EGNSS-R

European GNSS Navigation Safety Service for Rail

H2020: EGNSS-BASED RAIL SAFETY SERVICE

D030 FINAL REPORT

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VERSIONS OF THE DOCUMENT

Revision	Date	Description
1.0	07/10/2022	First Version of the document
1.1	30/05/2023	Implementation of FR RIDs (see Table 2: Sum-up of FR RIDs implemented in version 1.1) Update the Table 7: DFMC and EGNOS for Rail performance description to add Rang Rate requirements and to complete the definitions

Table 1: Versions of the document

RID references	Sections	Pages	Implementation
GDP-48	Executive Summary, 8		Added executive summary
GDP-49	1.1	16	Added bullet for continuous localisation
GDP-50	1.2	17	Changed date of completion of project
GDP-51	1.2	17	Added the Figure 1-3 with EGNSS-R consortium and roles
GDP-52	3	21	Corrected typo
GDP-53	3.1	21	Removed unused bullet
GDP-54	3.1	21	Added reference of Norway Odometry project
GDP-55	3.3	26	Enlarged the Figure 3-6 – Requirements concerning half confidence interval for position and speed
GDP-56	4.1	30	Corrected typo
GDP-57	4.1	30	Enlarged Figure 4-3 – Overall candidate TLS OBU Functional Architecture
GDP-60	6	46	Explained differences between scenario 1 (with GNSS) and scenario 2 (without GNSS)
GDP-61	6	46	Added order of magnitude for the Net Present Value
GDP-62	7	50	Corrected sentence
GV-63	1.1	16	Corrected sentence

RID references	Sections	Pages	Implementation
GV-65	3.1	21	Changed GSA to EUSPA
GV-67	References, 3.3	26	Add reference for Operational Conditions
GV-69	4.3	36	Added more details about needed kilometres of data for test strategies
GV-72	5	38	Changed "safe" HAS by "Safety of Life" HAS
GV-73	Acronyms and abbreviations		Moved acronyms annex in chapter "Acronyms and abbreviations" and checked all acronyms
GV-68, GV-70, GV-71, GV-76	5 8	38 54	Added information that new requested study about security aspects is necessary for the next step.
FR -ACTION#05	4.1	30	Corrected figure title and added Stanford diagram
GDP-58	4.2		Development on performance requirements guidelines
GDP-59	5		Added recommendation on the consolidation process of TBC performance commitments
GV-75	Executive summary, 6,7		EGNOS service EiS timeframe needs for Rail operators

Table 2: Sum-up of FR RIDs implemented in version 1.1

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APPLICABLE AND REFERENCE DOCUMENTS

APPLICABLE DOCUMENTS

Reference ID	Title
[AD.1]	Contract N°762/PP/GRO/RCH/19/11304 (including annexes) *Contract with the European Commission*

Table 3: Applicable documents

REFERENCES

Reference ID	Title
[RD.1]	D250 - EGNSS GLOSSARY FOR RAIL EGNSSR_D250_WP2_EGNSS-Glossary, v1.0, 01/03/2021
[RD.2]	A Framework for Certification of Train Location Determinization System Based on GNSS for ERTMS/ETCS, July 2018 (Authors : Ales Filip, Salvatore Sabina, Francesco Rispoli)
[RD.3]	Presentation “Norway ERTMS National Implementation”, ERTMS 2022 Conference Valenciennes, 28/04/2022 https://www.era.europa.eu/sites/default/files/events-news/docs/2_-_on-board_implementation_of_ertms_in_norway_-_vincent_garin.pdf
[RD.4]	OCORA-TWS01-101_Localisation-On-Board-(LOC-OB)-Requirements https://github.com/OCORA-Public/Publication/blob/master/06_OCORA%20R2/OCORA-TWS01-101_Localisation-On-Board-(LOC-OB)-Requirements.pdf

Table 4: References

ACRONYMS AND ABBREVIATIONS

ACRONYM	DESCRIPTION
AD	Applicable Document
ADS	Airbus Defence and Space
ANSP	Air Navigation Service Provider
APIS	Authorization for Placing Into Service
AsBo	Assessment Body
CAPEX	CAPital EXPenditure
CBA	Cost Benefit Analysis
CC	Commercial in Confidence
CCS	Control-Command and Signalling subsystem
CENELEC	European Committee for Electrotechnical Standardization
CI	Confidence Interval
CST	Common Safety Target
DeBo	Designated Body
DFMC	Dual Frequency and Multi-Constellation
EASA	European Union Aviation Safety Agency
EC	European Commission
EDAS	EGNOS Data Access Service
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European GNSS (EGNOS and Galileo)
EGNSS-R	European GNSS Navigation Safety Service for Rail EGNSS-based Rail Safety Service
ERA	European Union Agency for Railways
ERGO	Panel of Experts in Rail for EGNSS Operational use
ERTMS	European Rail Traffic Management System
ESA	European Space Agency
ESP	EGNOS Service Provider
ESSP	European Satellite Services Provider
ETCS	European Train Control System
ETSI	European Telecommunications Standards Institute
EU	European Union
EUG	ERTMS User Group
EUSPA	European Union Agency for Space Programme
EVC	European Vital Computer
FDE	Fault Detection and Exclusion
FE	Feared Event
FOG	Fiber Optic Gyros
FRMCS	Future Railways Mobile Communication System
GEO	Geostationary Earth Orbit
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSA	European GNSS Agency
GSM	Global System for Mobile communications

ACRONYM	DESCRIPTION
H2020	European Union’s Horizon 2020 research and innovation programme
ICAO	International Civil Aviation Organization
IGSO	Inclined GeoSynchronous Orbit
IM	Infrastructure Managers
IMU	Inertial Measurements Unit
INS	Inertial Navigation System
IR	Integrity Risk
ISO	International Organization for Standardization
ITU	International Telecommunication Union
KF	Kalman Filter
LEO	Low-Earth Orbit
LTC	Long Terms Corrections
MCI	Maximum Confidence Interval
MFCI	Maximum Feasible Confidence Interval
MOCI	Maximum Operational Confidence Interval
MOPS	Minimum Operational Performance Standard
N/A	Not applicable
NMA	Navigation Message Authentication
NoBo	Notified Body
NPV	Net Present Value
NSA	National Safety Authority
OBU	On-Board Unit
OPEX	Operational Expenditure
OS	(EGNOS) Open Service
PL	Protection Level
PNT	Positioning Navigation and Timing
PTC	Positive Train Control
PU	Public
PVT	Position, Velocity and Time
R&I	Research and Innovation
RAIM	Receiver Autonomous Integrity Monitoring
RAMS	Reliability, Availability, Maintainability and Safety
RBC	Radio Block Centre
RD	Reference Document
RTCA	Radio Technical Commission for Aeronautics
RTK	Real Time Kinematic
RU	Railway Undertakings
S2R	Shift2Rail
SBAS	Satellite Based Augmentation System
SDD	Service Definition Document
SIL	Safety Integrity Level
SiS	Signal in Space
SLA	Service Level Agreement
SNCF	Société Nationale des Chemins de fer Français
SoL	(EGNOS) Safety of Life (SoL) Service

ACRONYM	DESCRIPTION
STARS	European Union's Horizon 2020 R&I program Satellite Technology For Advanced Railway Signalling project
THR	Tolerable Hazard Rate
TIM	Train Integrity Management
TLOBU	Train Localisation On-Board Unit
TLS	Train Localisation System
TSI	Technical Specification for Interoperability
TTA	Time To Alert
UCP	User Consultation Platform
UDRE	User Differential Range Error
UNISIG	Union Industry of SIGnalling
WAAS	Wide Area Augmentation System
WP	Work Package
WUL	Worst User Location

EXECUTIVE SUMMARY

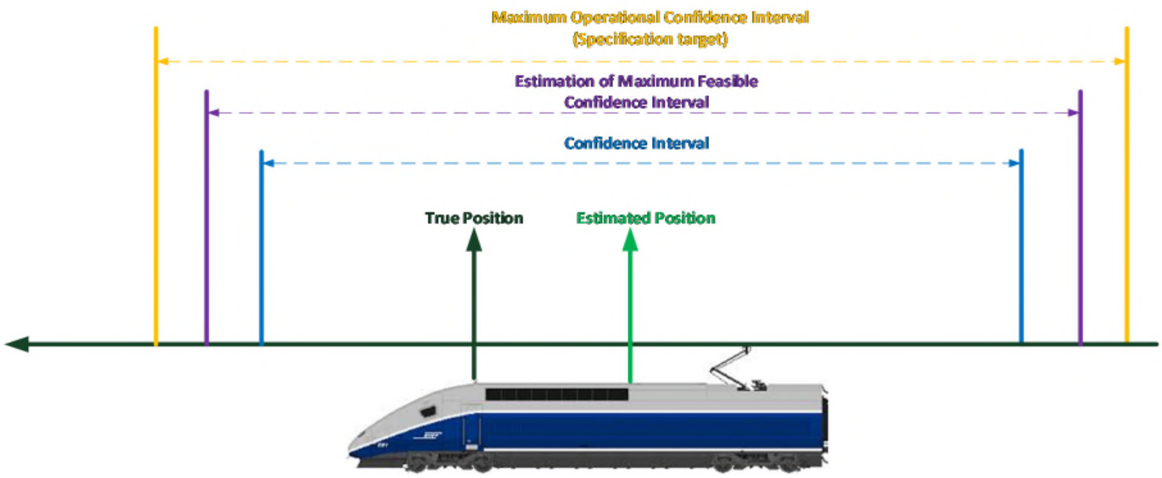
Safe on-board localisation of trains using GNSS services is a key enabler for signalling systems digitalisation and evolution towards higher ERTMS levels. This represents also a potential improvement of costs, accuracy, availability, capacities and predictability of train operations.

The EGNSS-R (European GNSS Navigation Safety Service for Rail) project objectives are:

- to analyse the needs and requirements of rail users (operators) for adopting train localization using EGNSS for Safety-of-Life applications
- to propose a localization integrity concept and a preliminary definition of a future EGNSS for Rail safety service
- to identify and give a preliminary evaluation of the decision criteria for adopting this new EGNSS service
- to elaborate a comprehensive service implementation roadmap, covering service development, rail standardisation, rail infrastructure evolutions and solution products development and deployment

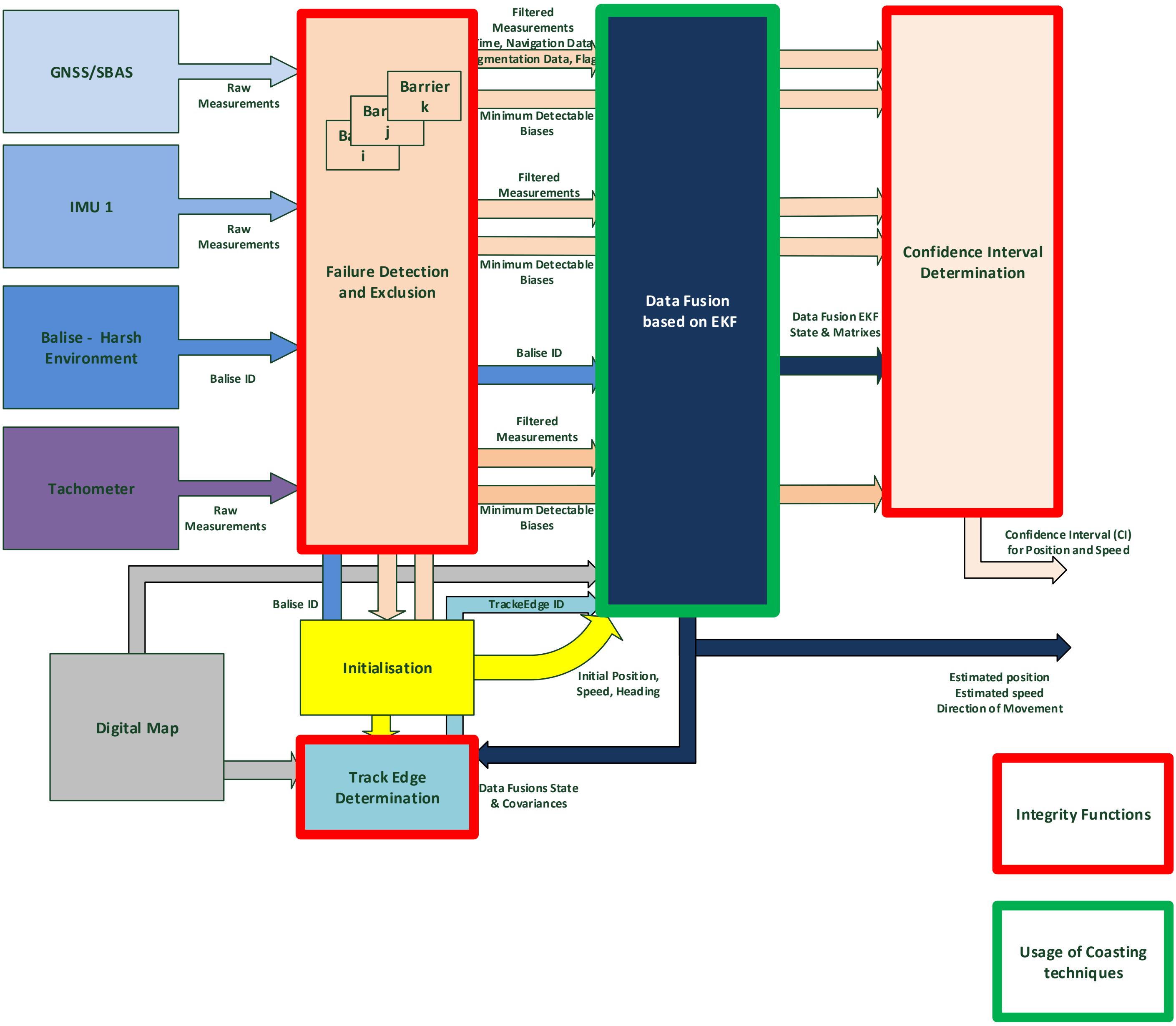
These requirements are highly demanding both in terms of performance (accuracy, safety level, integrity risk and availability) and in terms of operational environment adversity (masking, multi-path, diffraction, etc.). Better performance and robustness are required than for aviation, of which needs are covered by EGNOS and Galileo operational or soon-to-be services, including EGNOS V3.

A novel integrity concept is proposed based on the budget allocation for each integrity risk, an analysis of feared events subject to occur for each sensor and integrity management through Fault Detection and Exclusion (FDE) algorithms and computation of Confidence Intervals on position and speed for safety-critical applications. The Train Localisation System (TLS) localisation algorithms combine several sensor measurements and the integrity risks are defined in the train position domain (position, speed). As the EGNSS Service for Rail cannot guarantee alone the integrity risk in the train position domain, the GNSS/SBAS integrity risk is defined at pseudo-range level (input to the fusion algorithms).



Configuration for Train Localization Solution / EGNOS service to be compliant with a given MOCI requirement (MFCI < MOCI)

The proposed service definition of the EGNSS-based Rail Safety Service (EGNOS for Rail and Galileo) is based on this integrity concept and generally enables **the use of tightly-coupled multi-sensor fusion algorithms** for Safety-of-Life positioning, allowing to envision compliance to the stringent integrity rail requirements on localization. This approach requires on one side innovative algorithms for CI computation, taking into account explicitly time correlation and biases of errors that would lead to unsafe protection level if based on standard fusion filters.



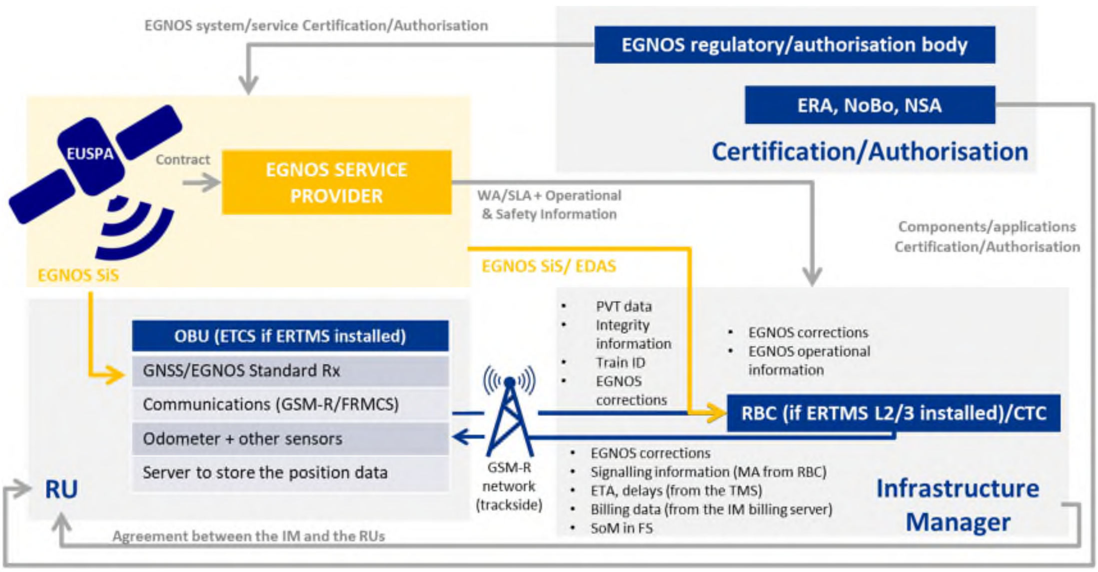
Overall candidate TLS OBU Functional Architecture

For GNSS/EGNOS measurements, these parameters could be determined by the EGNOS system. They can be provided either as pre-assessed static parameters, in the form of commitments associated to the Service Definition, necessarily worst-case, or as dynamic parameters, evaluated in real-time and broadcast by a future EGNOS service. The second approach will allow better performance, especially in harsher environment.

Reaching an Integrity Risk requirement of the order of 10-9/h on along-track position and speed is a difficult challenge that will require high performance FDE.

Service implementation and provision require the involvement of all actors with the following roles:

- The EGNOS Owner (European Commission): to maintain the service with evolution and finance, to accept service for the rail;
- The EGNOS Program Manager (EUSPA): to maintain the service by delegation to EC and to check compliance of the EGNSS-based Rail Safety Service Provider regarding the rail service;
- The Airspace/Support Industry: to support the EGNOS Programme Manager in the maintenance and development of the system, as well as providing support systems;
- The EGNOS Service Provider (ESP): To develop, tailor and deliver the service in accordance with the SDD for the service, to set-up and execute the different engineering and maintenance activities and support rail users;
- The Infrastructure manager: to receive operational data about the service and to react adequately, to maintain the trackside equipment for the provision of the service;
- The end-users: to equip trains with certified Train Localization Systems, including GNSS/SBAS receivers following requirements for using the EGNSS-based Rail Safety Service.



EGNSS-R proposed Service Provision Scheme

After identifying decision criteria such as rail standardisation and target market time and price, a simplified generic Cost Benefits Analysis showed that GNSS ERTMS Level 3 is likely to bring value to Infrastructure Managers (IM) and Railway Undertakings (RU), providing a global approach with monetization of benefits on Track, Rolling Stock and passenger traffic.

The economic justification is driving the decision of railway stakeholders (IM, RU and industrials). However the schedule of EGNOS service up to Entry-into-Service (EiS) is also of primary importance for the sector to endorse EGNSS. Given the official horizon of ERTMS deployment by Rail operators on their Core Network by 2030, adoption of EGNSS for safe train positioning requires that an EGNOS service for Rail is available by the end of the decade with sufficient performance figures.

For the sake of budget and schedule, it is recommended to build the EGNOS for Rail safety service on the basis of the EGNOS system planned for providing the DFMC service for aviation (EGNOS V3).

In complement to EGNOS services, the use of the Galileo OS-NMA service will increase security for the EGNSS rail service thanks to the authentication of the Galileo messages. Security could be enhanced later on with other services such as the Commercial Authentication Service of Galileo or the CHIMERA service of GPS by authenticating ranging and signal. Besides, the first mandatory step is to consolidate the security requirements to be applied to the GNSS services in the Train Localisation System.

Definition of regulations, assessment of service operation and maintenance is a necessary step to undertake as soon as possible with railway stakeholders and notably ERA in order to consolidate the necessary budget for service operation and maintenance.

The proposed global roadmap develops several activity streams, managed by different stakeholders that are inter-dependent and must run in parallel. Coordination, synchronization and anticipation by all stakeholders will be paramount.

- Standardisation: ERMTS TSI milestones, possibly in 2025, and in more likely in 2027
- Upgrade of rail infrastructures including communication network and roll-out
- Development of train localisation solution products
- Certification of train localisation solution
- EGNSS Services: EGNOS and Galileo systems upgrades, service certification and service provision

The proposed service implementation roadmap for the adoption of Train Localisation System with EGNSS consists in two steps, that are complementary and both recommended:

- a **short term step, called "DFMC for Rail", with availability of service in 2028**, based on EGNOS DFMC messages disseminated via the GEO SiS (same messages as for aviation), associated with written commitments (not part of the messages but to be included in specific SARPS and MOPS for Rail services):
  - performance commitments at pseudo-range level
  - performance commitments on additional parameters(static worst-case values)
  - guidelines for service usage in OBU algorithms
- a **second step, called "EGNOS for Rail" with availability of service in 2030, based on a** an evolution of the EGNOS V3 system for:
  - provision of additional parameters in broadcast messages (dynamic values replacing static commitments), including range rate corrections and integrity bounds
  - SoL terrestrial gate for safe dissemination to rail terrestrial networks (e.g. FRMCS)

  This service would also be associated with performance commitments for performance prediction and guidelines for service usage in OBU algorithms.

If ERTMS TSI does not takes place in 2025 or does not fully covers updates necessary for localization using E-GNSS, DFMC for Rail service will not be formally certified, but it should still be implemented as a first experimental step for supporting standardisation (through demonstrators) and for allowing incremental development of train localisation solution products.

A critical action in the roadmap is to **accelerate the preparatory work towards the update of railway regulations** to include the usage of EGNSS in ERTMS standards and the certification process of EGNOS in rail domain

Proposed next steps are the following:

- **Share and consolidate roadmaps** with all stakeholders to accelerate adoption and start activities in each domain for reaching the timeline target of operators: introduction of GNSS-based localisation units from 2030.
- **Perform further performance analyses** for assessing the relative performance figures expected at user level of the different EGNOS for Rail sub-services options (EGNOS V3 Legacy, EGNOS V3 DFMC for Rail, EGNOS for Rail) and confirming the benefits for rail operators to use EGNSS. These analyses require taking assumptions on performance commitments on additional parameters for short-term services, and also assumptions on achievable performance macro-models for EGNOS for Rail additional parameters. Both require a deep knowledge of EGNOS V3 algorithms and their potential evolutions.
- **Complementary work on operational requirements**, especially on security, integrity (safety level), maximum operational confidence interval (MOCI) requirements according to more specific operations criteria, availability and continuity.
- **Perform further Cost-Benefits Analyses**, including more parameters, more precise computation and application on various business cases in several countries, enabling a European convergence.
- **Procurement and development of DFMC service demonstrator (testbed), followed by development of EGNOS for Rail service testbed (based on preliminary processing algorithm prototypes)**
- **Define preliminary performance commitment parameters** and models for the short term service "DFMC for Rail " for allowing usage of the DFMC service demonstrator for Rail

1 INTRODUCTION TO EGNSS-R PROJECT

This document is the Final Report of the European GNSS Navigation Safety Service for Rail study, also called "EGNSS-R" hereafter. It summarises the activities conducted by the consortium and their outcomes:

- to analyse the needs and requirements of rail users (operators) for adopting train localization using EGNSS for Safety-of-Life applications
- to propose a localization integrity concept and a preliminary definition of a future EGNSS for Rail safety service
- to identify and give a preliminary evaluation of the decision criteria for adopting this new EGNSS service
- to elaborate a comprehensive service implementation roadmap, covering service development, rail standardisation, rail infrastructure evolutions and solution products development and deployment

1.1 Context

Safe on-board localisation of trains using GNSS services is a key enabler for signalling systems digitalisation, paving the way for promising concepts such as the moving block. This represents also a potential improvement of costs, accuracy, availability, capacities and predictability of train operations. For this purpose, new localisation systems based on sensor hybridization and using GNSS (Global Navigation Satellite Systems) are studied, with both objectives of to assess feasibility (proof-of-concept) and to prepare rail standards in the frame of ERTMS.

The European Commission is defining the roadmap for the evolution of the European GNSS programme, including new services of Galileo (European GNSS constellation) and EGNOS, on the basis of the needs expressed by the user communities, including Railways. EGNOS is the European Satellite Based Augmentation System (SBAS) developed for improving the performance of GNSS (such as GPS and Galileo) in term of accuracy and integrity information of the GNSS positioning with a continuous monitoring of the continuity and availability of the signal in the space and associated services, enabling Safety-of-Life positioning application.

In this context, projects like STARS or CLUG have been engaged with objectives to fill the gap in the ERTMS needs for safety critical applications and GNSS services and to provide a preliminary feasibility study of an on-board localisation unit. Two approaches using GNSS are considered:

- Virtual Balise: based on replacing physical trackside balises by virtual ones corresponding to a GNSS position, this solution minimizes changes of on-board architecture but maintains the on-board odometer and associated overall performance.
- Continuous localisation: this new and modular approach aims at minimizing trackside equipment and replacing also the on-board odometer by delivering continuously the train localization data (position, speed, track occupancy, etc.). This solution requires more evolutions in the ERTMS standards.

An EGNSS Safety Service for Rail shall be defined for adoption in both approaches. Like for aviation, the main challenge when using GNSS for train localization is matching integrity requirements (i.e. the level of trust that can be placed in the correctness of the position, the velocity or the time estimate provided by the localization function).

Figure 1-1 – High-level architecture of the train localization system considered in the EGNSS-R project

The EGNSS-R project focuses on the GNSS service part for the train localisation system illustrated on Figure 1-1, the train on-board part performing the localization function being the also called the On-Board Unit (OBU). The service definition proposed in the frame of this study aims at being adopted by several potential OBU design approaches, including continuous localization based on tightly-coupled fusion of multiple sensors to provide localisation and speed.

The following definitions will be used throughout this document:

- TLS is used for “Train Localisation Solution”
- OBU is used for “Train Localisation On Board Unit”, the on-board component providing the train localisation function
- “EGNSS for rail” is used as the generic term for the safety service providing information (signals, data …) by GNSS/EGNOS dedicated to the rail sector.

1.2 The project

The EGNSS-R project started on September 2020 and has been completed on November 2022. Funded by the European Commission, this project answered the EC call 62/PP/GRO/19/11304 and was conducted under technical supervision of European Union Agency for Space Programme EUSPA (ex GSA). The EGNSS-R project aimed at defining the future EGNSS-based rail safety service for train localization systems.

The consortium was composed of Airbus Defence and Space (leader), SNCF and FDC. ESSP, sub-contractor of Airbus Defence and Space, brought their unique experience on SBAS Service Provision.

The main objectives of EGNSS-R were:

- to collect and define mission requirements of the safe localization function for railway applications;
- to propose a definition of a future EGNSS-based rail safety service;
- to identify service adoption decision criteria and to elaborate a roadmap for service implementation, outputs for the evolution process for the future ERTMS TSI post 2022.

The study work packages logic is presented in the following figure:

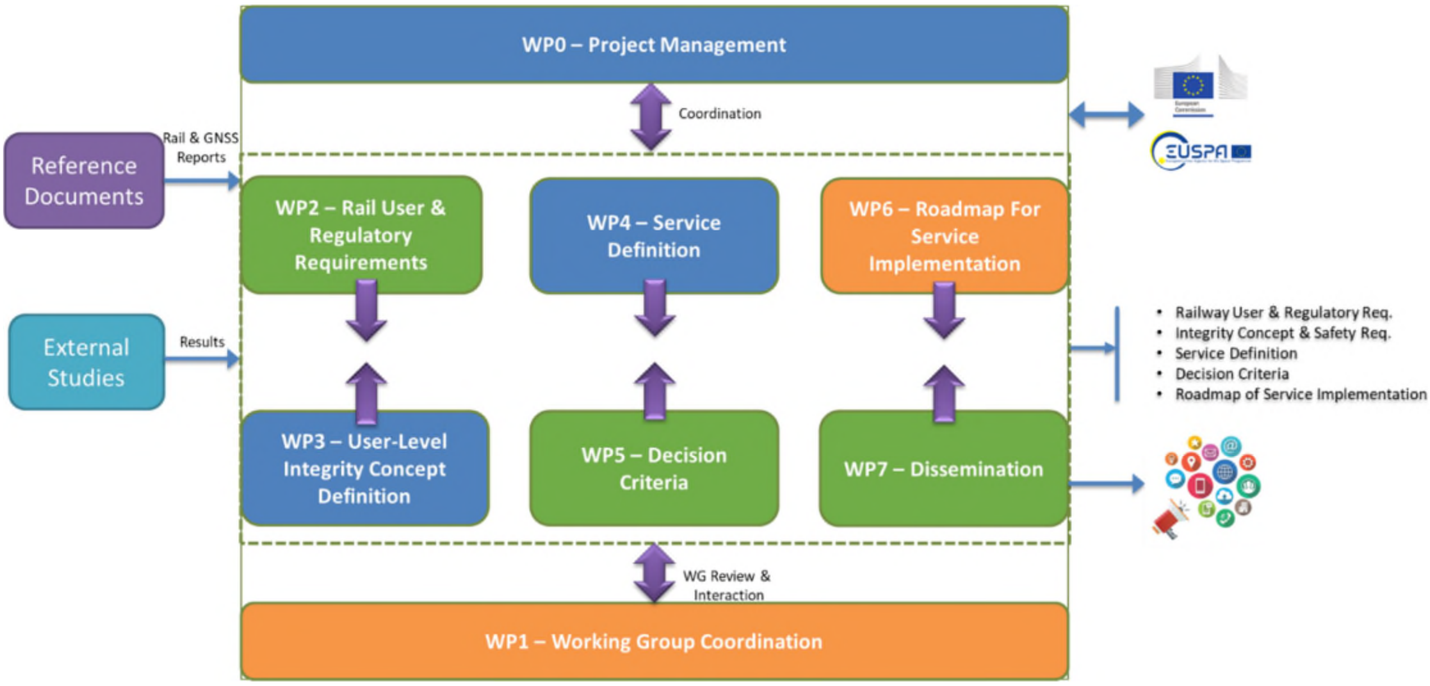


Figure 1-2 – EGNSS-R study logic

The first part of the study in work package WP2 consisted to collect needs about PNT by rail operators and to identify legal and technical framework. In work package WP3, the integrity concept was defined for the new service of localisation using the EGNSS for rail. The EGNSS-based Rail Safety Service for rail was then described in the work package WP4. The work package WP5 provided service adoption decision criteria and a cost benefits analysis. The service implementation roadmap proposed in work package WP6, includes two steps, short-term and mid-term, that are complementary and both recommended.

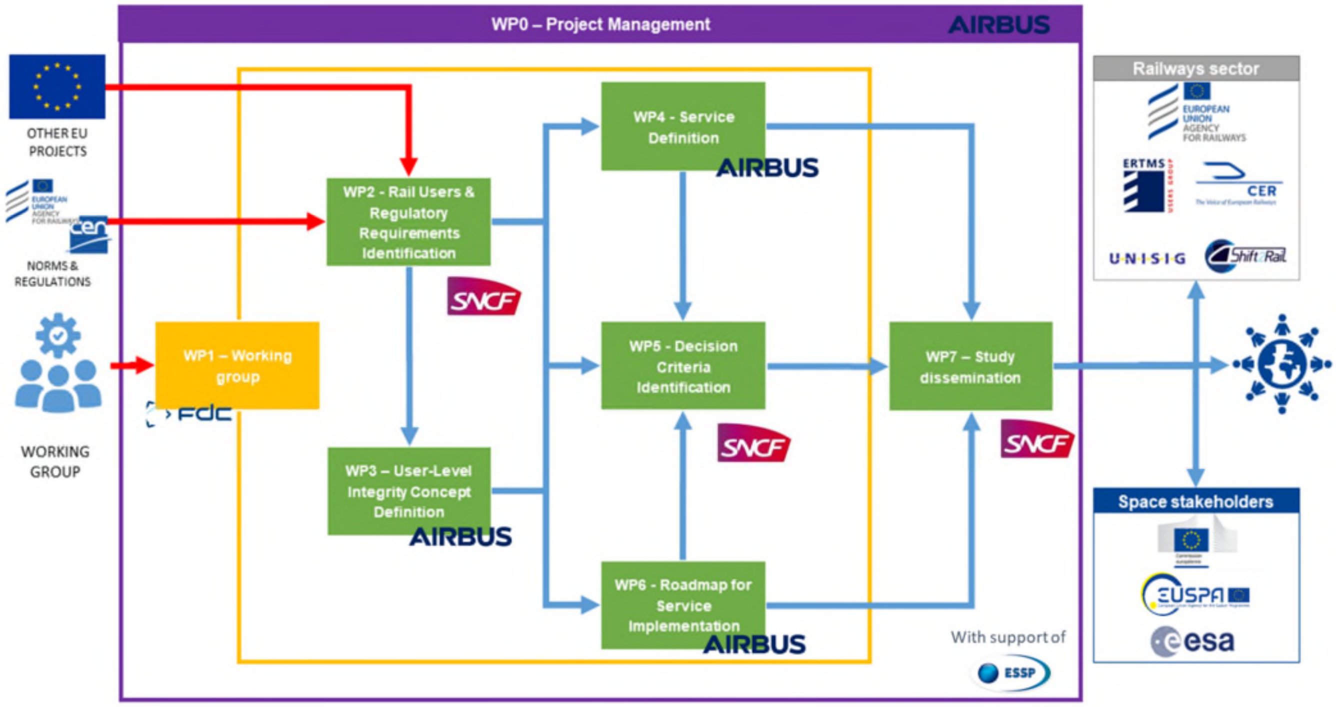


Figure 1-3 – EGNSS-R Consortium & roles

All along the project, the consortium exchanged outcomes with a wide panel of Rail stakeholders and EGNSS actors, the ERGO Panel, in the frame of working sessions, the so-called ERGO panel workshops. Work package WP1 was dedicated to the organisation of these exchanges and workshops.

2 WORKING GROUP COORDINATION

End of year 2020, the European Union Agency for the Space Programme (EUSPA) initiated a working group gathering key rail and GNSS experts in order to assist the Agency in consolidating and validating the EGNSS-based Safety Service for rail and in line with the European Rail Traffic Management System (ERTMS) standards. This group, called ERGO (Experts in Rail for EGNSS Operational use) aims at supporting and feeding the decision process to implement EGNSS safety service for rail.

The EGNSS-R consortium had the opportunity to consult the panel members individually or collectively in dedicated meetings and to collect inputs or get feedback for consolidating the study outcomes.

The consortium organised and participated to four main meetings with the college of ERGO experts:

- ERGO #1 (16/12/2020): Presentation of the study: consortium, organisation, objectives and work plan.
- ERGO #2 (01/02/2021): Discussion and validation of WP2 results (user needs and requirements for rail signalling and train control applications)
- ERGO #3 (05/10/2022): Discussion and validation of Integrity concept proposed by WP3 and high-level roadmap for the service implementation
- ERGO #4 (16/02/2022): Presentation of Service definition, decision criteria for service adoption and roadmaps

Feedbacks and improvements collected during these meetings were included in the EGNSS-R project documents.

3 RAIL USERS & REGULATORY REQUIREMENT IDENTIFICATION

The WP2 aimed at analysing PNT for railway critical applications under both technical and economical approach worldwide. A dedicated share of this work focused on EGNSS role and costs, and their related implications for railway and Europe.

Indeed, a large variety of projects have been or are currently developed in Europe for PNT application, several of them already with EC, EUSPA or ESA support. Some were reused in this project to match its short timing and capitalise on EC's previous investments. A complete review of the available PNT solutions suitable for railway was done and is summarised in section 3.1.

The consortium analysed the shape of Europe current PNT and innovation market. Particular care has been given to legal constraints and user needs, summarized in section 3.2, 3.3 and 3.4.

A glossary is available [RD.1] with the aim to provide definition of EGNSS terms and concept adapted to the rail as it has been defined in ENGSS-R project. Hence, EGNSS wording concerning aviation has been tailored to the rail sector.

3.1 THE EUROPEAN PNT LANDSCAPE FOR RAIL SAFETY APPLICATION ANALYSIS

The train localisation system data are used by many consumers on-board and off-board the train through a unique distributor, the European Vital Computer (EVC). Consuming applications can operate on the trackside, i.e., out of the train, or on-board the train. Train consumers are classified into safety and not safety relevant applications. The study focuses particularly on safety railway critical applications such as Train Integrity Monitoring (TIM) and Train Protection (TP) since they require the most stringent specifications for the localisation solution. The current train localisation technology, in the European Train Control System (ETCS), is based on trackside sensors (i.e., balises) and odometry. A possible evolution to remove these physical elements on the track could be the virtual balise concept.

Collected from different inputs of previous European projects (e.g. STARS…), the potential technologies for next localisation solution for train could be based on:

- EGNSS that consists in augmentation systems as EGNOS or RTK and GNSS systems as Galileo.
- Inertial sensors (e.g., FOG INS) for railway PNT solutions.
- Map-based PNT solution (no information are provided here since this could be delivered by other on-going EUSPA projects such as CLUG or RAILGAP).

Hereafter some train PNT solutions results of the above-mentioned technologies are presented:

- **EGNSS SNCF (test field result in crossing bridges area)**

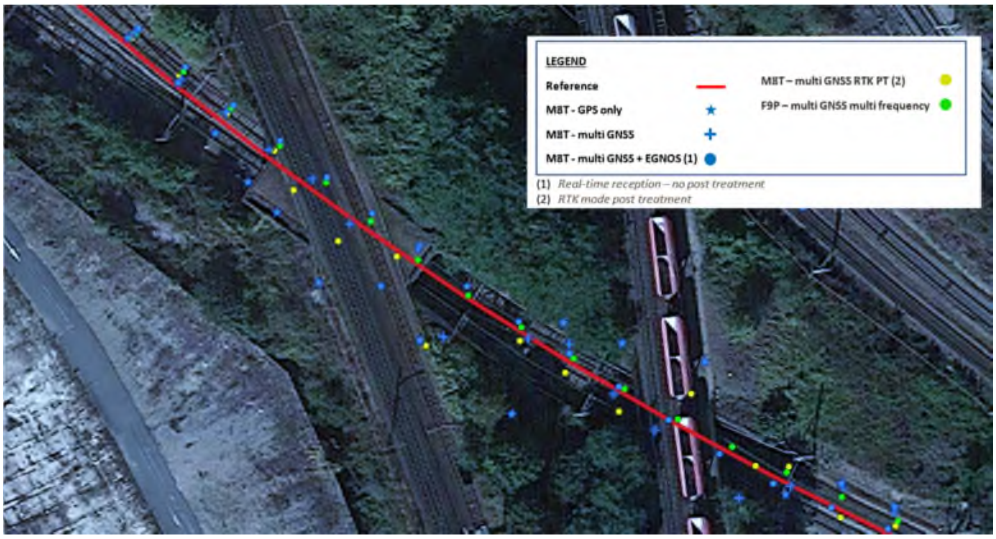


Figure 3-1 – Illustration of localisation test result done by the SNCF using EGNSS sensor

- **INS (SNCF test field result in dense foliage area)**

Figure 3-2 – Illustration of localisation test result done by the SNCF using INS sensor

From worldwide train PNT-based solutions, the provided examples are the Norway enhanced odometry project (see [RD.3]) of the Bane Nor (Norway state-owned railway agency). The system was based on Alstom solution that rely on GNSS/INS data fusion and the PTC (Positive Train Control) solution. It was developed in North America based on digital map, INS, GNSS and WAAS. It has been concluded that Alstom solution brings better robustness to the system but not better accuracy performance. The PTC is still under second step of tests to remove the human track initialization.

To analyse the different existing PNT solutions, several criteria in relation with safety critical concern have been identified:

- Safety
- Along track position
- Track selectivity
- Speed
- Availability

After the high-level analysis, it is recommended to use an architecture relying on:

- GNSS,
- SBAS augmentation,
- good medium grade IMU,
- map,
- odometry

The fusion process of these sensors achieves all performance requirements with high probability.

Type	Estimated Price (1)	Along-track position	Track selectivity	Indoor (3)	Speed	Availability	Safety
GNSS low cost / IoT + augmentation	<500 €	😐	☹	☹	☹	☹	☹
High grade GNSS + augmentation	3 - 12 k€	🙂	😐	☹	😐	😐	☹
GNSS + augmentation + low grade IMU + map + odometry	8-12k€	🙂	🙂	🙂	🙂	🙂	😐
GNSS + augmentation+ good medium grade IMU + map + odometry	30 – 40 k € (2)	🙂	🙂	🙂	🙂	🙂	😐 (4) 🙂

(1) Standalone devices (integration inside train not included, additional)

(2) Would have maximum CAPEX cost per localisation unit, unit prices

(3) Indoor stand for GNSS denied areas, e.g. tunnels or roof coverage

(4) Strong challenge

Figure 3-3 – Table issued from high-level analysis to compare different existing PNT solutions

These analyses could be extended in future work to cover not safety related applications in order to draw a complete analysis including additional parameters i.e., accelerations and attitudes.

3.2 European railway Legal requirements & regulation regarding rail safety

The European railway safety regulatory framework is composed on three main pillars:

- European directives, which aim at defining interoperability and safety framework. Technical Specification for Interoperability, Common Safety Methods and Safety Management Systems are the European regulations derived from these directives
- National rules which are adopted in a European Member State and contain railway safety or technical requirements
- EN standards such as CENELEC standards, which are electrotechnical standards. They help developing the Single European Market/European Economic Area for electrical and electronic goods and services

Figure 3-4 – Overall description of European railway safety regulatory framework

This regulatory framework defines railway safety requirements based on identified railway risks. A classification specific to each country is provided regarding their severity. Safety requirements are of two types:

- Safety quantitative objectives are defined function to system level, Common Safety Target (CST), Risk Acceptation criteria and Tolerable Hazard Rate (THR). The standard EN 50129 from CENELEC apply these objectives to each railway function by associating a Safety Integrity Level (SIL). A correlation is performed between THR and SIL to present maximal acceptable occurrence of system failure regarding its potential impact (see Table 6).
- Safety qualitative objectives are defined in case of simple random failure, to be ensured that safety critical systems are still fail-safe. Following methods are applied to these objectives: composite safety, reactive safety and intrinsic safety.

Safety integrity level	Probability of dangerous failure per hour	Consequence of a failure
SIL4	10^{-9} < THR ≤ 10^{-8}	Several possible dead people in surrounding community
SIL3	10^{-8} < THR ≤ 10^{-7}	Several possible dead people
SIL2	10^{-7} < THR ≤ 10^{-6}	Possible serious wounded people or one dead person
SIL1	10^{-6} < THR ≤ 10^{-5}	Possible minor wounds
SIL0	No requirement	N/A

Table 5: EN 50129 SIL and THR correlation

The safety conformity assessment is defined by internal standard (ISO/IEC 17000) as procedures or by European regulations (Commission decision (EC) 768/2008 and Commission decision (EU) 2010/713) as modules.

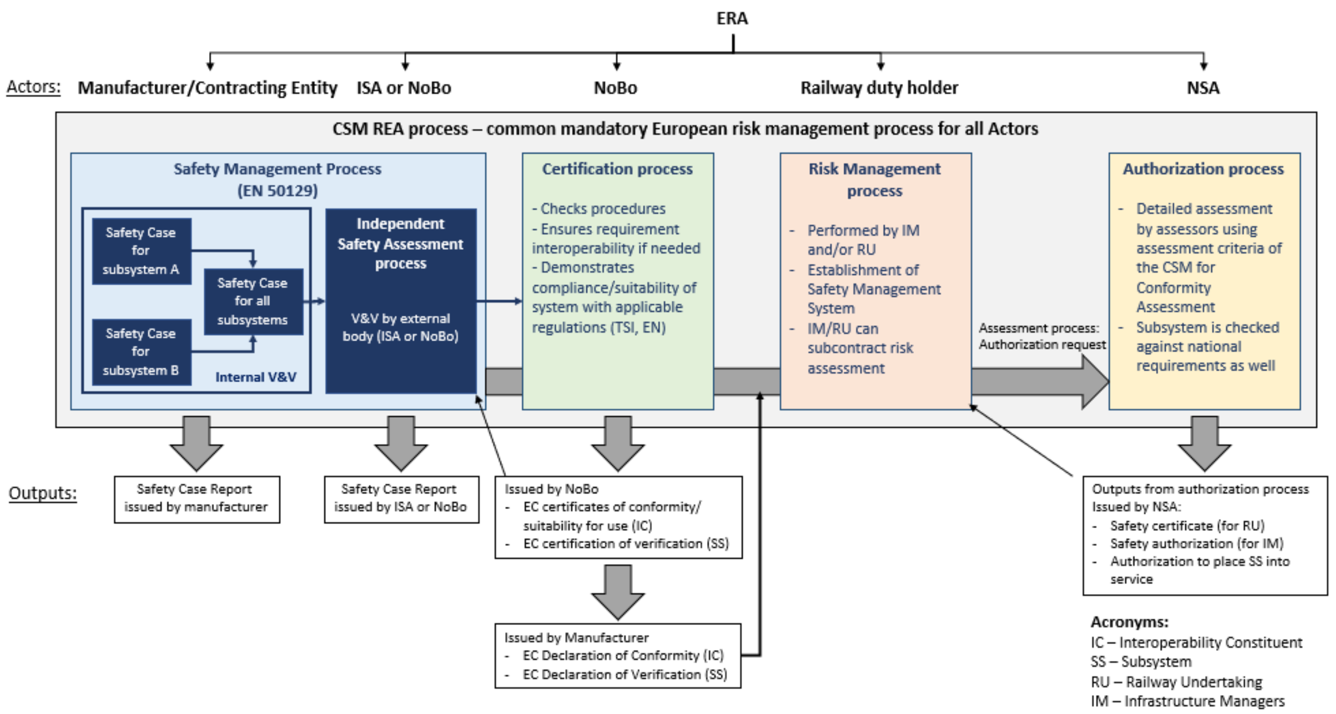


Figure 3-5 – Railway safety conformity assessment process ([RD.2])

At the end of the conformity assessment process, the Authorization for Placing Into Service (APIS) is delivered to a system or a subsystem. The certification and authorization for placing in service new Interoperability Constituent (IC) is expected to include three main activities:

- EC declaration of Conformity, issued by Applicant, with respect to specifications (i.e. certification of IC's conformity assessed by Notified Body)
- EC declaration of verification of a subsystem, performed by Applicant (i.e. Certificate of verification assessed by Notified Body)
- Authorization for the placing in a service of a new system/subsystem by Member State (MS)/ railway National Safety Authority (NSA).

In the railway sector, the ERA defines requirements through the ERTMS/ETCS documents on following parameters:

- Train position
- Track selectivity
- Train orientation and direction of movement
- Train velocity

For the EGNSS current regulatory framework, the EGNOS SoL Service is designed to be used in safety-critical transport applications. However the EGNOS SoL service requirements have currently only been issued in civil aviation. Regulations (CE) 550/2004 and (EU) 2017/373 are applied for service provision. The EGNOS safety requirements contains risk classification, quantitative system and software safety requirements and qualitative safety requirements. In addition to EGNOS SoL Service regulation documents, EGNOS user segment (i.e. SBAS receivers embedded on aircrafts) are specified by SBAS Minimum Operational Performance Standards (MOPS) which are published by the Radio Technical Commission for Aeronautics (RTCA).

Finally, a first comparison of EGNSS and rail legal constraints indicates that adaptation with an ad-hoc tailoring is required for the EGNSS Rail Safety service as for the sector environment, the movement dimensions and the position needs. The EGNOS SoL Service Provider shall be adapted to the rail service.

3.3 EUROPEAN RAILWAY USERS CURRENT NEEDS REGARDING RAIL SAFETY SERVICE

The EGNSS-R study aims at identifying and analysing railway users' requirements for train localisation using EGNSS safety services. The European railway regulatory was provided based on ERTMS subsets which were written by EUG and UNISIG that evolves railway industrials. The main used input is the subset-041 since it contains metrics that define what should signalling systems perform. Further regulatory was driven from TSI and EUG based on their guidelines for the next ERTMS L3 which is still being defined currently through TSI reviews, as the update of localisation standards in TSI, is planned in May 2022, with an initial Railway Interoperability and Safety Committee (RISC) meeting and will enable the use of GNSS in railway signalling systems.

The EUG guidelines were considered as a complement to subset-041. Please note that they focused only on the needs for track selectivity at the time of the project. The scope of requirements in EGNSS-R encompass all localisation needs.

Safety and non-safety critical requirements of the train localisation system (TLS) and its on-board unit part (OBU) that are relevant for the definition of the EGNSS-R safety service for Rail have been produced. They were collected on the basis of the European railway regulatory, operators' recommendation, internal SNCF ongoing projects (e.g., CLUG) and the User Consultation Platform (UCP) report to ensure as much as possible consistency with rail application definitions and common requirements identified for all safety critical applications.

Requirements were elaborated following a rational methodology: first collect and analyse the needs of the rail applications using localisation (localisation consumers), then deriving the TLS requirements so as to fulfil the mission needs. Non-functional needs were specified at the highest possible level. This approach is believed as an advantage for future European standardisation discussions.

The main safety critical requirements are reproduced below.

Position integrity. In safe operation, the OBU shall provide train position, train speed and train direction with a Integrity Risk (IR) better than 0.33*10-9 errors per hour

Track selectivity integrity. In safe operation, the OBU shall provide the Track ID identifier of the track occupied by the train with a THR better than 0.66*10-9 errors per hour.

Position accuracy. In safe operation, the OBU shall provide:

- train front end position with a half confidence interval better than 10 m, for speeds lower than 40 km/h, and better than the distance run in 1s, for speeds between 40 km/h and 500 km/h.
- train speed with a half confidence interval better than 2 km/h, for speeds lower than 30 km/h, and better than a value increasing linearly up to 12 km/h at 500 km/h, for speeds between 30 km/h and 500 km/h.

A Confidence Interval is the interval within which the error on position/speed must lie with the probability corresponding to the Integrity Risk.

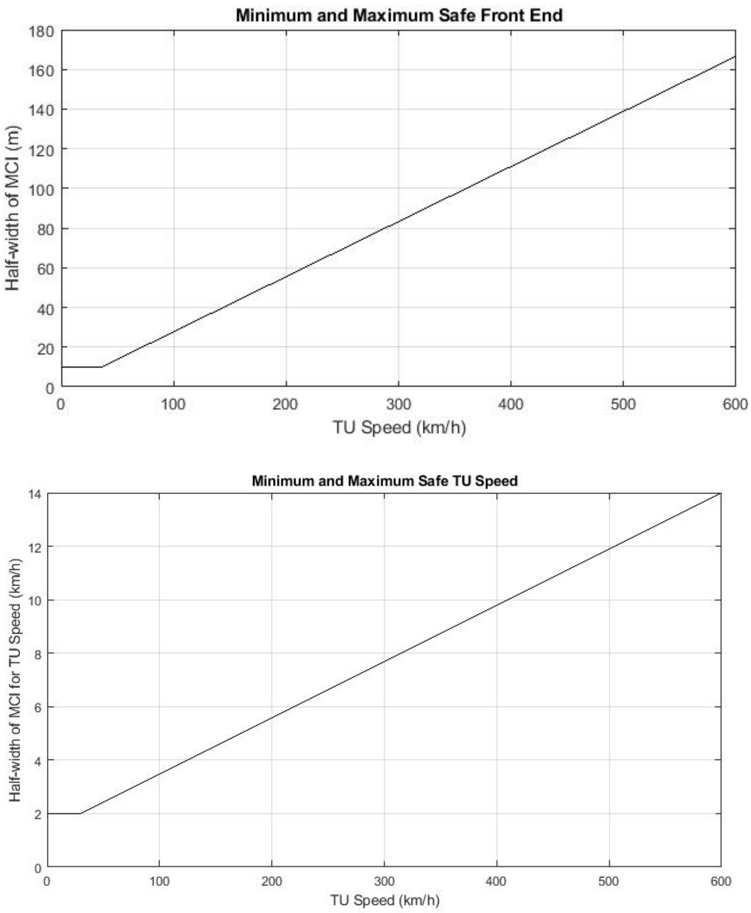


Figure 3-6 – Requirements concerning half confidence interval for position and speed

Start of Mission. The TLS shall reach full operational capability in less than 10 minutes with minimal human supervision

Operational conditions. The TLS shall operate under all railway operational conditions including both nominal and degraded situations defined in the ERTMS regulation (defined in [RD.4]).

These localisation requirements are to the best knowledge available in the consortium at the time of the project. On-going European standardisation activities including in EUG, RCA, OCORA and SHIFT2RAIL are expected to provide further inputs and improvements to these requirements.

3.4 EGNSS FORESEEN CONTRIBUTION IN RAIL SAFETY

Another part of EGNSS-R project aims at analysing present and future contributions of EGNSS in the rail domain, focusing on rail safety service design.

First were identified the available options for the EGNSS contribution to the rail safety service that are viable economically and programmatically in the context of a short-term ERTMS evolution (post-2022).

Following a 4-phase methodological process, a review was carried-out of all existing and short-term planned EGNSS services (i.e., GNSS & SBAS). Based on both the technical characteristics of each EGNSS solution and high-level train localisation requirements, technically feasible EGNSS combination strategies were identified and further analysed through a series of criteria (i.e. main performances, cost sensitivity, schedule, and implementation challenges).

Considering the important expectations in the railway domain in terms of position integrity, it is clear that the provision of an appropriate GNSS integrity concept constitutes the first key building block of a future EGNSS SoL service for rail, yet at the expense of other accuracy and security aspects as a first step.

Based on this outcome, two approaches were presented concerning the evolution of EGNOS for SoL railway applications. The first one consisting in the introduction of rail-dedicated elements inside EGNOS V3 on-going developments; the other one consisting in the development of a new EGNOS service. The second approach is expected to better suits the performance expectations than the first one and it would imply an EGNOS system upgrade.

4 USER-LEVEL INTEGRITY CONCEPT DEFINITION

The objective of the "User-Level Integrity Concept Definition" was to elaborate a concept of integrity suitable for the rail sector up to the definition of associated safety requirement for each of the components (Train Localisation On Board Unit (OBU) sensors including EGNSS …) participating to the integrity of the Train Localisation function. The concept is as agnostic as possible to the OBU architecture to comply with interoperability needs of the OBU with regard to train safety critical applications. Nevertheless, the concept defined the required sensors to be embarked to reach rail performance requirements (integrity, continuity, accuracy, availability).

This work was structured in three parts:

- Definition of the Concept of Integrity (section 4.1)
- Identification of Receiver Model requirements (section 4.2)
- Test campaign requirements proposal (section 4.3)

4.1 USER INTEGRITY CONCEPT AND EGNSS MISSION REQUIREMENTS

The analysis of functional and performance train localisation requirements provided in WP2 indicates that performance concepts in the rail domain may differ from SBAS classical definition used for aviation:

- Accuracy: defined for position in several reference frames (3D, along track and across track), and also for speed, acceleration and heading;
- Availability: TLS is considered available as long as it provides localisation parameters compliant with accuracy and integrity requirements;
- Continuity: no continuity requirement was identified so far;
- Integrity: as in aviation, defined on the basis of Integrity Event/Risk derived from Tolerable Hazard Rate (THR) and Safety Integrity Level (SIL) on TLS function outputs;
- Confidence Interval: Interval within which the position error must lie with a specified probability corresponding to the Integrity Risk. Equivalent to the Protection Level (PL) in aviation (but CI = 2 * PL).
- Integrity Event/Risk: event when the TLS localisation error exceeds the confidence interval. The Integrity Risk (IR) is the corresponding probability of occurrence;
- Alert: no alert mechanism is needed at the train localisation function level, but the integrity alert mechanism of the SBAS service has to be managed by the localisation function;
- Alarm limit: not relevant, as related to the Alert mechanism;
- Time To Alert (TTA): No TTA requirement is foreseen at the output of the rail localisation function (but the TTA at the level of the SBAS service has to be managed by the localisation function);
- Misleading Information: Similar to aviation but extended to the speed domain;
- Hazardously Misleading Information: not relevant, as related to the Alert mechanism.

Maximum Operational Confidence Interval (MOCI) or Mission Confidence Interval for Operations (MCI)

The Maximum Operational Confidence Interval is the maximum extent of the Confidence Interval compatible with nominal operations.

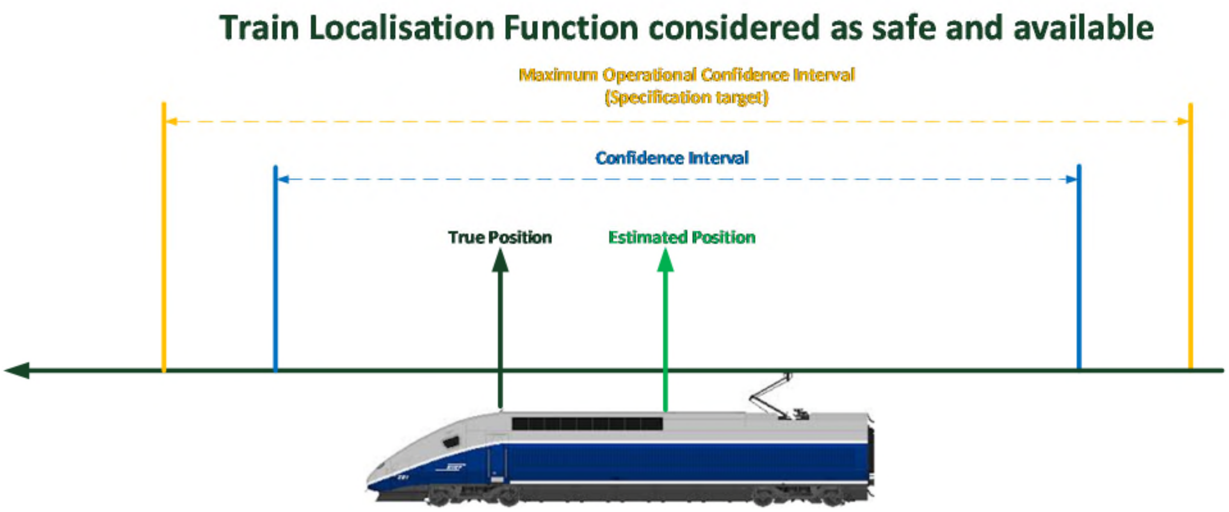


Figure 4-1 – Confidence Interval & Maximum Operational Confidence Interval

This is an operational requirement, not a safety limit: if CI > MOCI, the localisation is still safe but train operations may be degraded (i.e. inducing delays or reduced traffic density), and the TLS is considered as not compliant with respect to the MOCI requirement.

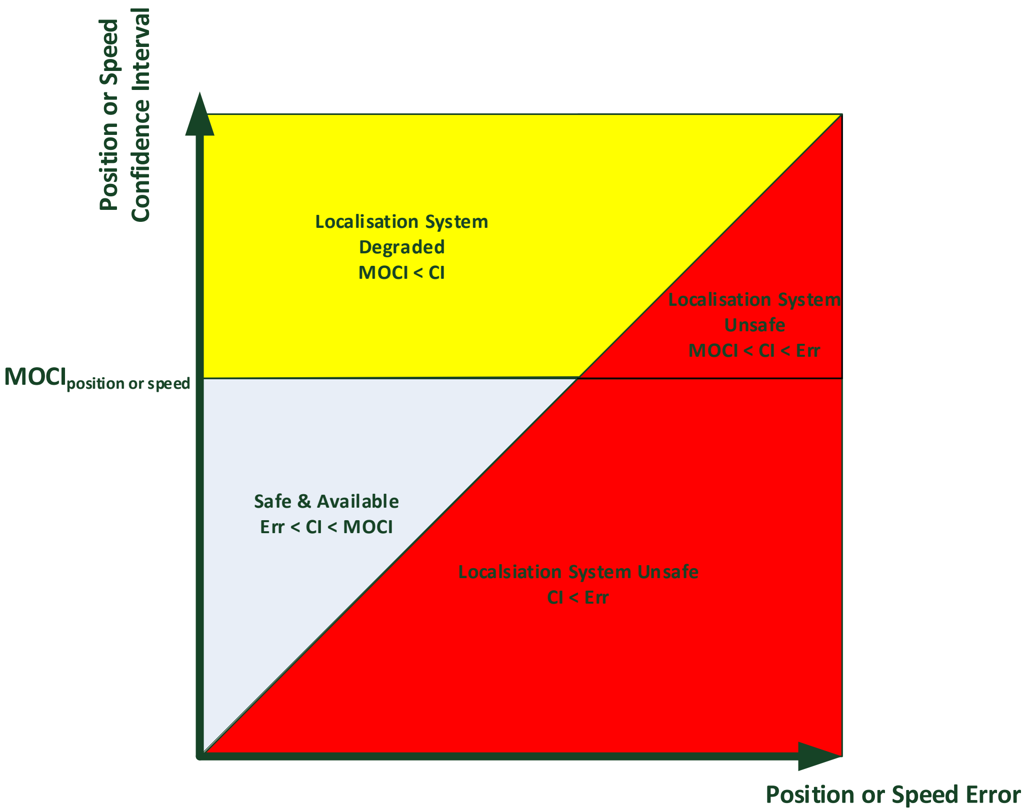


Figure 4-2 – Railway Stanford Diagram for Position and Speed

Performance and the safety requirement targets for the Train Localisation Solution identified in WP2 are summarized in Table 6 below.

<table>
<tr><th>Localisation Parameter</th><th>Integrity Risk Target (Safety Integrity Level)</th><th>Half Confidence Interval Target</th><th>Accuracy 95% Target</th><th>Availability Target</th></tr>
<tr><td>1D Distance (Position with regard to a Reference point)</td><td>0,33x10^{-9}/h
(SIL4)</td><td>• 10 m for speeds lower than 30 km/h
• 10 m plus 2 % of the travelled distance since the last reference point, for speeds between 30 km/h and 500 km/h.</td><td>Not defined</td><td rowspan="4">Not defined
99.91%[1] is proposed as availability target</td></tr>
<tr><td>1D along-track Speed</td><td>0,33x10^{-9}/h
(SIL4)</td><td>• 2 km/h for speeds lower than 30 km/h
• Linear Limit from 2 km/h to 12 km/h for speeds between 30 km/h and 500 km/h.</td><td>Not defined</td></tr>
<tr><td>Along-track train direction (linked to heading)[2]</td><td>0,33x10^{-9}/h
(SIL4)</td><td>Not applicable</td><td>Not applicable</td></tr>
<tr><td>TrackEdge Identifier
(for track selectivity purpose)</td><td>0,66x10^{-9}/h
(SIL4)</td><td>Not applicable</td><td>Depending on the method to determine the trackedge identifier (Position driven or Shunting identification), a new safety-critical localisation parameter (3D position) could emerge</td></tr>
</table>

Table 6: Performance and Safety Requirements target for the Train Localisation Solution

Following the analysis of requirements, different sensors for the TLS have been selected, including the GNSS sensors (managing Galileo OS-NMA and EGNOS SBAS services) combined with an Inertial Measurement Unit (IMU), a Tachometer and a Balise Reader. The global OBU architecture approach relies on continuous multi-sensor fusion considering all sensors in a global fusion filter. It does not follow the traditional architecture based on Balise Reader and Odometer functions, with the aim of reducing on-board equipment cost with respect to this traditional solution. Usage of physical balises may be required in some specific places, only where they are mandatory to reach the performance requirements (e.g. in long tunnels or long urban corridors).

[1] This value was provided in the frame of CLUG project as a « working status » of the Train Localisation Solution.

[2] The along-track train direction is not directly studied as part of the Integrity concept as it may be derived from heading localisation parameter. Instead heading localisation parameter is considered in the study.

The proposed integrity concept is based on 3 topics:

1. Integrity risk allocation principle: this point presents the methodology of integrity budget allocation;
2. Analysis of Feared Events to be protected against: a high-level description of feared events from sensors that could generate errors and could be propagated in the localisation parameters estimate (position, speed …). Characterisation of these feared events (i.e. probability of occurrence, …) was not part of EGNSS-R study;
3. Integrity monitoring: in charge of protecting the safety-critical applications from feared events which could generate an integrity event, this integrity monitoring is based on design of barriers to detect and exclude faulty measurements, and on the computation of the Confidence Intervals to be provided to the safety-critical applications;

TLS localisation integrity risks are defined in position domain (position, speed). As the TLS algorithms combines several sensors measurements in addition to GNSS/SBAS, the EGNSS Service for rail cannot guarantee alone the integrity risk in the position domain. Therefore the GNSS/SBAS integrity risk will be defined at pseudo-range level (input to the fusion filter). So the pseudo-range integrity risk can be defined as the probability that a fault-free GNSS/SBAS receiver experimenting residual errors that are not bounded by broadcasted integrity parameters (defined in service definition) and an alert is not raised within the SBAS time-to-alert to the SBAS user.

A candidate functional architecture of TLS OBU is proposed for a future implementation of the integrity concept, depicted on Figure 4-3 – Overall candidate TLS OBU Functional Architecture.

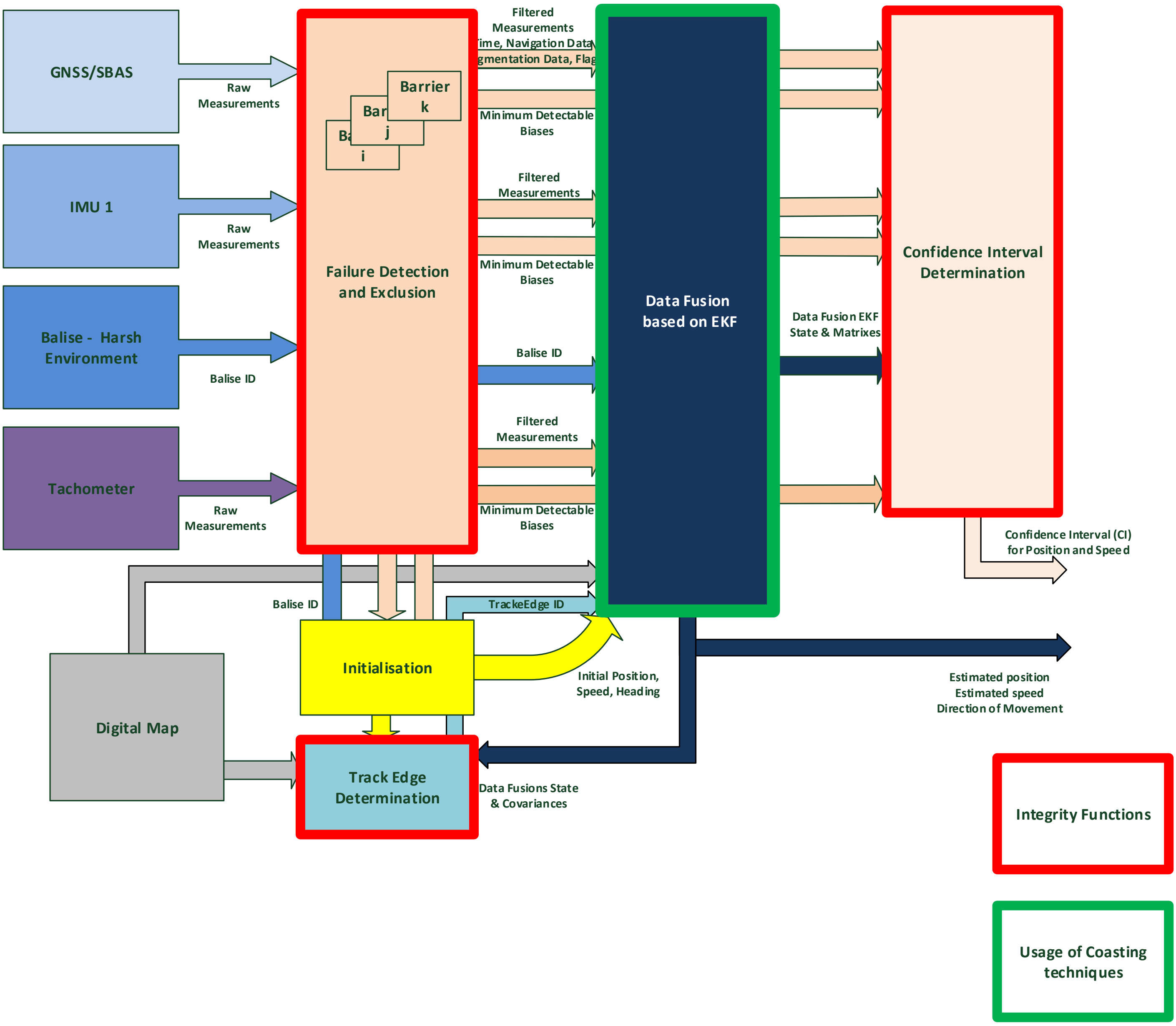


Figure 4-3 – Overall candidate TLS OBU Functional Architecture

Four main functions participates to the on-board train localisation unit:

- Initialisation (start of mission): it provides initial data as position, speed, attitude and track identifier to feed the along-track localisation chain.
- Data fusion (along-track localisation): function using a tightly-coupled Extended Kalman Filter to provide localisation data mixing GNSS and other sensors measurements.
- TrackEdge determination: function providing the track identifier after each rail track node.
- Integrity monitoring: functions insuring position safety, data Fault Detection and Exclusion (FDE) algorithms and Confidence Intervals computation algorithms.

The EGNSS-based Rail Safety Service is a main contributor in this architecture by furnishing safe information for computing the train position and the speed through the GNSS/SBAS sensor.

Confidence interval computation guidelines for EKF-based fusion filters

The standard Extended Kalman Filter relies on some assumptions that are not fulfilled by EGNSS pseudo-range measurements (that must also to be fulfilled by other sensor measurements):

- Measurements errors are not correlated in time (i.e. successive measurement errors not correlated)
- Zero-mean Gaussian Distribution of measurements errors (i.e. no bias)

If errors time correlation and biases are not taken into account, the Confidence Interval computed using the EKF state covariance from a simple inverse Gaussian function is underestimated, and this is an integrity issue. The CI computation algorithm must take into account models and parameters (e.g. correlation time, paired over-bounding). Concerning GNSS measurements after EGNOS corrections, these parameters could be determined by the EGNOS system itself. There are two options to take them into account in the OBU CI computation algorithm:

- Static parameters, evaluated beforehand, provided as commitments associated to the Service Definition Document (worst case values that must be valid every time, everywhere for all satellites)
- Dynamic parameters, evaluated in real-time, depending on satellite and time (typically) and broadcast to users by the EGNOS for Rail future service

The second approach will allow better performance (smaller confidence intervals), then a wider compliance to the rail requirements (in harsher environments).

Reaching an Integrity Risk requirement of the order of 10-9/h on along-track position and speed is a difficult challenge and will require high performance FDE. If such level of IR cannot be reached by a single localisation chain, a proposed approach would be a mixed decision fusion/data fusion solution based on two independent fusion chains with different set of sensors, with different integrity risk allocations.

4.2 Receiver Model requirements

The receiver model requirements are guidelines for the implementation of the GNSS/SBAS sensor in the Train Localisation Solution allowing the use of EGNSS based Rail Safety Service data for ensuring the integrity performance. Indeed, some assumptions about the receiver performance and design must be made in the design of the SBAS system itself.

Such requirements may be envisioned at two levels, applicable to:

- the GNSS receiver which provides pseudo-range measurements corrected and augmented by SBAS data (defined in equivalent to the Minimal Operational Performance Standard for aviation)
- the Train Localisation Solution (TLS) and in particular the OBU which contains the GNSS receiver (defined in ERTMS Rail standards)

Two types of requirements are provided:

- **Functional requirements, such as**:
    - specifications for antennas system: GNSS bands L1/L5/E1/E5 to cover Legacy and DFMC, use of several antennas;
    - signal processing: observables such as pseudo-range, carrier phase, Doppler;
    - environment: conditions of use of receiver (temperature, humidity…);

  - export and customs: avoiding export restriction and application of standards such as CE, Railway Standard For Fire Safety (EN 45545-2);
  - power supply: compatible to train environment;
  - RAMS: SIL level and RAMS indicators;
  - Security: linked to train security requirements;
  - configuration: configuration parameters of receivers;
  - integrity concepts: implementation of data FDE for excluding local feared events and mitigation of attacks;

  The aim is to comply with the use of Galileo and EGNOS services with measurements of other signal / sensors like GPS (for GNSS receiver) or IMU (for TLS);

- **Performance requirements**:
  - performance of antennas: in line with Interface Specification for GPS, Interface Control Document for Galileo and EGNOS documentation;
  - signal processing: reception, application of SBAS corrections;
  - integrity concept: guidelines on design and performance of data FDE and confidence interval computation to comply with the use of the EGNSS-based Rail Safety Service;

Data FDE correspond to an extension of the exclusion criteria requirements as defined in the aviation MOPS document. These guidelines should include on one side an exposition of the integrity concept on which rely the EGNSS safety service, including the definition of all parameters associated to the service (in particular performance commitments and dynamic values) and on the other side a set of recommendations on desirable (but not mandatory) data FDE functions, such as for detecting interferences or multi-path events.

Producing these requirements at the stage of service definition will allow the GNSS receiver and the Train Localisation Solution to be designed and developed before the entry-into-service of the EGNSS-based Rail Safety Service. This preliminary version shall have to be upgraded following the evolution of the integrity concept and the service definition.

4.3 Test Campaign requirements

The Train Localisation Solution is intended to be a reference for the future ETCS (European Train Control System) on-board localisation standard, which will replace the more than 20 different national train control systems in Europe and will allow trans-European railway operations.

The test and validation of the TLS supported by the EGNSS-based rail safety service is a strategic step to prove its capabilities and compliance with the functional and performance requirements.

The project collects requirements related to test campaigns, from the **testing strategies** with real data and simulated data, to the **test scenarios** definition and the requirement related to **results analysis**.

Test scenarios definition is two-fold:

- Definition of the input data to be used (simulated measurements from sensors of the TLS, real measurements from sensors of the TLS, collection of GNSS augmentation data through EDAS) in order to check the behaviour of the TLS under these conditions.
- Evaluation of the system outputs when considering the feared events identified in WP3.1 and safety requirements from WP3.2 in different operational use cases.

The **testing strategy** should rely heavily on real data acquisition in the railway environment, under real operational and environmental conditions over several thousands of kilometres.

Numerous environmental and operational factors could affect the performance of the TLS system (including outage or reflection of GNSS signals, slip and slide, weather etc.). Many of these problems are difficult to forecast or manage. The test environment with replayed real data has the advantage that algorithm tests can be performed with exactly the true field in post-processing, which is of great help in the development of the fusion algorithm. Improvements in performance of updated algorithms can therefore be analysed quickly and reliably, which would not be possible when testing on trains in real-time.

However, these field trials cannot be sufficient to check for integrity requirements. Therefore, they must be complemented by theoretical models, including faulty scenarios probability of occurrence and simulations considering fault injection and specific behaviours that cannot be replayed in real-time.

The **test scenarios** requirements are presented along spatial and operational scenarios definition, which means that the TLS shall be tested under all the identified scenarios (i.e. spatial and mission).

The **results analysis** requirements are proposed by defining the metrics of TLS performance and some results plots. Validation of the integrity concept mainly relies on GNSS cases that are classified into two types. The first one is the GNSS fault free performance in nominal operational conditions and the second one is the GNSS faulty performance related to scenarios with local fear event occurrence.

5 EGNSS-BASED RAIL SAFETY SERVICE DEFINITION

The proposed EGNSS-based Rail Safety service is defined as a combination of EGNOS and GALILEO services:

- Galileo Open Service - Navigation Message Authentication (OS-NMA) service to increase security
- EGNOS Railway SoL Service to increase accuracy and provide integrity (augmentation of GPS and Galileo)

The concept of the EGNSS-based Rail Safety service relies on allowing service usage by iterative multi-sensor fusion solutions (e.g. Kalman filter based). As expressed in the WP2, Rail signalling requires continuous train localisation even if environment is not suitable to the GNSS positioning. Fusion with others sensors is necessary and tight coupling is desirable for better performance.

The OS-NMA service, included in Galileo navigation messages provided by the Galileo constellation, offers authentication of signal thanks to the TESLA algorithm. The description of the messages, the algorithm and the process are defined in the Galileo OS-NMA User ICD. It is worth noting that security could in addition be enhanced by using other services such as the Galileo Commercial service (CS) and by using the future secured GPS service (CHIMERA). Proposed recommendation is first that security requirements at localization function level are consolidated by the railway operators. Then a specific study would allow analysing these security requirements and identifying potential solutions and impacts on receivers design.

The EGNOS Railway SoL Service can take the form of three different sub-services, each with incrementally improved performance. These sub-services are defined at pseudo-range level and are associated with performance commitments, different from aviation services:

- Legacy for Rail: same interface as the Legacy Single Frequency Safety of Life aviation service, to be delivered by EGNOS V3.1, with additional performance commitments at pseudo-range level.
- DFMC for Rail (Dual Frequency Multiple Constellation): same interface as the DFMC Safety of Life aviation service, to be delivered by EGNOS V3.2, with additional performance commitments at pseudo-range level. Augmenting both GPS and Galileo constellation on two frequencies, performance are increased with respect to Legacy.
- EGNOS for Rail: providing additional augmentation data with respect to EGNOS DFMC, to further improvement of performance and potentially allow reaching railway expectations, requires an update of the EGNOS V3 system.

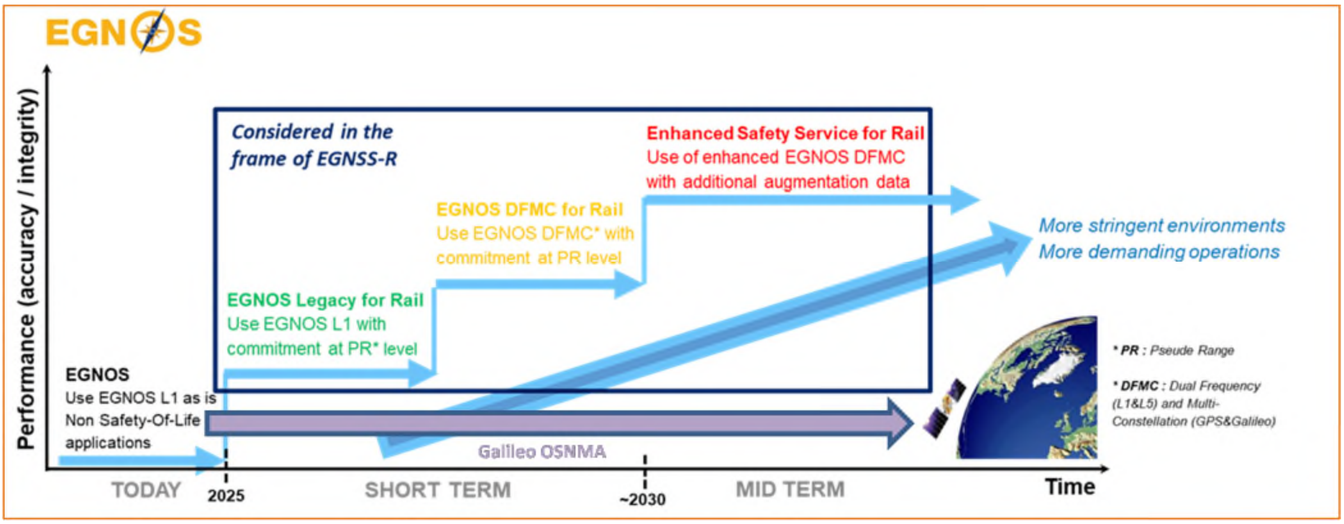


Figure 5-1 – EGNSS-based Rail Safety service: proposed incremental implementation steps from short to mid-term

The Legacy and DFMC EGNOS capabilities being currently defined for aviation service, necessary additional integrity parameters to allow safe Confidence Intervals computation at train position and speed level will be defined by static upper bounds commitments. However, this solution is not expected to allow reaching Rail requirements in the less favourable environmental contexts, meaning operational impact or requiring expensive complementary trackside equipment such as physical balises.

The EGNOS for Rail service would broadcast additional parameters dynamically to the Train Localisation Solution. These additional parameters are the following, for each GNSS satellite (Galileo and GPS):

- Parameters of SBAS range error time correlation over-bounding model (correlation time, magnitude)
- Paired over-bounding of SBAS residual range error (bounds and bias)
- SBAS Range Rate corrections
- Paired over-bounding of SBAS Range Rate residual error (bounds and bias)
- Parameters of SBAS range rate error time correlation over-bounding model (correlation time, magnitude)
- Integrity Alerts on residual range Alert Limit and range rate Alert Limit

The performance of EGNSS-based Rail Safety service must be evaluated in a user-driven way, i.e. at pseudo-range level (after applying EGNOS corrections). The classical approach using Satellite Range Error (SRE) Root Mean Square (RMS) during 24h at Worst User Location (WUL) is appropriate for system specification and qualification. However it is not well suited for accurate performance prediction of train localization solutions (at user level) as it is a worst and average value, not reflecting the actual performance at a given time and at a given user location. The proposed approach is to use performance macro-models (e.g. for modelling the UDRE and other performance bounds), that can be developed in the frame of the EGNOS program.

The table below gives a synthesis of the proposed performance figures for the EGNOS DFMC for Railway and EGNOS for Rail Services.

SUB-SERVICE PERFORMANCE REQUIREMENTS	**DFMC FOR RAIL**	**EGNOS FOR RAIL**
Service area	EGNOS Participating States	EGNOS Participating States
GNSS Satellite Minimum Elevation angle [deg]	5°	5°
Satellite Range Error (SRE) – Pseudo-range Standard deviation	Dynamic values in messages	Dynamic values paired over-bounding in messages
• System requirement [m]	0.65 (95 %) *	0.65 (95 %) *
• Performance commitment [m]	Macro-model of instantaneous standard deviation	Macro-model of instantaneous standard deviation and of bias upper-bound
Satellite Range Rate Error (SRRE) - Range rate standard deviation	N/A **	Dynamic values paired over-bounding in messages
• System requirement [m/s]	N/A **	0.4 (95 %) *
• Performance commitment [m/s]	N/A **	Macro-model
Time correlation model parameters (Gauss-Markov model)	No data in messages	Dynamic values in messages
• System requirement [s]	4000 *	4000 *
• Performance commitment [s, m]	6000 *	Macro-model *
Availability [%]	99	99
Continuity	~ 1E-5/h	~ 1E-5/h
Integrity Risk	~ 1E-6/h	~ 1E-6/h
Alert limit	(if necessary)	
• Maximum Satellite Residual Error (within service area) [m]	4 - 5	4 – 5
Time to Alert [s]	5.2s	5.2s (SIS), 4 s (SoL Gate)
Dissemination Channel	• SBAS SIS	• SBAS SIS • Terrestrial Radio Network SoL Gate

Table 7: DFMC and EGNOS for Rail performance description

With following parameters definitions:

- Service area: Geographical area where the EGNSS-Based Rail Safety service will be available to users without taking into account the local geographical environment.
- GNSS Satellite Minimum Elevation angle: Fixed elevation angle referenced to the user's horizon below which satellites are not covered by the service and consequently shall be ignored in the position computation.
- System requirement: Value to be applied as a requirement to the EGNOS system; for system development by the system manufacturer.

- Performance commitment: Value that can be used by service users as a commitment regarding the performance of the service.
- Satellite Range Error (SRE) – Pseudo-range standard deviation: Standard deviation of the difference between the reconstructed orbit and clock after applying SBAS orbit and clock corrections to the GNSS navigation messages, and real SV orbit and clock projected in the direction of the user line of sight.
- Satellite Range Rate Error (SRRE) – Range rate standard deviation: Standard deviation of a satellite Doppler-based pseudo-velocity residual error after application of the SBAS corrections.
- Time correlation model parameters (Gauss-Markov model): Model parameters of the time correlation of a satellite pseudo-range residual error after application of the SBAS corrections.
- Availability: Probability that the data provided by the navigation service are available at the beginning of the planned operation. The service is considered available when the accuracy, integrity and continuity requirements are met and it is measured in terms of probability of the system being available for any given user at any given time. In practice, the availability is computed by measuring the probability of a protection level/confidence interval being below its corresponding performance commitment. It should be noted that a lack of availability is not a safety concern but prevents the nominal operation of the system, and implies an associated impact on the service operation status.
- Continuity: Probability that the specified data performance will be maintained for a given duration (typically the duration of a phase of operation, e.g. 1 hour), presuming that the system was available at the beginning of that phase of operation and was predicted to operate throughout the operation.
- Integrity Risk: The probability during the period of operation that an error, whatever is the source (but excluding malicious attacks), results in the real position being outside of the computed position Confidence Interval, or in the real speed being outside of the speed Confidence Interval, and the on-board localisation unit is not informed within the specific allocated time.
- Maximum Satellite Residual Error: Maximum residual error of the pseudo-range for each satellite. In case of value outside of this bound, the EGNOS system tags as unavailable the pseudo-range.
- Time to Alert: Maximum allowable time between the occurrence of a failure in the system (e.g. satellite fault or EGNSS-Based Rail Safety service) and the presentation of the alert to the user (user processing time is not taken into account).
- Dissemination Channel: Communication means for the dissemination of the service data from the SBAS system to the users.

Performance commitments consolidation recommended process

The macro-models and "*" values indicated in Table 7 cannot be determined at this stage. They must rely on a thorough analysis of range (and range rate) errors distributions on long-run scenarios. Such analyses are close to the system development activities, because they must reflect EGNOS DFMC, then EGNOS for Rail, performance "as developed". Commitments should then be endorsed by the Agency as part of the Service Definition and Operational performance standard.

The DFMC for Rail does not propose range rate correction or integrity as no data is provided by the DFMC EGNOS system for this service. To obtain these parameters, the manufacturer shall compute itself values by deriving SRE data. So the performance of SRRE is noted "N/A **" in the Table 7.

Three successive steps can be foreseen in the determination and consolidation of these performance commitments (for each sub-service, DFMC for Rail and EGNOS for Rail):

1. Early version, associated with an early service testbed, necessary for the phase of prototyping and testing of user solutions (demonstrators). Analyses based on processing algorithms models and simulated scenarios.
2. Preliminary version, associated with the preliminary service available for test (after system deployment). Analyses performed during system validation and qualification based on final algorithms.
3. Committed version, associated with the Entry-into-Service, being the official commitment associated with the operational service. Analyses consolidated with long-run performance monitoring with real stations data, during the service certification phase.

EGNOS Railway service dissemination

OS-NMA service: no change foreseen for the dissemination by Galileo with respect to currently planned service.

For EGNOS Legacy or DFMC for Rail, as the broadcast data is the same as the DFMC data for the aviation service, the same message format is foreseen in order to avoid EGNOS system functional updates.

For EGNOS for Rail future service, as additional augmentation data is proposed, several options have been analysed and the trade-off is open between completing current messages with new ones and defining a new appropriate structure, depending on the dissemination means.

The dissemination of the EGNOS Railway Service (Legacy, DFMC or EGNOS for Rail) requires a new channel in complement to the geostationary satellite, due to strong impact on availability of GEO satellite masking in rail environments.

This complementary dissemination should make use of the Euroradio rail terrestrial network (GSM-R or FRMCS) with two technical options: as a first step, a trackside GNSS receiver injecting GNSS data into the network and later on a direct terrestrial connection with EGNOS through an EGNOS Safety-of-Life Network Gate. In the long term, new satellite orbits can also be envisaged to increase visibility (higher elevation).

Long term perspectives

On the longer term, beyond the short and mid-term proposed implementation steps, EGNSS further evolutions could improve the service in four domains:

- Safety & integrity: with evolutions of EGNOS system and adopting new concept as ARAIM;
- Accessibility & continuity (at high latitudes and in urban canyons or mountains): with dissemination from new types of satellite orbits, such as HEO, IGSO or LEO, leading to higher elevations
- Security & resilience: by extending MAC authentication to other constellations
- Accuracy: by using a future Safety of Life High Accuracy Service

Train Localisation solution performance evaluation

The confidence interval is an output of the Train Localisation Solution and it is impacted by the EGNOS service performance. In the frame of fusion algorithms (contrary to aviation), it does not depend only on EGNSS but it takes into account all sensors performance. The commitment at pseudo-range in the EGNSS-based Rail Safety Service is an information for the Train Localisation Solution manufacturer, for performance computation with other sensors parameters.

We propose an indicator of solution performance called the Maximum Feasible Confidence Interval (MFCI). This value is an estimate of the maximum confidence interval reachable by the Train Localisation Solution, using a selected sub-service in a given environment context and possibly depending on other parameters such as the train speed. This approach relies on the definition of standard environment contexts, such as:

- Open-sky: low angle of masking, no physical obstacle between antenna of receiver and satellites
- Canopy/Sub-urban: either trees/forest or a masking environment that degrade GNSS signals;
- Urban: Physical obstacles on the trackside with high angle of masking and local effects. This environment is the worst for the EGNSS-based positioning performance.

Each environment context is characterized by a set of parameters or functions, defining satellite masking models and local feared events models (including for instance amplitude and probability of occurrence).

For each sub-service, an estimate of the Maximum Feasible Confidence Interval with the Train Localisation solution should be predicted, then compared to the Maximum Operational Confidence Interval of the operational specifications.

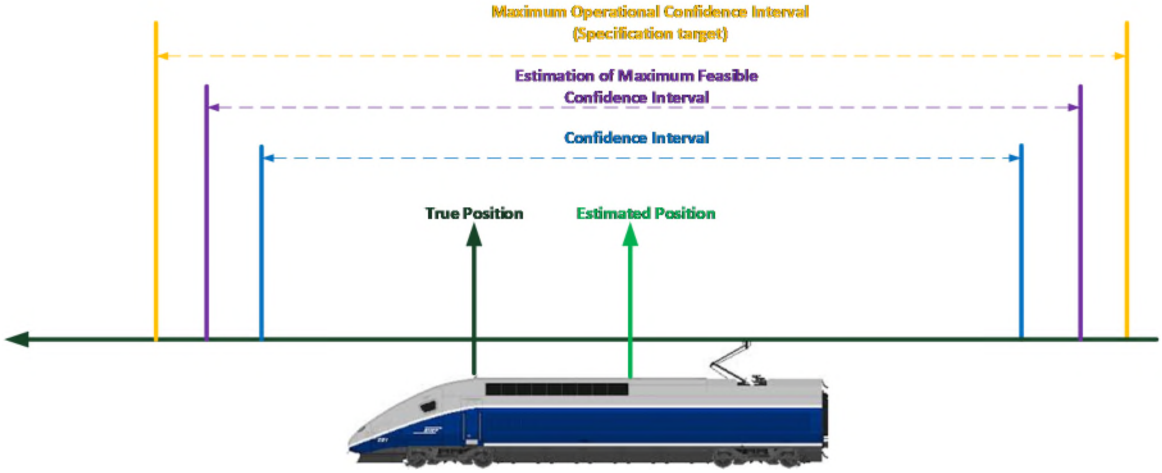


Figure 5-2 – Configuration for Train Localization Solution / EGNOS service to be compliant with a given MOCI requirement (MFCI < MOCI)

The performance compliance synthesis of a Train Localisation solution using a given EGNSS-based Rail Safety Service sub-service will indicate, for each standard environment context, the level of compliance with the applicable MOCI requirement in terms of probability that (MFCI < MOCI).

The table below gives an example of such a Train Localisation solution performance compliance synthesis table. In the table the colour indicates the level of compliance with each specific MOCI value: green indicates a high probability of compliance, operationally acceptable, orange indicates a risk of partial non-compliance that is likely to degrade operations and red indicates an unacceptable probability of non-compliance.

Half-Maximum Operational Confidence Interval	Physical environment		
	Open-sky	Canopy/Suburban	Urban
XX meters			

Table 8: Example of an On-Board Unit performance compliance at user level (using a given EGNOS service)

Standardisation and certification processes

The rail standards provided by the Technical Specifications for Interoperability (TSI) shall have to be updated for the introduction of the GNSS for the train localisation and into the rail radio network interfaces. The documentation baseline dedicated to the EGNSS rail services shall be provided and maintained by different actors:

- EGNOS Service Provider (ESP) for EGNOS service;
- The European Union Agency for Railways (ERA) for rail standardisation with the support of Infrastructure Manager (IM) for the definition;

The certification process is two-fold: the acceptance of EGNOS system and ESP for the EGNOS Railway SoL service provision. ERA could manage both, considering the work done before for aviation. For the conformity assessment of ERTMS Interoperability Constituents (ICs) using EGNOS, it is expected that the conformity assessment of IC implementing GNSS functions that use the proposed EGNOS Railway SoL Service would be carried out by a Notified Body (NoBo).

The applicant (e.g. equipment manufacturer) would be able to establish the EC declaration of conformity accompanied by the certificates of conformity issued by the NoBo(s). The authorisation of ICs and CCS subsystems implementing the enhanced on-board localisation function using EGNOS to augment GNSS would rely on the acceptance by ERA of the certification of the ESP and documentary evidence of the above points with respect to the EGNOS-related functions.

In addition to the certification aspects liability aspects have to be considered including the main elements of the Service Level agreement (SLA) to cover roles and responsibilities. This aforementioned cross acceptance mechanism may require ERA to propose an update of the Single European Railway Area regulation.

Service Provision Scheme

Service implementation and provision require the involvement and commitment of all actors with the following roles:

- The EGNOS Owner (European Commission): to maintain the service with evolution and finance, to accept service for the rail;
- The EGNOS Program Manager (EUSPA): to maintain the service by delegation to EC and to check compliance of the EGNSS-based Rail Safety Service Provider regarding the rail service;
- The Airspace/Support Industry: to support the EGNOS Programme Manager in the maintenance and development of the system, as well as providing support systems;
- The EGNOS Service Provider (ESP): To develop, tailor and deliver the service in accordance with the SDD for the service, to set-up and execute the different engineering and maintenance activities and support rail users;
- The Infrastructure manager: to receive operational data about the service and to react adequately, to maintain the trackside equipment for the provision of the service;
- The end-users: to equip train with certified Train Localization Systems, including GNSS/SBAS receivers following requirements for using the EGNSS-based Rail Safety Service.

Next figure described the EGNSS-R proposed Service Provision Scheme.

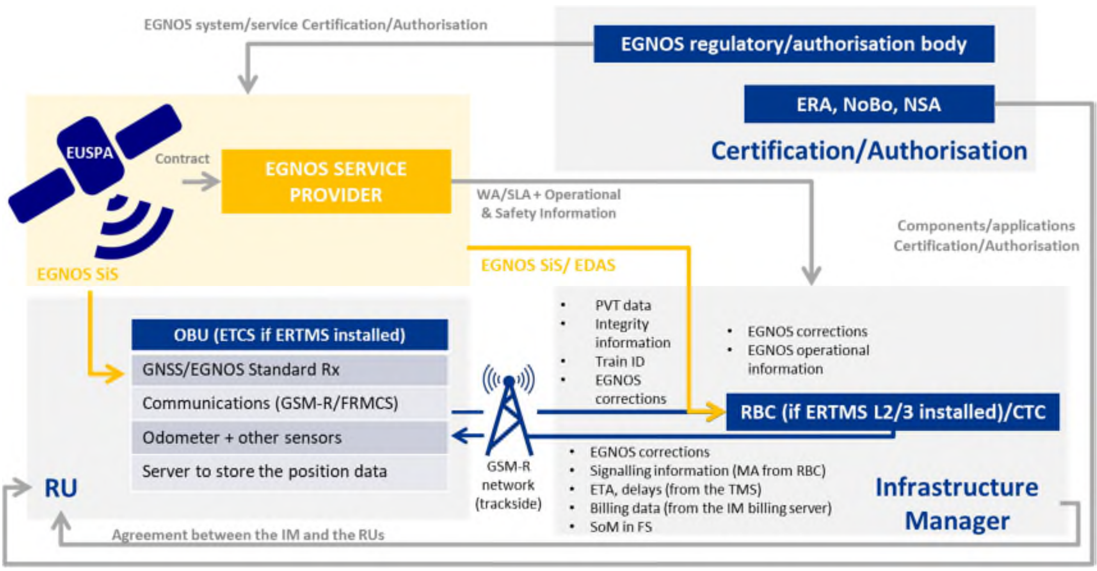


Figure 5-3 – EGNSS-R proposed Service Provision Scheme

6 DECISION CRITERIA ANALYSIS

The decision criteria analyses aim at identifying the elements that would lead all involved stakeholders to endorse EGNSS-R-designed rail safety service:

- Adequacy to railway needs
- Costs
- Schedule
- Migration /Production efforts
- Recommendations

The identified stakeholders are: the users (Infrastructure Managers & Railway Undertakings), the railway solution manufacturers, EGNSS infrastructure owners (EC/Agency), EGNSS services Providers. A survey of the main decision criteria with respect to each stakeholder allowed to find the potential benefits and interest for each of them to adopt or develop the EGNSS-based Rail Safety Service.

To feed this analysis, the EGNSS-R project team exchanged with several rail stakeholders to highlight quantitative and qualitative criteria. The rail stakeholders include Infrastructure Managers (IM), Railway Undertakings (RU) and railway industrials such as CAF, HITACHI, MERMEC and SIEMENS. Additional inputs have been collected from the existing IM and RU CBAs.

Market criteria

The first market analysis performed in EGNSS-R project points out that the solution manufacturers consider the regulation as the main criteria for decision since the regulation update is a pre-requisite for every signalling system modification in Europe. Their economic opportunity is assumed to be sized by the ERTMS regulation and the market size, which may justify the provider investments in the solution development, production and sales.

IM & RU decision criteria

The EGNSS-R project also provides a high-level cost-benefit analysis (CBA) assessing the interest of EGNSS-based navigation solutions from IM & RU point of view. This CBA is based on lessons learnt from previous CBAs made on ERTMS projects and GNSS Rail projects such as SR40, STARS, HITACHI, HPMV, OCORA, Shift2Rail-X2RAIL2.

Main lessons learnt are the need for a global analysis RU and IMU, the need to consider the capacity and operation efficiency benefits, the importance to select the proper business case (main and regional). We learnt also the difficulty to address the transition scenario in a global study.

A 3-steps top-down approach was defined, the first step being studied in the frame of this project.

- Step 1: Modelling a simplified generic scope in order to identify which are the main decisions making criteria and their relative importance
- Step 2: Modelling with more details the sizing factors and implementation on 4 national Networks and Rolling stocks
- Step 3: Modelling detailed business cases for specific lines

In step 1 two projects' scenarios EGNSS ERTMS L3 (S2) with EGNSS-Based Rail Safety Service and ERTMS L2 (S1) with current ERTMS defined sensors (Odometry and Balise Reader) were compared and an evaluation of CAPEX and OPEX benefits and costs for IM and RU was produced based on items of two categories:

- <u>CCS assets</u>: including the percentage of track assets (Balise, Axle counters) that can be decommissioned in the project scenario, Digital mapping cost and the evolution of localisation engine from the current used sensors (Odometry and Balise Reader) to the on-board Localisation engine using GNSS, IMU and Balise reader, etc.

- Operational characteristics: including the percentage of capacity increase that can be commercialized and corresponding additional revenue, the estimation of the social benefit through punctuality improvement and a standardized Green Deal approach which is used to model the Greenhouse Gas (GHG) savings.

The CBA evaluation was computed using the following formula:

CBA results = DELTA CAPEX (S2 – S1) + Net Present Value DELTA OPEX (S2 – S1) over 20 years

Where:

- DELTA CAPEX (S2 – S1): delta between CAPEX for scenario 2 and CAPEX for scenario 1
- Net Present Value: Factor computed as followed:

$$NPV = \frac{R_t}{(1+i)^t}$$

t = time of the cash flow
i = discount rate
R_t = net cash flow

- DELTA OPEX (S2 – S1): delta between OPEX for scenario 1 and OPEX for scenario 2

First results are positive and encouraging with a NPV (Net Present Value) of more than 80 k€ per km of track but this outcome needs to be refined through the second step to draw solid conclusions.

This simplified generic CBA proves also that GNSS ERTMS Level 3 might bring value to IM & RU, providing a global approach with monetization of benefits on Track, Rolling Stock and passenger traffic. A deeper analysis (step 2) is recommended, including more parameters, precise calculation and application on various business cases in several countries, enabling a European convergence.

Schedule criteria

Moreover, Member States have legal deadlines for ERTMS deployment (in "COMMISSION IMPLEMENTING REGULATION (EU) 2017/6 of 5 January 2017 on the European Rail Traffic Management System European deployment plan"): the Core Network (CN) has to be equipped by 2030, and the Comprehensive Network by 2050.

Deployment roadmaps planned by each country will use the technology available at that time. As the Core Network has to be equipped by 2030, adoption of EGNSS for safe train positioning requires that an EGNOS service for Rail is available by the end of the decade (with sufficient performance figures) in order to be able to deploy ERTMS with satellite positioning without delay.

Service implementation and provision decision criteria

The following decision criteria related to the service implementation have been analysed for the different proposed service steps: feasibility of features to be developed, Entry-into-Service schedule, budget to develop the service, possibility of its reusability by other domains and scenarios for the service development and certification.

The service implementation indicative schedule was elaborated based on the experience of Airbus. This target schedule is reflected in the EGNOS evolutions roadmap in the following chapter 7.

The knowledge of ESSP about the service operation and maintenance has been used to state and qualify the main parameters leading to the definition of the service operation and of the associated budget. From service provision point of view, the decision criteria for an EGNOS new service are established at programmatic level, derived from the EGNOS MRD. The criteria parameters are designed and validated by the EGNOS Program Manager (EC/EUSPA), and then the decision requirements are flow down to the EGNOS Service Provider (ESP) through the EGNOS Service Provision Contract. Service preparation activities and service provision activities are provided in the following Figure.

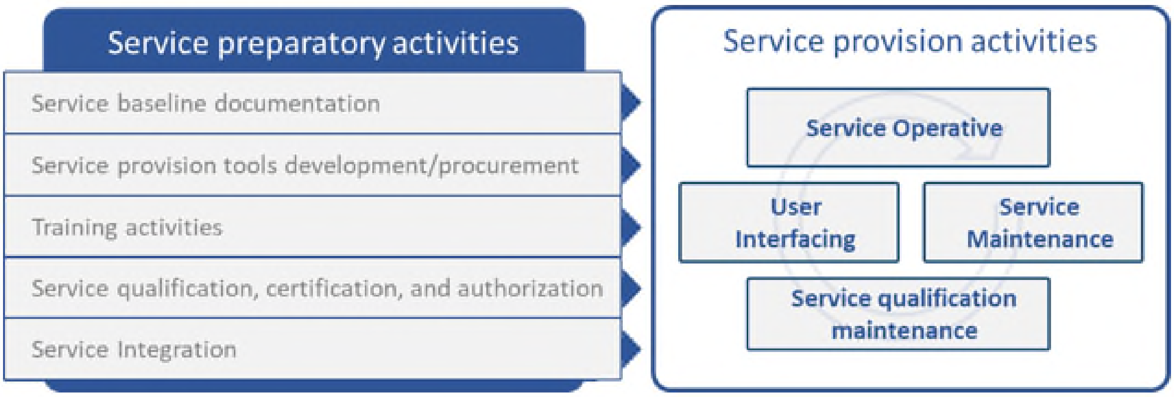


Figure 6-1 – Key indicators and service provision activities

The main effort is related to the provision activities. This assessment is based on the assumption that the current ESP extends its scope to the future rail services, so as to exploit expertise and synergies with EGNOS service. The main drivers to assess service provision costs are the identification of the EGNOS Service Provider for Rail, identification of synergies with existent EGNOS services in place, identification of required tools for the service provision, alignment with EGNOS programmatic activities and close iteration with potential users.

The economic justification is driving the decision of railway stakeholders (IM, RU and industrials), however the timeline of EGNOS service up to the Entry-into-Service (EiS) is also of primary importance for the sector to endorse EGNSS.

As will be exposed in chapter 7, roadmaps of localisation solution manufacturer and of EGNSS service implementation can be aligned with the roadmap of TSI updates (2027-2030), leading to the introduction of GNSS-based localisation units from 2030.

In order to contain the budget for developing the EGNOS service for rail, and to match the rail stakeholders expectations in terms of EiS, it is recommended to build the EGNOS for Rail safety service on the basis of the EGNOS system currently planned for providing the DFMC service for aviation (EGNOS V3), rather than a new EGNOS generation, for the short-term as for the mid-term solutions.

Definition of regulations and assessment of the service operation and maintenance is a necessary step to undertake as soon as possible with railway stakeholders and notably ERA in order to consolidate the necessary budget for service operation and maintenance.

7 SERVICE IMPLEMENTATION ROADMAP

A comprehensive service implementation roadmap was elaborated combining the outcomes of WP2, WP4 and WP5. This roadmap encompasses all activities that are necessary until the operational deployment of a train localisation solution using the proposed EGNSS-based Rail Safety Service, i.e. not only the service development and deployment but also the standardisation process, the product solution development and certification, and the rail infrastructures upgrades. The purpose of this roadmap is two-fold: estimate feasible solution implementation schedules and identify dependencies between activity streams and critical paths.

A train localisation solution requires that the following achievements are deployed and operational:

- A Train Localisation On-Board Unit (TLOBU) product: the on-board localisation function will be designed, developed and qualified.
- Update of rail communication network: train localisation data will be exchanged for operations (ERTMS 2) with the future rail radio system Future Railways Mobile Communication System (FRMCS). This communication channel should also convey dissemination of EGNOS data (to complement poor GEO SiS reception where affected by masking) as well as digital map data necessary for the train localisation system. These new exchanges also require an update of the Radio Block Centre (RBC) component;
- Update of infrastructure/roll-out: tracks and vehicles integrate equipment necessary for the new localisation system; processes for the rollout will be qualified. A pilot line will be used for testing and then for the certification and qualification processes;
- EGNSS services: EGNOS system will be upgraded to support the proposed EGNOS service for rail that will then require certification and service provision processes until its entry into service. Galileo OS-NMA will be also in service;
- Solution certification: the localisation solution (TLOBU using EGNSS Service for rail) integrated in vehicle and with updated rail infrastructure will be certified to allow starting train operations.

Two timeframes were identified by EUSPA to be considered in this study. Each was developed in a specific roadmap, presented below. They are fully compatible and complementary and both are recommended to be implemented as they target two successive steps for fulfilling railway expectations:

- Short-term (before 2030): providing a solution using EGNSS as soon as possible, even if performance requirements are not fully satisfied;
- Mid-term (from 2030): providing an economically viable train localisation solution to rail operators.

This mid-term horizon corresponds to the official deadline of ERTMS deployment by Rail operators on their Core Network, as explained in section 6.

The proposed global roadmap is composed of several activity streams related to solution development and deployment, certification and EGNSS services adoptability:

- ■ Train Localisation Standardisation: Based on fixed milestones, this roadmap must be coordinated with certification and infrastructure update/rollout for introducing the train localisation solution with EGNSS services.
- Train Localisation solution: This section is composed of several roadmaps:
    - ■ Update of rail infrastructures including communication network and roll-out
    - ■ Development of the train localisation solution(s)

  - ■ Certification of the train localisation solution(s)
- ■ <u>EGNSS Services</u>: This stream covers the introduction of EGNSS services for Rail including the update of EGNOS and Galileo systems up to service provision operations and service certification.

Obviously, these different activity streams are inter-dependent and managed by different stakeholders. In order to optimize the overall solution implementation schedule, it is mandatory that these streams can run in parallel, therefore requiring coordination, synchronization and anticipation by all stakeholders.

The most critical schedule driver is the Train Localisation Standardisation stream with the Technical Specifications for Interoperability (TSI) milestones that drive the schedule of rail infrastructure updates and of the overall solution certification. As the TSI schedule in the upcoming years is subject to evolutions, two TSI milestones are considered (hypothesis to be confirmed) in these roadmaps, one in 2025 and one in 2027-2028.

Another important driver is the decision on launching EGNOS system upgrades in the coming years. Short-term and mid-term developments need not to be launched simultaneously, but it is desirable to meet the expectations of railway operators that such decisions are planned in 2023.

Short-term roadmap

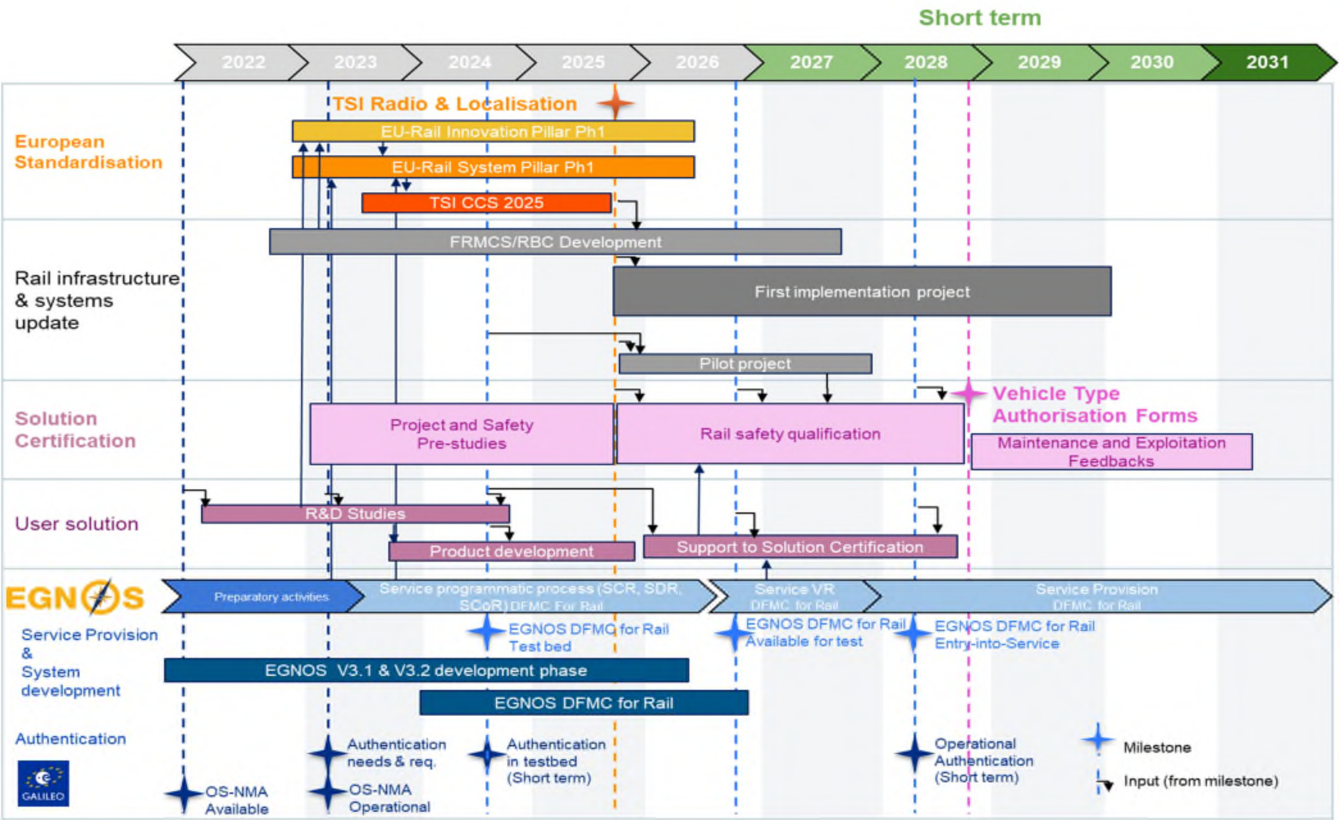


Figure 7-1 – EGNSS-based Rail Safety Service short-term roadmap with Entry-into-Service in 2028

The short-term roadmap targets a train localisation solution to be operational by end 2028. This scenario depends on the decision from European Commission or EUSPA to launch some specific activities to build a DFMC service for Rail based on EGNOS V3.2 system release: specification, validation and performance quantification of the necessary commitments at pseudo-range level.

Certification of this service is dependent on the assumption that the complete localisation standards are settled in the 2025 TSI. However, if this scenario does not realize, this short-term service is valuable to develop as an experimental first-step service (not certified, so not used in safe rail operations), with the goal to support the mid-term roadmap, by assessing the localization functionality and performance on the long run in real operational conditions. Moreover, the short-term solution, that will allow to reach required performance only in open-sky environments, thus with a limited benefits with respect to the mid-term solution, may not be worth the overall certification effort.

Basing the short-term solution on EGNOS V3 Legacy service is not favoured with respect to DFMC, with the three following justifications. First, the DFMC capability should already be available as well before the end of the standardisation activities (V3 DFMC is planned only one year after V3 Legacy). Secondly, performance commitments for Legacy are more complex (thus costly and lengthy) to establish than for DFMC, because of ionospheric corrections in Legacy. Last, better performance will be achieved with DFMC as compared to Legacy, thus better supporting the adoption of the EGNSS-based Rail Safety Service by the rail operators.

Mid-term roadmap

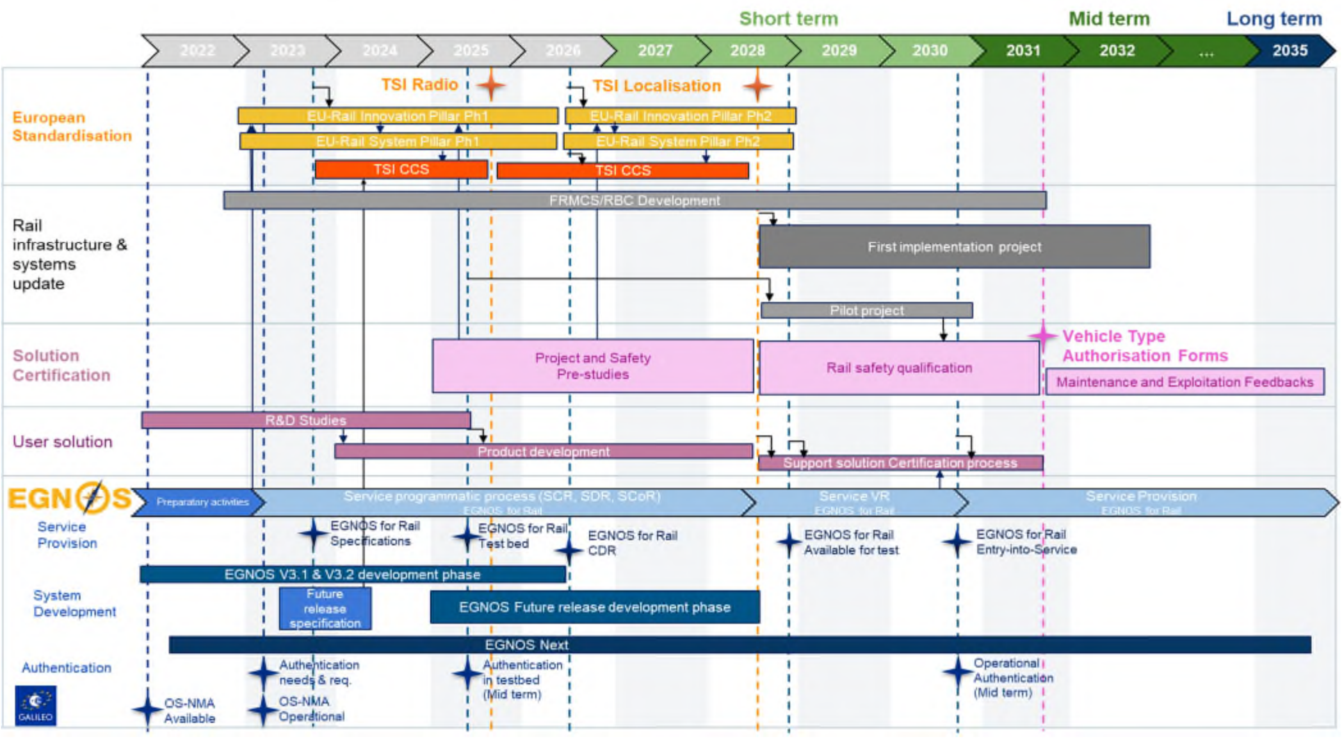


Figure 7-2 – EGNSS-based Rail Safety Service mid-term roadmap with Entry-into-Service in 2030

The mid-term roadmap shows that a certified train localisation solution could be operational in 2031. Standardization could take two steps, a first TSI in 2025 would focus on rail radio network update and GNSS interfaces, and a following one in 2027-2028 would fully cover the new localisation function standards.

A new release of EGNOS System can be developed and qualified within this timeframe, including the development of additional features supporting the proposed EGNOS for Rail service (dynamic parameters and safe terrestrial network gate) as well as the service definition documents and the associated performance commitments. This update of system leads to have a longer certification schedule (2 years).

According to the certification and the solution development roadmaps, the localization solution development and certification require three main milestones in the EGNSS services implementation roadmap:

- Early service testbed 2025
- Early service for testing 2028
- Entry-into-service 2030

Following a "Service offer driven approach", usage of EGNOS by Rail will be derived from EGNOS service definition (this approach being opposite to the approach followed for aviation services in the past). The localization TSI standards will be based on the EGNOS for Rail specifications and performance commitments. The EGNOS for Rail CDR Milestone can therefore take place before the TSI. Nevertheless EGNOS specification and TSI preparation will be performed in parallel and coordinated to ensure their consistency.

Increased performance will be achieved in this mid-term scenario, hopefully reaching railway needs in most areas, consequently increasing benefits to railway operators and fostering adoption of EGNSS services by rail stakeholders.

8 CONCLUSION

The Executive Summary at the beginning of this documents provides a complete summary of the activities performed along the EGNSS-R project and their main outcomes.

Proposed next steps are the following:

- **Share and consolidate roadmaps** with all stakeholders to accelerate adoption and start activities in each domain for reaching the timeline target of operators: introduction of GNSS-based localisation units from 2030.
- **Perform further performance analyses** for assessing the relative performance figures expected at user level of the different EGNOS for Rail sub-services options (EGNOS V3 Legacy, EGNOS V3 DFMC for Rail, EGNOS for Rail) and confirming the benefits for rail operators to use EGNSS. These analyses require taking assumptions on performance commitments on additional parameters for short-term services, and also assumptions on achievable performance macro-models for EGNOS for Rail additional parameters. Both require a deep knowledge of EGNOS V3 algorithms and their potential evolutions.
- **Complementary work on operational requirements**, especially on security, integrity (safety level), maximum operational confidence interval (MOCI) requirements according to more specific operations criteria, availability and continuity.
- **Perform further Cost-Benefits Analyses**, including more parameters, more precise computation and application on various business cases in several countries, enabling a European convergence.
- **Procurement and development of DFMC service demonstrator (testbed), followed by development of EGNOS for Rail service testbed (based on preliminary processing algorithm prototypes)**
- **Define preliminary performance commitment parameters** and models for the short term service “DFMC for Rail “ for allowing usage of the DFMC service demonstrator for Rail