EGNSS-R

European GNSS Navigation Safety Service for Rail

The objective of EGNSS-R was to assess the feasibility of EGNSS-based safety service for the rail beyond 2022. Such service would enable the introduction of Galileo and EGNOS in European railway localisation.

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Project Segment: Horizon 2020, EGNSS-BASED RAIL SAFETY SERVICE

Duration: 34 months (September 2020 – June 2023)

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Project Partners: Airbus Defence & Space (France), FDC (France), SNCF (France), ESSP (France)

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Background

Localisation systems, also known in railway as signalling systems, are necessary to ensure train safe traffic, i.e., no collision or derailment. Historically, signalling systems were specific to each area of operation. Interoperability across Europe will be achieved through the ERTMS (European Rail Traffic Management System) norm, under ERA (European Union Agency for Railways) patronage.

The current ERTMS standard relies on train on-board balise reader and odometer coupled with trackside detection systems to estimate trains speed and track occupancy that are computed on the trackside. To increase railway traffic capacity and sustainability, trains should instead continuously compute on-board their position and speed (defined in ERTMS level 3). This technological step can be achieved through multi-sensor localisation systems using Satellite Navigation services (EGNSS in Europe, EGNOS and Galileo services). Such EGNSS-enabled multi-sensor localisation systems could already be used in ERTMS level 2.

In this new paradigm, a specific concept of integrity for train safe localisation is necessary, that can be designed in reference to the integrity concept developed for the usage of EGNOS in civil aviation.

On the basis of the needs stated by the user groups, including Railways, the European Commission (EC) is developing a roadmap for the evolution of the European GNSS programme, including additional services for Galileo (the European GNSS constellation) and EGNOS. EGNOS is the European satellite-based augmentation system (SBAS) designed to enhance GNSS (GPS and Galileo) performance in terms of accuracy and integrity information for GNSS positioning with continuous monitoring of the continuity and availability of the signal in space and associated services, enabling Safety-of-Life positioning applications.

Former projects like STARS (https://www.stars-rail.eu/) or CLUG (https://clugproject.eu/fr) were conducted to close the gap between ERTMS requirements for safety-critical applications and GNSS services and to perform preliminary feasibility analyses of an on-board localisation unit using EGNSS.

Two approaches are considered for the usage of EGNSS for on-board localisation of trains:

- Virtual Balise: this method aims at minimizing evolutions of the on-board architecture by adding a GNSS-based virtual balise reader that detects pre-defined locations instead of physical balises. The on-board odometer is kept unchanged and as well the overall performance.
- Continuous use of EGNSS (the CLUG approach): this innovative and modular method promises to improve overall performance while reducing the amount of trackside equipment and functionally replace the odometer and the balise reader. This solution requires more updates of the ERTMS standard.

An EGNSS Safety Service for Rail must be defined for GNSS adoption in both approaches.

The key problem when using GNSS for train localisation, as in aviation, is to demonstrate compliance to availability and integrity performance requirements, i.e., the level of trust that can be placed in the safe bounds on the position, velocity, or time estimate provided by the localisation function.

Project objectives and activities

The main aim of the EGNSS-R project was to propose a future EGNSS-based safety service that would enable the introduction of GNSS in railway localisation.

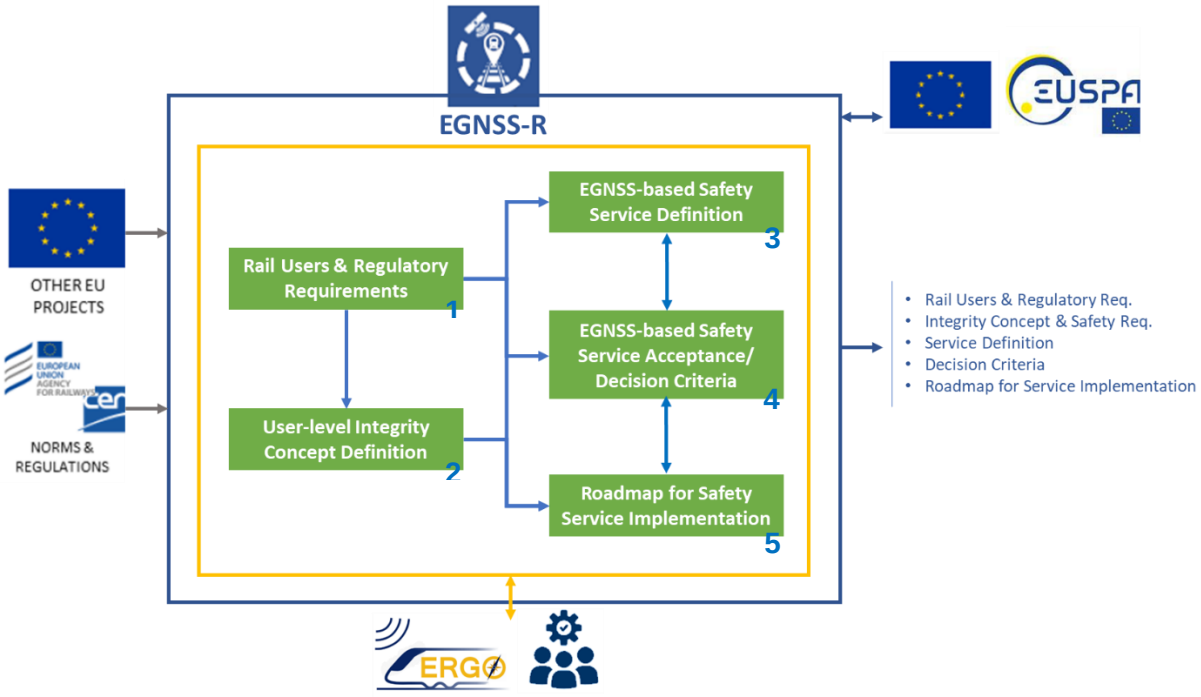
The main objectives of the project were:

- to collect and define Mission requirements and definition of the EGNSS SoL service for railway applications;
- to define a novel EGNSS-based Rail Safety Service;
- to perform a preliminary assessment of the service;

- to deliver recommendations on the evolution process for the future ERTMS TSI.

The EGNSS-R project studied a new EGNSS service dedicated to the rail user allowing a mix of EGNSS and navigation techniques that would enable safe and continuous train localisation for safety-critical applications. This approach includes handling satellite signals outages caused by the railway operational environment (local feared events such as satellite masking, multipath, signal interferences or diffraction). Based on the design of an adequate integrity concept, a preliminary definition of an EGNSS-based safety service has been proposed, associated with an incremental implementation roadmap.

The project was composed of five main tasks.



The first step was the identification of operational requirements, safety requirements and system feared events based on inputs from former European projects, European railway operators and from a working group set-up by EUSPA, called ERGO (Experts in Rail for EGNSS Operational use), that involved key representatives from railway operators, railway and GNSS industry. These requirements were then translated into a user-level integrity concept and a preliminary EGNSS-based service definition for safety critical railway applications. The overall designed concept was then analysed to determine the decision criteria for the EGNSS-based safety service acceptance by all stakeholders. Finally, a roadmap for the implementation of this future service was elaborated.

The consortium organised four main meetings with the collaboration of the ERGO experts, where their feedback and suggestions were collected so in the end they could validate each of the main tasks of the project:

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

Main EGNSS-R outcomes

The needs and requirements of rail users (operators) for adopting train localisation using EGNSS for Safety-of-Life applications 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.

The first phase of the project was completed in April 2021 and led to the definition of a consolidated set of requirements applicable to the Train Localisation System (TLS) and summarized in the Table below:

Localisation Parameter	Integrity Risk Target (Safety Integrity Level)	Half Confidence Interval Target	Accuracy 95% Target	Availability Target
1D Distance (Position with regard to a Reference point)	0,33x10-9/h (SIL4)	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.	Not defined	Not defined 99.9 % (1) is proposed as availability target
1D along-track Speed	0,33x10-9/h (SIL4)	2 km/h for speeds lower than 30 km/h Linear Limit from 2 km/h to 12 km/h for speeds	Not defined	

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

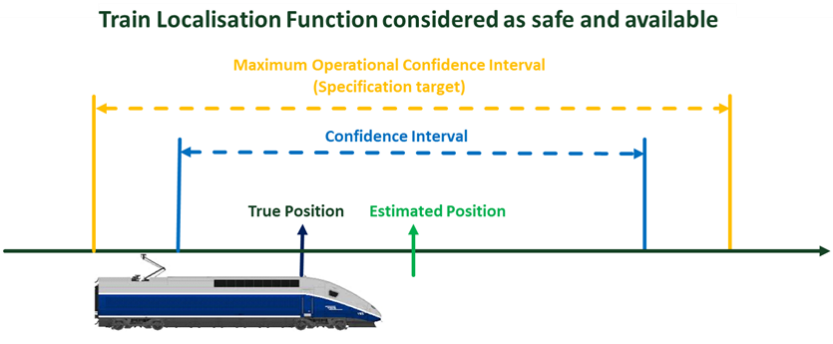
Localisation Parameter	Integrity Risk Target (Safety Integrity Level)	Half Confidence Interval Target	Accuracy 95% Target	Availability Target
		between 30 km/h and 500 km/h.		
Along-track train direction (linked to heading) (2)	0,33x10-9/h (SIL4)	Not applicable	Not applicable	
TrackEdge Identifier (for track selectivity purpose)	0,66x10-9/h (SIL4)	Not applicable	Depending on the method to determine the trackedge identifier (Position driven or Shunting identification), a new safety-critical localisation parameter (3D position) could emerge	

Performance and Safety Requirements target for the Train Localisation Solution

In order to cope with the potential unavailability of GNSS signals and to benefit from the complementarity of other sensors, the TLS algorithms will combine measurements from several sensors. As the integrity risk is defined in the train position domain (position, speed), the EGNSS Service for Rail cannot guarantee alone this integrity risk and the GNSS plus SBAS integrity risk has to be defined at pseudo-range and range-rate level (inputs to the fusion algorithms). A novel integrity concept is proposed based on a budget allocation for each sensor integrity risk, an analysis of feared events subject to occur for each sensor and integrity management through data Fault Detection and Exclusion (FDE) algorithms and computation of Confidence Intervals (CI) on position and speed. Note that the Confidence Interval can exceed the operational requirements while the safety related to the TLS output data is respected. This situation is considered as degraded.

Integrity risk is a Safety issue

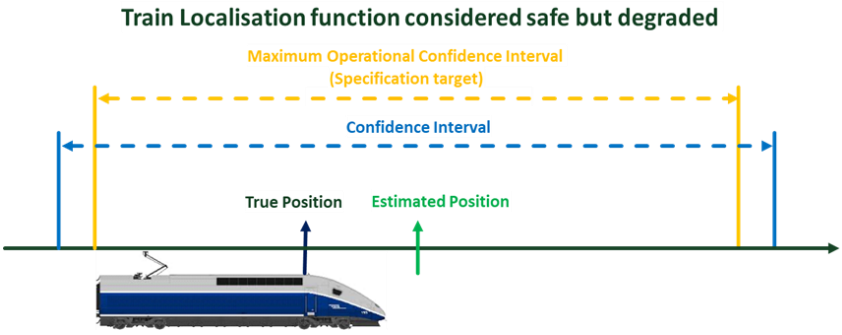
Probability of (speed or position outside of CI) < Integrity risk



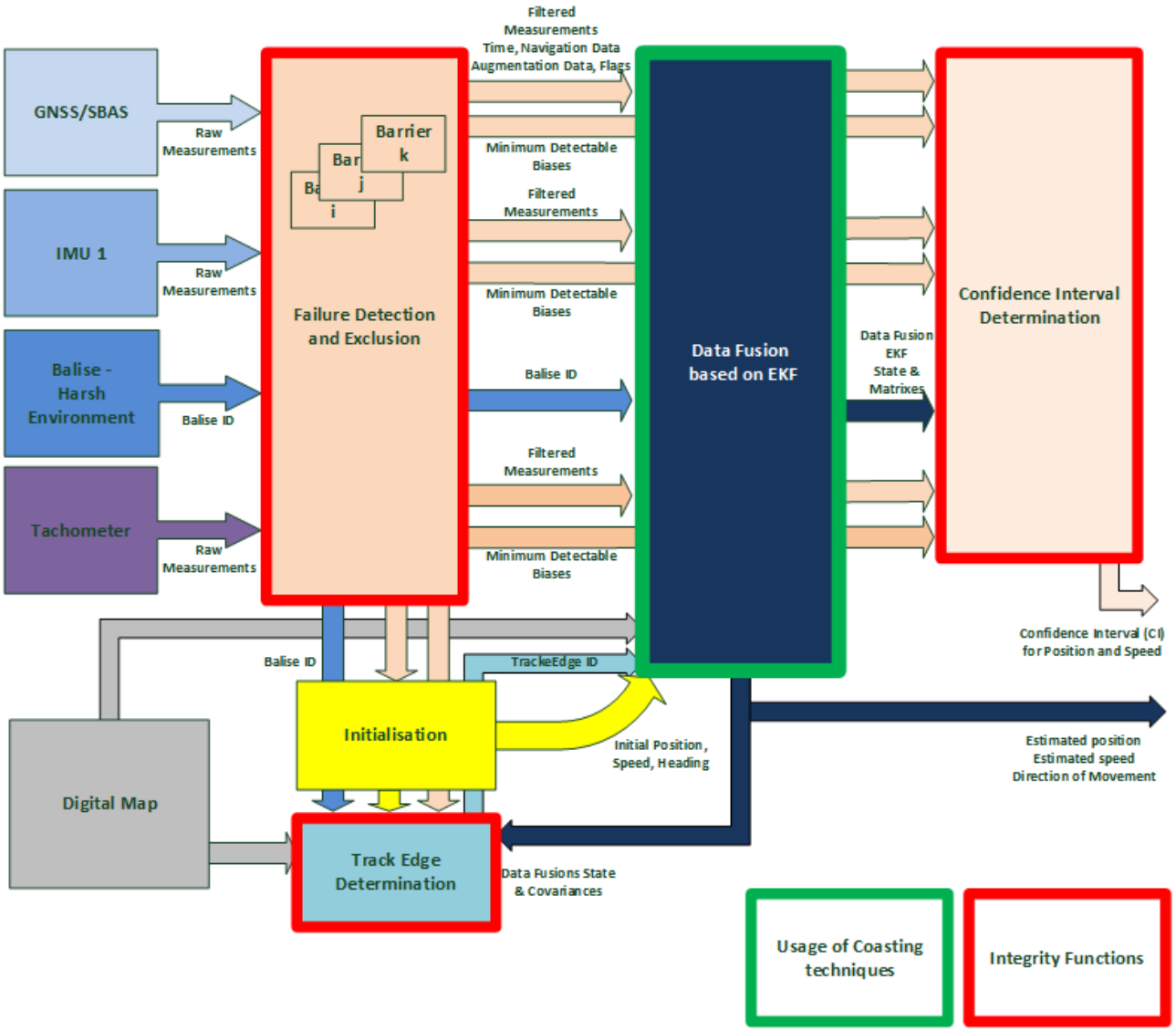
[2] The along-track train direction is not directly studied as part of the Integrity concept as it may be derived from heading localisation parameter. Instead heading localisation parameter is considered in the study.

Confidence Interval size is an operational concern

Impacts timely arrivals, traffic density…



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. This approach requires innovative algorithms. On one-side tailored fusion algorithms based on Extended Kalman Filter. And on the other side, algorithms for Confidence Intervals computation taking into account complex error models (including time correlation, error biases, integrity alerts), knowing that using simple classical error models would lead to unsafe Confidence Intervals.



Example of on-board train localisation system architecture from CLUG project that has been used in the EGNSS-R project

For GNSS/EGNOS measurements, the parameters of these complex error models will 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 broadcasted by a future EGNOS service. The second approach will allow better performance, especially in harsher environment. Proposed additional parameters are the following, for each GNSS satellite (Galileo and GPS):

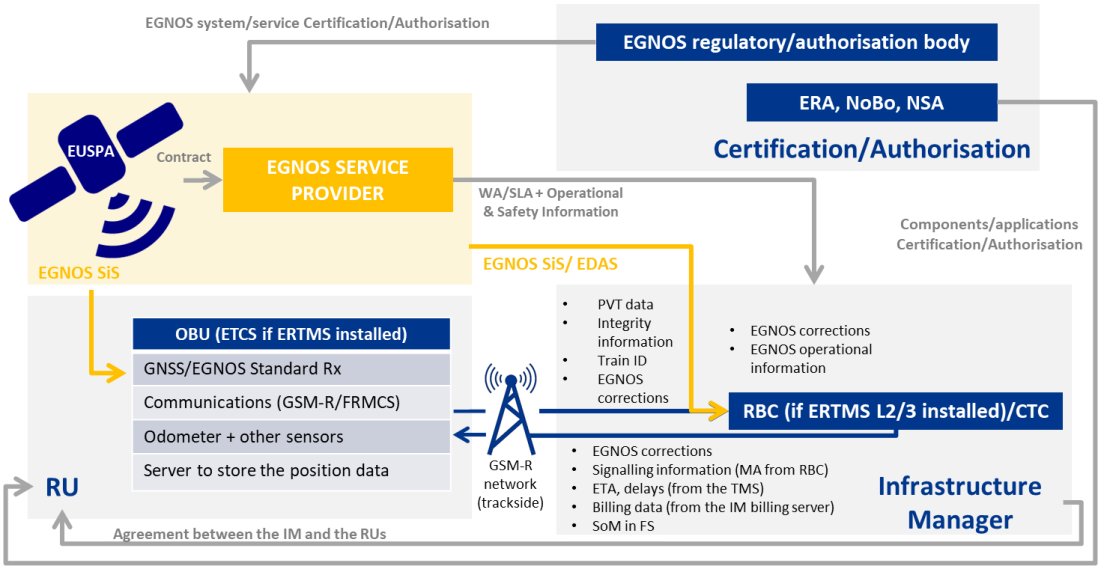
- Parameters of SBAS range error time correlation over-bounding model (correlation time, magnitude)

- 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

An integrity risk of 10^{-6}/h is allocated to the GNSS/EGNOS measurements, corresponding to the EGNOS V3 requirement for aviation. 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 data FDE.

Service implementation and provision require the involvement of all actors with the following roles, as depicted on the Figure below:

- The European Union (EU) is the owner of the EGNOS system and is in charge of ensuring the long term plan of EGNOS and Galileo services.
- The European Commission has the overall responsibility for the implementation of the EGNOS Programme, including for security and determines the priorities and long-term evolutions.
- The European Union Agency for the Space Programme (EUSPA) is in charge of the EGNOS and Galileo exploitation.
- The Regulation/authorization bodies: to certify/authorize the service for railway localisation usage
- The Airspace/Support Industry: to support the EGNOS Programme Manager in the maintenance and development of the system, as well as providing technical support;
- EGNOS Service Provider (ESP): To develop, tailor and deliver the service, to set-up and execute the different engineering and maintenance activities and support rail users;
- Rail Infrastructure Manager (IM): to receive operational data about the service and to react adequately, to maintain the trackside equipment for the provision of the service to the on-board train components;
- Railway Undertakings (RU) End-users: to equip trains with certified Train Localisation 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 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 schedule of EGNOS service 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.

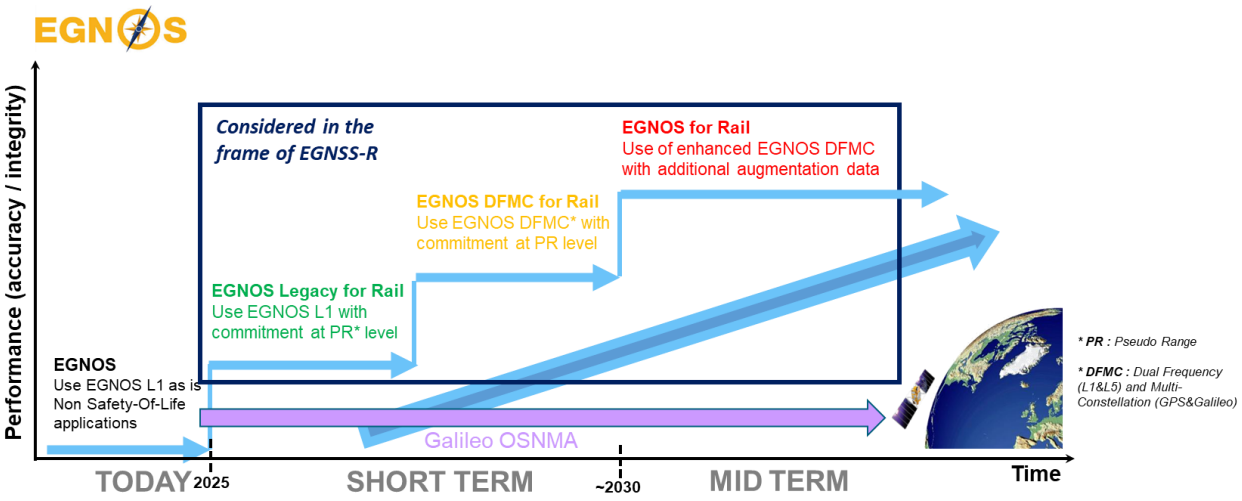
For the sake of budget and schedule, it is recommended to build the EGNOS for Rail safety service on the basis of the EGNOS system planned for providing the DFMC service for aviation (EGNOS V3).

Complementary to EGNOS services, the use of the Galileo OS-NMA service will increase security 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 2025-2026, and in more likely in 2028-2029
- Upgrade of rail infrastructures including communication network and roll-out
- Development of train localisation solution products
- Certification of the train localisation solution products
- EGNSS Services: EGNOS and Galileo systems upgrades, service certification and service provision.

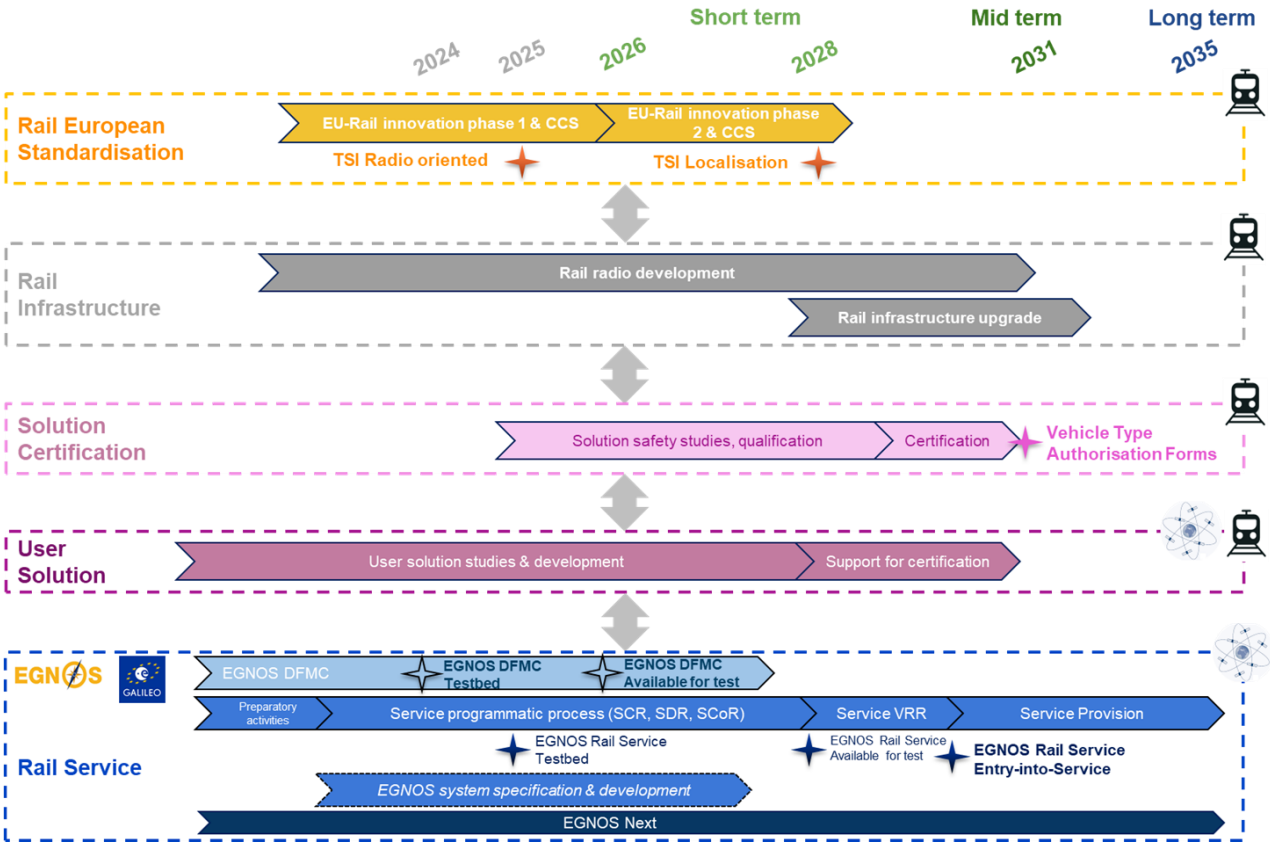


The rail standardisation roadmap will achieve the integration of GNSS in the rail domain after the Entry-in-Service of the EGNOS DFMC, which leads to consider the EGNOS legacy for preliminary derisking phase only.

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", in service in 2028 but not SoL certified**, based on EGNOS DFMC messages disseminated via the GEO SiS (same messages as for aviation), associated with performance commitments
- **A mid-term step, called "EGNOS for Rail" in service in 2030 and certified**, enabled by EGNOS V3 system evolutions:
    - provision of additional parameters with respect to DFMC (range / range-rate integrity alerts and dynamic error models parameters and bounds)
    - safe dissemination via rail terrestrial networks (e.g. FRMCS) through a "SoL Gate"

Both services will be associated with performance commitments provided in EGNOS for Rail SARPS and MOPS documents, required for product design and performance prediction for product qualification against train localisation requirements, and guidelines for service usage in OBU algorithms.



High-level EGNOS safety service for Rail proposed implementation roadmap

As the next ERTMS TSI would probably not completely cover all necessary updates for localisation using E-GNSS, DFMC for Rail service will not be formally certified. However, it can 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 E-GNSS in ERTMS standards and the certification process of EGNOS services in the rail domain.

Expected impact and way forward

GNSS was recognized by the railway community as one of the key game changers that could improve efficiency of train localisation within the future ERTMS evolution. The EGNSS-R study has highlighted the need to develop a railway EGNSS-based safety service.

In addition, the integrity concept first proposals will feed ERTMS standardisation processes on GNSS introduction in the railway domain. It will also engage the first step for rail multi-sensors localisation system certification, which is to be built-up (ERA and rail safety national bodies impact).

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

Disclaimer: The project proposals represent the views of the consortium. They do not necessarily represent the views of the European Commission and they do not commit the Commission to implementing the results.