a reference, which allows to describe about 37.900 km of ETCS L2 lines in Europe. See Figure 13 as a sketch of the used information. The map is divided into sections, where a section is equal to a track edge model, that is it is limited by a start node and end node. Each section has been analysed dividing it into straight lines, curves or clothoids. For each section type the following distances have been counted:

- Europe ETCS level2 Straight Sections:
  - Accumulated Distance: 27465.849 (km)
  - Number of sections: 202249
- Europe ETCS level2 Curve Sections:
  - Accumulated Distance: 5496.668 (km)
  - Number of sections: 24721
- Europe ETCS level2 Clothoid Sections:
  - Accumulated Distance 4937.774 (km)
  - Number of sections: 60509

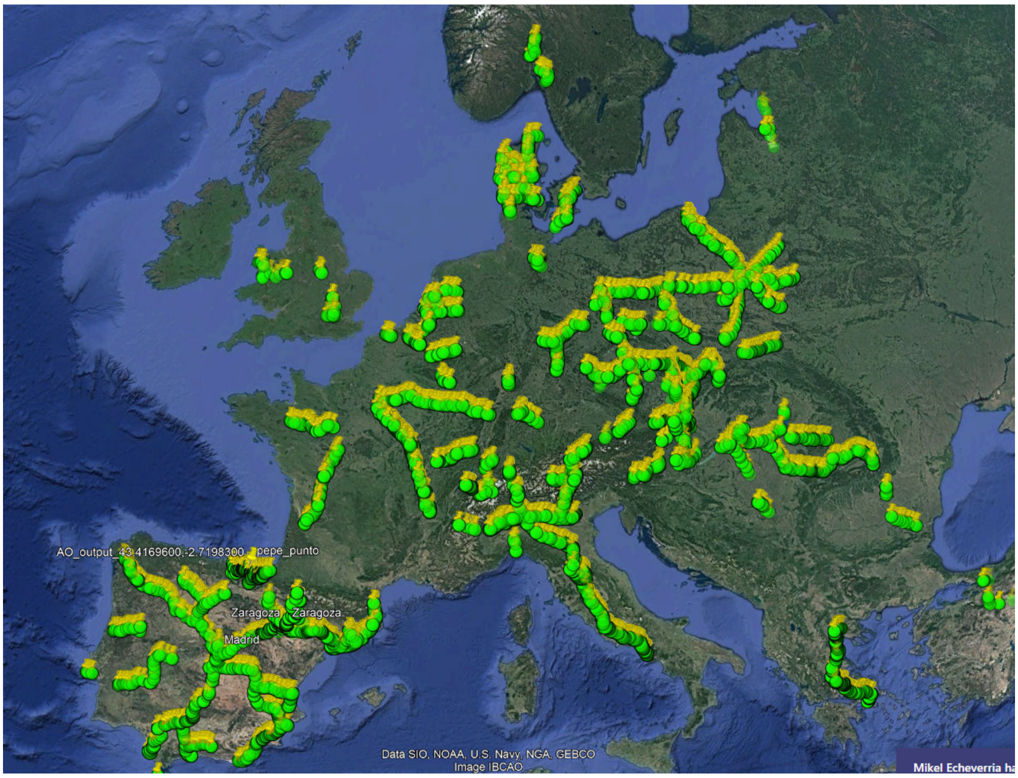

Figure 13: ETCS Level 2 data reference from OSM used for statistical purposes

Each section can be represented in either way, in a vector-based system or a point-based system. In order to define the size of a section it is considered the following. In Vector Based Map, a section size is of 48 bytes and we only have one section size per straight line or curve or clothoids:

- Latitude, Longitude and Height data of the start of the section: 12 bytes, 4 bytes per data.
- Latitude, Longitude and Height data of the end of the section: 12 bytes, 4 bytes per data.
- Heading at the start of the section: 4 bytes
- Heading at the end of the section: 4 bytes
- Distance from the start Track edge to the start of the section point = 4 bytes
- Distance from the start Track edge to the end of the section point= 4 bytes
- Curvature at the start of the section: 4 bytes
- Curvature at the end of the section: 4 bytes

In point-based maps, a section size is of 40 bytes and each section covers either 10, 30 or 50 meters of arch length distance, analysis is carried out for all these cases. If the section is smaller than 10 meters, then a unique section is considered. In addition, it is considered that an optimised point-based system is used where in straight lines only one section is used:

- Latitude, Longitude and Height data of the start of the section: 12 bytes, 4 bytes per data.
- Latitude, Longitude and Height data of the end of the section: 12 bytes, 4 bytes per data.
- Distance from the start Track edge to the start of the section point = 4 bytes
- Distance from the start Track edge to the end of the section point= 4 bytes

- Heading at the start of the section: 4 bytes
- Heading at the end of the section: 4 bytes

However, it the digital map is not offering heading and the distance to the start of the track edge is computed by calculating the accumulated distance calculation from point to point then the list of data can be simplified to 24 bytes. The error accumulated by accumulating the distance values will be related to the error committed when in a curve the distance error between two points does not represent the reality (for in depth analysis see section 9.2.1.1).

In the following graph it can be seen how the Smart Point representation could work. The smart point representation is obtained by an estimated curvature of the recorded data to determine whether a section is straight and or a curve. Once this is carried out it only defines a list of absolute points. Therefore, to calculate the travelled distance from the start of the track edge representation, the onboard system needs to add all the 'di' values until the point in which the train is located.

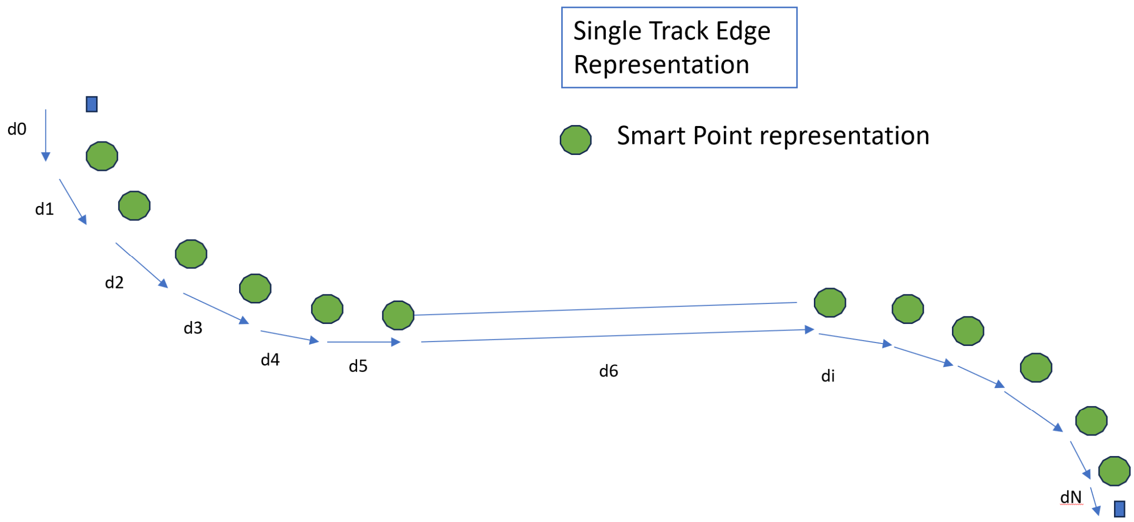

Figure 14: Single Track Edge representation

The results from the analysis are shown in the following Table 6. In columns there are two possibilities: vector-based and point-based with different, fixed sampling values (10, 30 or 50 m). In rows, the bytes per section are extracted, following the rules defined earlier where the straight lines, noting that the point-based solution is a smart point where there are only two points.

Branch A **Branch B**

40 bytes Point based	Vector Based	Point Based (10m)	Point Based (30m)	Point Based (50m)
Bytes Straigth sections	9707952	8089960	8089960	8089960
Bytes Curve sections	1186608	22485280	7821120	4906680
Bytes Clothoid sections	2904432	20976940	7812540	5234660
Sum	13798992	51552180	23723620	18231300
Δ=Difference (Point based - Vector based)		37753188	9924628	4432308

24 bytes Point based	Vector Based	Point Based (10m)	Point Based (30m)	Point Based (50m)
Bytes Straigth sections	9707952	4853976	4853976	4853976
Bytes Curve sections	1186608	13491168	4692672	2944008
Bytes Clothoid sections	2904432	12586164	4687524	3140796
Sum	13798992	30931308	14234172	10938780
Δ=Difference (Point based - Vector based)		17132316	435180	-2860212

Table 6: Table comparison with both vector-based and point-based (with fixed sampling)

Subsequently, the analysis focused on fixing a given accuracy value with a variable sampling. More specifically, considering the concepts underlying the Chord Theorem (already discussed in section 9.2.1.1) and fixing the transversal accuracy at 0.1m, resulting in a lateral accuracy slightly higher than 1mm over 50m (i.e. 0.002%), the density points (as fractional and integer contribute) and the average weighted radius were derived.

All evaluations made are visible in the flowchart shown in the figure Figure 15. In addition to what has already been described, which is the vector-based evaluation (indicated in the figure as *branch A*) and the point-based evaluation with fixed and variable sampling (referred to as *branches B* and *C* in the figure, respectively), further evaluations are added for the sake of completeness, starting from the original points of the OSM file. In particular, *branch D* represents the evaluations made considering representing the original OSM points with a data structure of 24B, 40B, and with the one proposed into X2R2 project (for more details, please refer to section section 9.3.3.3 of D3.2 [25]).

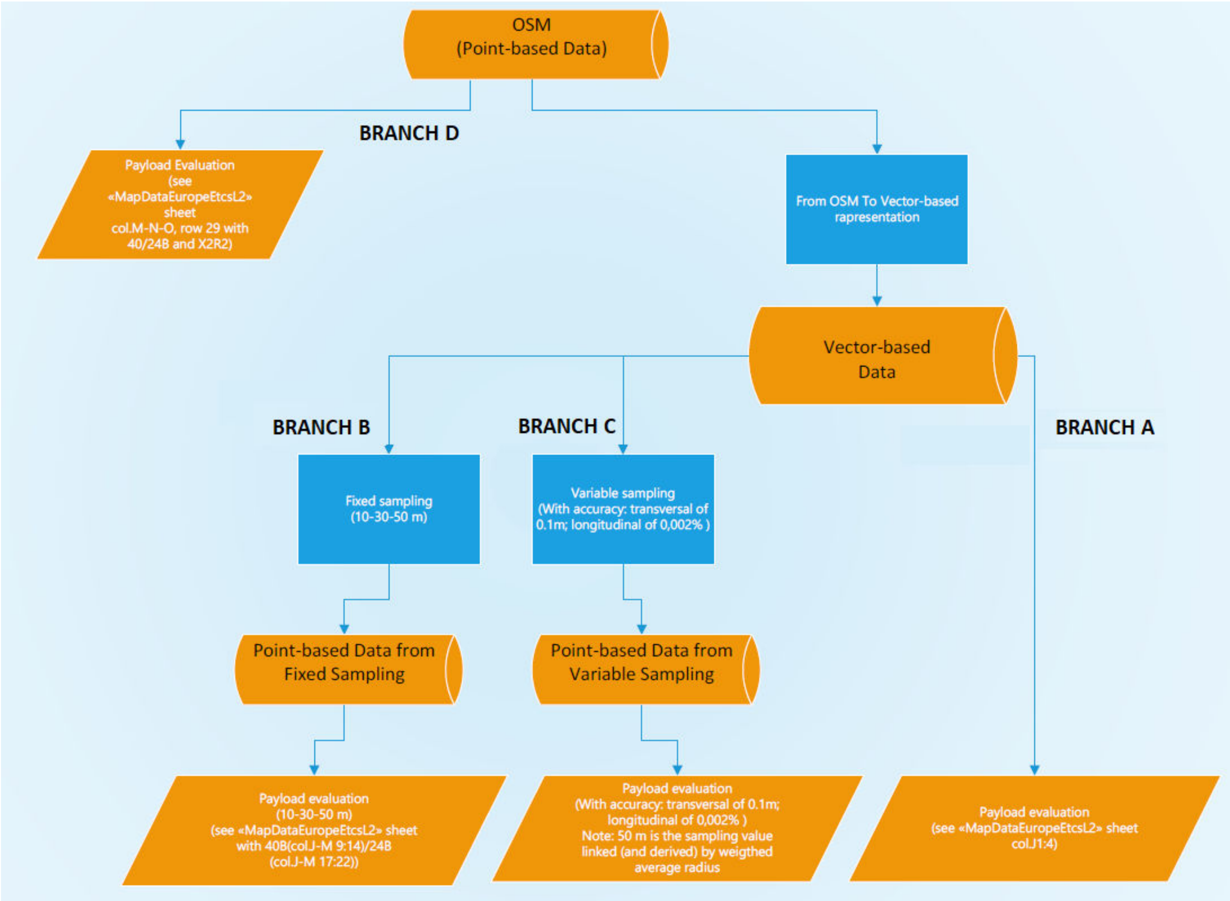

Figure 15: Flowchart on DM Analysis

The resultant numerical evaluations are reported in table Table 7.

	Branch A	Branch C		Branch D		
	Vector Based	Point Based (variable density points, w.r.t extracted Average Weighted Radius), Fractional	Point Based (variable density points, w.r.t extracted Average Weighted Radius), Integer	Point Based - OSM	Point Based - OSM	Dataload required in point-based representation with the data structuring as presented in D3.2 of X2R2
Tot. Dataload [Byte]	13.798.992,00	11.296.474,89	12.438.959,31	9.971.376,00	16.618.960,00	8.496.443,30

Table 7: Table comparison with vector-based, point-based (with variable sampling), OSM and X2R2-based approaches

9.2.3 DM Management

The discussions held within WP5 regarding DM data management focused on various aspects, including the method (in terms of process and interface) for transferring data from DM-TS to DM-OB, the procedure for updating the DM at the edge, and the possibility of deactivating it if needed. The following are the key considerations extracted from the technical discussions.

To provide DM data from the trackside to the onboard system the approaches analyzed are reported in [18]. They range from solutions that are seamlessly integrated into the existing message communication between trackside and on-board systems (such as ETCS/ATO), to dedicated map services that deliver the on-board DM through a dedicated channel. These dedicated map services also ensure the synchronization of the current and previously provided map versions in relevant situations, such as when a new movement authority is issued. The WP5 orientation is to consider the integrated approach, or at least the MAP service variant with CCS-TS employment to preserve already present ETCS mechanisms.

Regarding the interface to be used between DM-TS and DM-OB to "publish" DM Data to the train, taking into consideration the concepts discussed in [18] and [17], within WP5 we assumed that the interface is an interoperable interface with a safety-related part and eventually a not safety-related part. The discussions among WP5 members were based on the analysis of the following scenarios [17]:

- *DMOPSC_10: Update of Map Data with non-safety related information;*
- *DMOPSC_11: Update of Map Data with safety related information (via ETCS SS-026 interface)*

The following conclusions were derived:

- All the mechanisms for integrity and coherence checks on DM Data (namely, those linked to DM Reference Data) should be allocated into a safe radio channel.
- This ETCS channel based on [22] is also used to detect Map DM Data updates. Since it is a safety and time critical channel responsible for core functionalities in the train, from safety point of view DM Data should be deactivated when this channel is down.
  The reason is noted in the document [17]: it cannot be excluded that DM-OB misses a DM Update, i.e. if the idea behind is to keep the interface DM-TS/DM-OB free of time-critical messages (as discussed in [18])
- The disconnection between TS and OB (be it the interface between RBC and ETCS-OB or interface between DM-TS and DM-OB) shall trigger a deactivation of the Map Data on-board. It is imperative to ensure this to avoid operation of on-board on unsynchronized DM Data.

To be noted that the scope of DM in RCA was clearly restricted to only radio based ETCS Levels i.e., DM Data is only available in radio-based levels (and the ERJU/System Pillar has the same restriction).

Some partners highlight that ETCS already defines criteria to delete and/or invalidate location related information and suggest adopting similar criteria for DM. However, another alternative strategy has been considered for deactivating an outdated onboard map. It is based on the use of a lifespan, which means that the DM data is deactivated upon expiration of a timeout. However, WP5 members agreed that the lifespan could also be used as criteria, but a safe threshold value should be argued for railway procedures.

The use of an external input to trigger a possible DM Data update was discussed internally into WP5, starting from the condition described in the last row of Table 6 from [17]:
"For optimization potentials like earlier Map Data updates, this trackside function receives triggers from external trackside sources which provide sufficient information to DM-TS to determine the required of Map data updates for a train. Examples of such triggers can be Movement Authority/Permission or Journey Profile or Operational Plan (train route part)."

WP5 team agreed that for LOC-OB consumer the DM update was supposed to take place during service procedures, without using dynamic updating of Map Data (just eventually before SoM).

Finally, the discussion was focused on how activate first location (It is important not to confuse this scenario with the track-selective localization required for the next operation) and link it with the concept of Max and Min. Required Map Area (see [17]). Through an exchange of opinions with the authors of RCA documentation, it has been clarified that:

- Currently, the documentation covers a specific scenario where LOC (location) provides an approximate position to DM-O. Based on this position, DM-OB only requests DM Data from DM-TS.
- For cross-border operations, the question arises regarding which DM-TS to contact. This aspect should be included in the communication principles for the interface but is currently not defined.

10 Initial draft inputs to the future TSI

From the timeline perspective, X2Rail-5 project, like X2Rail-2 in the past, is not be intended to prepare complete fail-safe train positioning specifications for the submission of future TSI. Rather, it has identified and prepared key inputs which will be further processed and complemented for their inclusion in the TSI.

This concluding chapter focuses on the key inputs that, identified during the work carried out in task 5.2.3 of WP5, require further analysis to converge towards a consolidated specification of the FSTP, and thus towards the integration of satellite-based localization in the TSI. Obviously, the aspects refer to the interfaces that have an impact on interoperability (GA and DM) and on which this document is focused.

10.1 GNSS Augmentation Data: Key Inputs towards TSI

The document set originally produced by ESA/GSA and EUSPA on the topic of GA has undergone several updates resulting from the work carried out by WP5, leading to the most recent version (referred to as 0g) for SRS, ICD, and SFHA. This version serves as input for the ERJU work packages currently underway within the European context (i.e., System Pillar and Innovation Pillar) for rail activities based on EGNOS. In addition to integrating the consolidated aspects over the years, these documents outline the gap to be filled in order to facilitate the use of GA in the fail-safe train positioning functionality. Specifically, in Appendix C of the SRS, starting from version of [4], the list of open points that are still pending but require high priority attention in order to ease the full integration of EGNOS into the system defined so far is defined. This annex should be referred to for future activities on this topic.

The last workshop held on October 2nd, 2023, among WP5, EUG, and ESA (the minutes of which can be found on the CT at the following link ***https://www.cooperationtool.eu/projects/goto.aspx?p=X2RAIL-5&doc=1da1fb3e-93bd-4eef-bf6d-e03d270d2132***), proved to be a valuable opportunity to identify the link between X2R5 and EuRail, with the aim of directing more specifically the future activities towards above mentioned pending issues that are considered more critical for standardization.

Particularly, the following are the key points identified:

1. *Validation of SRS*: It must be considered in EGNOS-related future activities.
2. *Development of guidance on how to deviate safely from prescribed critical user receiver parameters*: receiver specifications is a key point to consider (only preliminarily analysed), crucial to favour the use of COTS receivers in order to facilitate the achievement of a positive business case (especially for vehicle owners).
3. *Degraded modes when augmentation is unavailable:* this topic is not currently addressed.

4. *Support for reception of SBAS SIS directly by LOC-OB*: This topic was extensively discussed in the past projects (e.g. STARS), however a partner sees the need to preserve this interface to be potentially used in regional line solutions. It was agreed that the GA-OB SBAS SIS interface will be left open for further assessment. Anyway, further study is needed to evaluate impact and concepts for its potential usage (e.g., separate channels for processing SBAS messages received via SIS and from trackside; currently it is noted in the SRS that information from SIS and trackside shall not be mixed due to impact on safety, however, this could be further assessed) and the related benefits (respect of using only GA information).

5. *Commitment at PR level activity for rail safe applications* given the fact that some results is expected soon from maritime sector.

10.2 Digital Map: Key Inputs towards TSI

The discussion held within WP5 on the topic of DM is the first one focused on safe train positioning. It highlighted the need to converge on various aspects to reach a specification regarding the use of DM to support the LOC functionality. Within this topic, there are activities that have started within SP (e.g. Transversal CS and Traffic CS) and IP (e.g. WP21, WP22, and WP27). These activities can benefit from the observations made in WP5 and serve as a starting point for further discussions. Additionally, concepts that have reached a mature level can be reused. A summary is given in this section.

Starting from DM data, the feedback by WP5 on pros and cons of the preferred mode to describe track axis (point-based versus vector-based track geometry) showed that most partners are in favour of a point-based representation; other partners (at least one) are in favour of a vector-based representation. Here, it is necessary a convergence to select the preferred approach and the consequent definition of data structures into data model.

Further, considering the new activities started on DM topic, it is important to verify if the information set identified in section 9.2.1 is present in the Data Model being formalized in SP. If it is not present, its integration should be planned.

The last workshop organized on September 29th (meeting minutes available at the following link ***https://www.cooperationtool.eu/projects/goto.aspx?p=X2RAIL-5&doc=33de230d-538a-4c1d-ad9e-44e3d4cb4e04***) by WP5 benefited from the extraordinary participation of some representatives from SP and IP, allowing WP5 members to directly discuss certain pending issues with them. Specifically, the following points were identified:

1. *DM-TS and DM-OB interface for LOC consumer*: Regarding the operational principles and corresponding requirements to be used for the DM-TS and DM-OB interfaces, they are currently not available for the localization function. In the IP, WP27 is currently

awaiting the requirements from WP21 and WP22 on ASTP for the interface and will then perform the necessary analysis together with WP27, WP21/22, X2R4, and X2R5.

2. *Deactivation of the on-board DM Data*: The disconnection between TS and OB (whether it is the interface between RBC and ETCS-OB or the interface between DM-TS and DM-OB) should trigger a deactivation of the on-board Map Data. This is crucial to ensure that the on-board system does not operate using unsynchronized DM Data. The use lifespan of DM (validity times) has not been considered yet due to the assumption that defining a generic safe threshold is difficult. However, due to the increased availability of map data on board (i.e. during disconnection), this concept should be further aligned, for example, within the Innovation Pillar.

3. *DM needs for supporting localization during the SoM scenario:* According to the RCA DM concept, the minimum/maximum required map area for initial loading (Start of Mission with untrusted position) is required by DM from LOC and should be based on the estimated confidence of initial localization without DM data support (if no other solution for initial positioning is available). Whether this functionality is safe or not depends on the question of whether the completeness check regarding sufficiently loaded map data itself is considered safety-related or not (into RCA context, the assumption is that it is safety-related, to replace the safe procedure of passing balises today).

4. Finally, there should be an overall architectural discussion on how important map-supported localization during SoM (Start of Mission) is, depending on the cost/complexity-benefit ratio of such functionality.

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Appendix A: Ownership of results

The following Table 11-1 lists the ownership of results for this deliverable.

Ownership of results			
Company	**Percentage**	**Short Description of share/ of delivered input**	**Concrete Result (where applicable)**
All beneficiaries contributing to WP5	-	The ownership of the WP5 results is shared between the X2Rail-5 beneficiary members of WP5. STS led the WP5 work and the WP5 members contributed to this work. STS and GMV-UK are the authors of this deliverable D5.3 “Contribution to the standardisation activities”.	Contribution to the standardisation activities

Table 11-1 Ownership of results

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