Rail to Digital automated up to autonomous train operation

D22.7 –Assessment of the need for an early EGNOS service

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EXECUTIVE SUMMARY

This deliverable presents and justifies the need for an early EGNOS service for use in rail SoL applications in the context of ASTP, where EGNOS is expected to play a crucial role in supporting the use of GNSS in a multi-sensor approach.

The request from RFI to have standards to refer to for the ERTMS implementation calls for tender expected for 2027-2028 in the context of the Italian ERTMS Accelerated Implementation Plan, is introduced alongside a description of the operational context in which an early EGNOS service could potentially be used. It is discussed how a GNSS-based positioning solution based on early EGNOS service could already provide significant benefits in terms of reducing trackside assets and operational costs associated with ERTMS deployment.

An early EGNOS service implies the possibility of following an incremental approach starting from a SFSC service. A series of evidence and considerations from past projects and demonstrators are reported in order to preliminary assess the technical feasibility of the request for an early service. A migration strategy to benefit from an early implementation of GNSS/EGNOS-based positioning solutions in the ASTP context is presented. However, it is out of the scope of this document to propose solutions to fit an early EGNOS service.

The advantages and disadvantages of an incremental approach are also discussed. An early EGNOS service should not hinder the different strategies that focus directly on the future evolution of EGNOS; on the contrary, it should facilitate the achievement of more ambitious goals based on EGNOS DFMC or future services because it could move up the resolution of technical and non-technical issues.

The document is intended to reflect the need of a part of the railway sector and will serve as input for the deliverable D22.6 "E4R roadmap and strategic plan" [17], which will define a common roadmap jointly agreed with the railway sector and the space sector for the introduction and the use of EGNOS in railway.

ABBREVIATIONS AND ACRONYMS

ASTP	Advanced Safe Train Positioning
ATO	Automatic Train Operation
ATP	Automatic Train Protection
AZD	AŽD Praha
CCS	Control Command and Signaling
CPF	Central Processing Facility
DFMC	Dual Frequency Multi Constellation
E4R	EGNOS for Rail
EGNOS	European Geostationary Navigation Overlay Service
EoA	End of Authority
ERA	European Union Agency for Railways
ERJU	Europe's Rail Joint Undertaking
ERSAT	ERTMS SATellite
ERTMS	European Rail Traffic Management System
ESA	European Space Agency
ETCS	European Train Control System
EU	European Union
EUROCAE	EURopean Organisation for Civil Aviation Electronics
EUSPA	European Union Agency for the Space Programme
EVC	European Vital Computer
FRMCS	Future Railway Mobile Communication System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HSTS	Hitachi Rail STS
ICAO	International Civil Aviation Organisation
IP	Innovation Pillar
LAAS	Local Area Augmentation System
LRBG	Last Relevant Balise Group
MOPS	Minimum Operation Performance Standard
ORBG	Other Reference Balise Group
PVT	Position Velocity Time

R2DATO	Rail to Digital automated up to autonomous train operation
RBC	Radio Block Center
RFI	Rete Ferroviaria Italiana
RIMS	Ranging and Integrity Monitoring Stations
RTCA	Radio Technical Commission for Aeronautics
RU	Railway Undertaking
SARPS	Standard Aeronautical Recommended Practices
SBAS	Satellite Based Augmentation System
SFSC	Single Frequency Single Constellation
SIL	Safety Integrity Level
SiS	Signal in Space
SoL	Safety of Life
SP	System Pillar
TCMS	Train Control and Monitoring System
TSI	Technical Specifications for Interoperability
VBR	Virtual Balise Reader

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1 INTRODUCTION

The present document constitutes the Deliverable R2DATO D22.7 / E4R D1.2 "Assessment of the need for an early EGNOS service" in the framework of the EGNOS 4 Rail (E4R) activities, conducted under Europe's Rail Joint Undertaking (ERJU) with external contributions of EUSPA, ESA and ERA.

This document reflects the need of a part of the railway sector and will serve as input for the second version of the deliverable R2DATO D22.6 / E4R D1.1 "E4R roadmap and strategic plan" [17]. The latter will define the expected timeline for the availability of an EGNOS SoL service for rail, as well as a jointly agreed and consolidated roadmap between the rail and the space sectors for the introduction of such a service in the railway domain.

The key objective of the document is to justify the reasons for an "early" implementation of the EGNOS service for being used in railway SoL applications for ETCS train localization in the context of ASTP solutions. This is based on the assumptions that ETCS is the main consumer of ASTP's outputs and ASTP will adopt GNSS (Global Navigation Satellite System) in order to achieve its goals which are, in summary: enhancement of train positioning accuracy (keep short the train confidence interval) and reduction of physical reference point (balises) along the track.

Over the last years, several R&D projects have showcased the potential of satellite technology in the railway domain for train positioning solutions. GNSS (Global Navigation Satellite System) is then expected to play a crucial role as one of the elements of the ASTP solution, where GNSS receivers are used alongside other sources in a multi-sensor approach.

However, GNSS alone cannot guarantee adequate performance for safety-critical applications, for which a GNSS augmentation system represents an enabler for achieving application-level performance requirements. Indeed, GNSS augmentation is essential in supporting safe satellite-based train positioning solutions, as it is responsible for providing correction and integrity data, monitoring integrity, and ensuring SBAS user safety and SBAS service availability, enhancing the overall performance of navigation systems.

In this context, EGNOS has an important role to play in supporting the use of GNSS in safe train positioning concepts. EGNOS is the Europe's regional satellite-based augmentation system (SBAS) that is used to improve the performance of GNSS, and enable its use for safety critical applications. It is intended to provide safety of life navigation services to aviation, maritime and land-based users. Currently, however, only SoL Aeronautical users and services are standardised (through ICAO SARPs and RTCA/EUROCAE MOPS), and therefore only SoL Aeronautical services are certified.

The future EGNOS Railway SoL Service is assumed to provide commitments on pseudorange domain performances excluding impact from the local environment. The on-board equipment perimeter would be responsible for protecting the user from local feared events (including intentional events such as spoofing and jamming), bounding of residual errors due to receiver and the local environment, and for computation of an along-track train position, velocity and acceleration and their respective confidence intervals.

While it is expected that future railway SoL services will be developed targeting Dual Frequency Multi Constellation (DFMC) augmenting GPS and Galileo L1/E1 and L5/E5a signals, there could be significant benefits to also targeting the SFSC service for developing an early certified service and thus follow a progressive approach towards the introduction of future services.

The progressive approach could begin by prioritizing the development of an early certified service based on EGNOS SFSC, solving the open points raised in EUG 20E085 [2], addressing the legal framework and certification/authorisation aspects, and thus meeting the railway needs presented in this document. A detailed approach to certification will be developed with the involvement of ERA and EUSPA within WP2 of the E4R Project.

Despite it is out of the scope of this document to propose solutions to fit with an “early” EGNOS service, a number of preliminary evidence and considerations from previous initiatives are just reported to justify the technical feasibility of the request.

It is also worth underlining that it is beyond the scope of this document to address the roadmap of other elements that, together with GNSS, are part of the ASTP framework and contribute to the fulfilment of its goals (e.g. Digital Map). In any way, regarding the introduction of EGNOS service in the TSI, this will come along with the ASTP solution to be introduced in the TSI. For that, ERA is expecting a consensual approach, both for ASTP and EGNOS service, coming from ERJU System Pillar through the Standardisation and TSI Input Plan. The feasibility of a short-term implementation will therefore have to be confirmed in v2 of R2DATO D22.6 / E4R D1.1 “E4R roadmap and strategic plan” [17].

The next chapters of the document are organized as follows:

- Chapter 2 provides the justifications of the need for an early EGNOS service.
- Chapter 3 provides the preliminary considerations about the technical feasibility for an early EGNOS service to be used in railway SoL application.
- Chapter 4 presents the advantages and disadvantages of a progressive approach focused on developing an early EGNOS service.
- Chapter 5 reports the conclusion.

2 JUSTIFICATION OF THE NEED FOR AN EARLY EGNOS SERVICE FOR RAIL SOL APPLICATIONS

This chapter provides the justification of the need for an early EGNOS service. It begins by presenting the need of RFI in the context of the ERTMS large-scale deployment plan underway in Italy and continues dealing with a description of the rail operational context in which an early EGNOS service could potentially be used. While in this chapter the need for an EGNOS service is presented from the RFI perspective, it is worth underlining that such a service could potentially be used and needed in other European countries as well.

2.1 RFI'S ERTMS LARGE-SCALE DEPLOYMENT PLAN

The current TEN-T Guidelines (Regulation (EU) No 1315/2013) establish ERTMS as one of the priorities for railway infrastructure development and set out a deadline for its deployment on the Core Network by 2030 and on the Comprehensive Network by 2050. In line with EU obligations, RFI's ERTMS Accelerated Plan, last revised in September 2023 (rev. Q) [10], involves investing more than 13 billion euros to equip the entire Italian railway network (16.800 km) with ERTMS by 2036, at a rate of about 1.000 km per year. At the same time, the gradual decommissioning of the national system and thus the upgrade to ERTMS of the entire operating fleet in Italy (around 4.000 on-board units in operation to date) has begun, with additional funding sources available to railway undertakings.

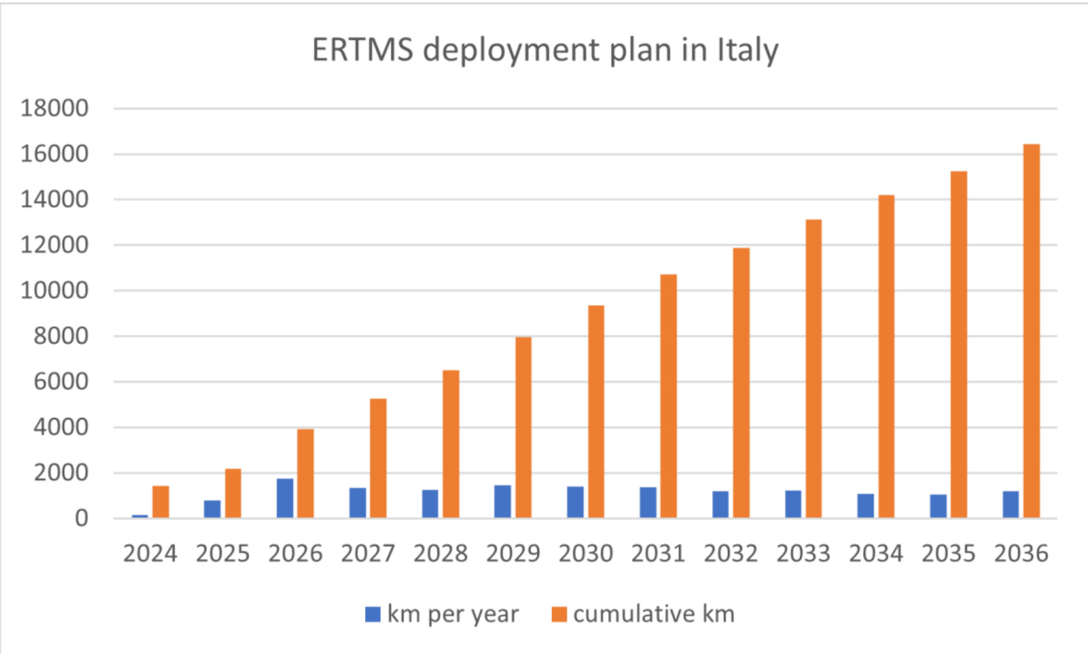

Figure 1: Forecast of per year and cumulative ERTMS-upgraded kilometres as per the RFI's Accelerated Plan

Today in Italy, out of a total of 16.800 km, about 1.000 km of High-Speed lines and 360 km of conventional lines on the Core Corridors are already equipped with ERTMS. In addition, contracts were signed for about 900 km of conventional lines and urban nodes with ERTMS overlapped with the Italian national class B system (SCMT). Moreover, additional 4.900 km were contracted through the so-called "Multitechnological Framework Agreement"; the latter includes Phase 1 (stipulated in February 2022) for the first 700 km and Phase 2 (stipulated in October 2022) for the others 4.200 km. Looking ahead, discussions are currently underway regarding the remaining segments that need to be tendered.

As part of the ERTMS deployment plan, local and regional lines represent a priority for RFI and a massive upgrade of these lines is planned in the coming year. Indeed, the first regional lines exclusively equipped with ERTMS with the national system decommissioned are expected in 2025 (534 km). For these kinds of lines, a solution based on an early EGNOS service can already bring to a positive business case by reducing investments and operational costs. In addition, since the upgrade of the fleet with ETCS is progressing in parallel with the trackside deployment, an early availability of standard specifications will also reduce the number of vehicles which will need to be upgraded twice, i.e. first with ETCS and then with ETCS+ASTP.

The large-scale deployment of ERTMS is thus creating an appealing and favourable environment for the introduction of a GNSS-based localization system, which can help improve both the sustainability and performance of the entire railway system. RFI believes that the benefits coming from an early EGNOS service would be crucial for the sustainability of the ERTMS, even more so in the context of the Italian large-scale deployment plan. GNSS-based train positioning solutions could allow reducing the number of physical balises along the line by replacing them with Virtual Balises. Reducing the number of physical balises not only lowers the initial capital expenditure (CAPEX) required for their procurement and installation, but also cuts down on the operational expenses (OPEX) associated with their maintenance. In addition, the reduction of physical balises reduces the probability of balise reading errors. Less balise reading errors are expected to reduce the necessity for braking. Less braking will enhance punctuality and customer satisfaction and is expected to reduce rail and wheel wear.

These considerations are even more valid if we consider that Infrastructure Managers need to plan huge investments to modernise the entire railway network, also including local and regional lines many of which are rather outdated. Implementing ERTMS on these low-traffic lines is necessary for their renewal, but the substantial modernization costs may not be fully justifiable. The application of GNSS provides an answer to streamline ERTMS deployment on regional lines with lower traffic volumes, reducing implementation, operation and maintenance costs while enhancing overall railway network efficiency and reliability.

Several business case studies have demonstrated that the advantages, both qualitative (e.g., increased performances and regularity of operation) and quantitative (trackside asset reduction), outweigh the cost incurred by the introduction of added complexity, which is mainly due to the integration of the on-board and trackside elements required for using GNSS in ERTMS train positioning (please refer to [11]and chapter 4 of [12] for more details). However, the upgrade of the fleet is an issue which inevitably needs to be considered because it undermines the Railways Undertakings' benefits (increase of punctuality and regularity, less braking interventions due to missing balises): financing mechanisms to support vehicle owners are therefore necessary (and in Italy already in place for ETCS) to ensure a balanced benefit for all actors. Those mechanisms are depending on the Member States, and they are out of the scope of this document.

In addition to these considerations, it is worth mentioning that RFI has gained considerable experience over the last years, believing in the opportunities of the introduction of GNSS technologies into ERTMS since 2012, when the ERSAT programme was launched. The primary objective was to test and validate the integration of GNSS technology in railways, by leveraging the "virtualization" of balises without altering the ERTMS architecture. Within the ERSAT Program, RFI has achieved significant results, having successfully tested GNSS positioning solutions in Sardinia on the "Cagliari-S. Gavino" line. Moreover, activities to support the validation and certification phase of the "Virtual Balise" functionality were recently commissioned by RFI on the Pilot Line "Novara-Rho", where ERTMS L2 is already in operation, with the aim of assessing that the specific solutions (Reference Stations and Virtual Balise Reader) are compliant to the requirements of the applicable CENELEC standard for SIL4 safety level.

Given the tight timeframe in which RFI intends to deploy ERTMS on its entire network, it would therefore be worthwhile to accelerate the development of standardized services, architecture and relevant interfaces to implement solutions based on GNSS/EGNOS as soon as possible and take full advantage of the opportunities provided by GNSS within the Italian ERTMS large-scale deployment plan. Hence, the need to have EGNOS standards for rail SoL applications to refer to in the RFI's calls for tender for ERTMS implementation expected from 2027 onwards, with the aim of enabling the development, certification and authorisation of products/subsystems.

This implies the need to include the specifications relevant for interoperability inside the TSI-CCS (different instrument, such as a Technical Opinion, could be used for early implementers while pending the update of the TSI, according to Art.11 REG 2023/1695).

Consequently, RFI's request is that the EGNOS roadmap for railway SoL applications be structured in such a way as to meet the aforementioned need.

2.2 RAIL OPERATIONAL CONTEXT SUITABLE FOR USING AN EARLY EGNOS SERVICE

With respect to the current ETCS specification expressed in [13], the train position information is defined as the relative position of the train front in relation to a reference location (balise group). Balise groups, strategically positioned along the track at set intervals, serve to pinpoint the train location while the on-bord odometry system tracks the train's speed and calculates the distance travelled since passing over the last balise group. Therefore, the train position is always longitudinal along the route and is determined by the oriented distance of the estimated train front end position from the reference balise group (LRBG).

The position report elaborated onboard includes the oriented distance between the LRBG and the estimated train front end, as well as the train position confidence interval (safety boundaries for the estimated position).

The confidence interval influences the operational performance of a line in terms of capacity, travel time or capability to approach a specific location within an acceptable operational interval and it is a function of:

- the on-board over-reading amount and under-reading amount, which includes the odometer inaccuracy and the error in detection of the balise group location reference;
- the location accuracy of the placement of the reference balise group (Q_LOCACC).

The odometry system of current ETCS implementations is typically based on wheel sensors and additional sensors, and the confidence interval increases with the distance travelled from the reference balise group depending on the accuracy and robustness (capacity to cope with failures and slip/slide phenomena) of the ETCS odometer function.

The performance requirement of the accuracy of the odometry is defined as a linear model of the measured distance from the reference balise group (LRBG). The current specification for the performance of the odometry is described in [14], where it is stated that for every measured distance *s*, the accuracy of distances measured on-board shall be better or equal to ± *(5m + 5% s),* which leads to the following:

$$\frac{1}{2}\,TrainPositionCI \leq Q\_LOCACC + 5m + 5\% * s$$

The principle for limiting the upper limit of the confidence interval is detailed in [13] and involves resetting it to a minimum value whenever the train crosses a reference point, e.g. physical balise. Consequently, the maximum value of the confidence interval is determined by the distance between LRBGs. The engineering rules for placing balises are thus essential to meet the operational performance targets of a line.

Activities to review train localization user requirements are within the scope of IP R2DATO, where a fixed values model for the confidence interval limits is proposed in [15] in the context of the ASTP (the work is still in progress). This model is based on the Max Accepted Position Underestimation (MAPU) and the Max Accepted Position Overestimation (MAPO). The former is a limit to the underestimation (L_DOUBTUNDER) of the estimated train front end position, while the latter is a limit to the overestimation (L_DOUBTOVER). A graphical representation is provided below.

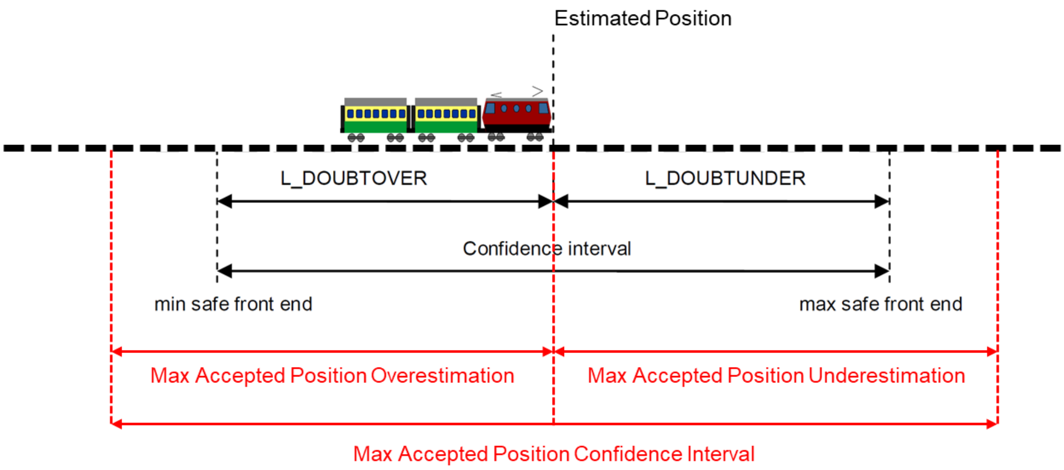

Figure 2: MAPU and MAPO visualization considering train position [15]

The fixed values for MAPO and MAPU of the model proposed in [15] have been defined for two types of areas and are listed in the Table below.

Type of areas	**MAPO, MAPU**
Area with negligible constraints *(mainline, dense traffic line, track section between two areas with constraints)*	**60 m**

Area with constraints *(station area (platform), traffic node (specific point), stopping point (EoA), limit of authority (LoA))*	**10 m**

Table 1: Fixed values confidence interval model [15]

This leads to the following limits for the confidence interval:

$$\frac{1}{2}\, TrainPositionCI \leq 60\ m \quad in\ area\ with\ negligible\ constraints$$

$$\frac{1}{2} TrainPositionCI \leq 10\ m \quad in\ area\ with\ constraints$$

Please refer to [15]for a more comprehensive description of the model.

Even without the possibility of significant improvements, a solution based on an early EGNOS SFSC service could potentially meet the above-mentioned performance requirements (please refer to Section 3.1) and could be suitable for the contexts where a high level of accuracy for train localization is not a priority, e.g., for local and regional lines. These types of lines represent a large part of the railway network in Italy and many other European countries.

An early EGNOS service could therefore provide significant benefits already in the short term, allowing to reduce trackside assets and operational costs associated with the implementation of ERTMS. Hence RFI's need is to have EGNOS standards that allow to leverage the benefits of GNSS-based train positioning solutions in line with the timing of the Italian ERTMS Accelerated Plan that was previously presented. Such standards could also be used and needed in other countries facing similar scenarios.

As the EGNOS service evolves and performance improves, GNSS adoption can then provide benefits in a larger number of operational scenarios having more stringent requirements in terms of accuracy (train coming to a halt at the EoA, stopping point, approach to a point where speed varies or to a track condition, leaving a speed restriction or releasing a device ...) improving sustainability and performances (in some specific case also ETCS safety could get benefit) on the entire railway system.

3 EVIDENCE OF FEASIBILITY FOR AN EARLY EGNOS SERVICE

This chapter begins by discussing why the current SFSC service could be considered suitable for an early service based on considerations coming from previous projects and demonstrators. Furthermore, it is discussed how the interest of Europe's Rail IP demonstrators in using EGNOS is the evidence that GNSS is considered by railways and the CCS suppliers' community as a very promising solution (albeit not yet fully mature) to be used in the ASTP context. Finally, a migration path allowing for a rapid implementation of GNSS/EGNOS-based systems is discussed.

3.1 SUITABILITY OF EGNOS SFSC SERVICE FOR TRAIN POSITIONING IN ETCS

The current EGNOS service (SBAS SFSC) broadcasts corrections and integrity information for the GPS satellites (L1C/A SIS), on the SBAS L1 frequency (1575.42 MHz) using geostationary satellites. The advanced services refer to the future EGNOS Dual Frequency Multi Constellation (DFMC) service, which will broadcast corrections and integrity information for both GPS (L1 C/A and L5 SIS) and Galileo (E1 and E5a SIS) satellites, on the SBAS L5 frequency (1176.45 MHz) using geostationary satellites. This advanced service is expected to provide higher accuracy and availability performance than the current service.

However, in defining the EGNOS roadmap, the opportunity of an early EGNOS SFSC service should not be excluded. The feasibility of this approach is also supported by the results of previous projects and demonstrations, in which EGNOS SFSC was tested in a real railway scenario.

In the frame of X2Rail-5 project, the main goal within the WP6 was to develop technological demonstrators to prove the effectiveness of satellite-based train positioning solutions implementing the Virtual Balise concept. The activity was carried out to define, develop and test Virtual Balise system prototypes able to use different technological solutions. Three distinct demonstrators created by AZD, HSTS, and MERMEC, each with its own related testbed, were developed by leveraging the latest satellite positioning technologies, augmentation networks, and kinematic sensor technologies.

The HSTS demonstrator is especially relevant to the purpose of this paper as one of its key outcomes was to evaluate the performance of the solution by relying on EGNOS SFSC to enhance satellite positioning in the real context of an ERTMS fully operational, low-traffic regional line.

The demonstrator used two different products - one using EGNOS v2 SFSC and the other utilizing a Local Augmentation Network with dedicated reference stations based on the avionic LAAS model. It's important to note that these two architectures were alternatives and did not work in a combined manner.

This additional experimentation allowed for a comparison of the positioning results achieved by using GNSS augmentation via SiS from EGNOS satellites versus those utilizing the dedicated augmentation network specifically designed for railway application.

One of the key indicators to assess the performance and suitability of EGNOS for use in SoL train positioning applications is represented by the Protection Level, which is the statistical bound of the position error. The outcomes of the demonstrator reported in [5] show that the average of the Protection Level values obtained with the EGNOS-based system is around the value of ± 12 meters (this numerical value has been retrieved from the data graphically shown through the Stanford diagrams reported in [5]). Compared to the Local Augmentation Network, in some cases the EGNOS-based system shows a greater dispersion of the Protection Level values and a small increase in the number of degraded performance epochs, resulting in a slight deterioration in performance. The mean and standard deviation of the position error are also significant key indicators. Also in this case, the results obtained are comparable and promising, as demonstrated by the metrics extrapolated from [5] and shown in the table below, where μ(ε) denotes the average of the position error and σ(ε) the standard deviation. These metrics have been computed off-line based on the position errors associated with the PVT samples in each train run. The error of the VBR measure has been quantified in post-processing by comparing all the measured VBR positions with the corresponding true positions provided by the applicable Ground Truth [5].

Train Run	EGNOS SFSC		Local Aug. Net.	
#	μ(ε)	σ(ε)	μ(ε)	σ(ε)
1	0,737 m	0,833 m	0,049 m	0,648 m
2	-0,785 m	1,46 m	-0,393 m	0,842 m
3	-0,752 m	1,491 m	-0,209 m	0,666 m
4	-0,577 m	1,136 m	-0,247 m	0,622 m
5	1,004 m	1,223 m	-0,341 m	0,618 m
6	-0,507 m	1,323 m	0,655 m	1,894 m
7	0,748 m	0,963 m	-0,379 m	0,79 m
8	1,532 m	1,963 m	-0,454 m	0,789 m
9	-0,687 m	1,234 m	0,976 m	2,515 m
10	0,68 m	1,303 m	-0,785 m	1,085 m
11	-0,69 m	1,327 m	0,496 m	1,866 m
12	0,741 m	1,632 m	-0,314 m	0,789 m
13	-0,674 m	1,346 m	-0,132 m	0,947 m

Table 2: Comparison of Position Error Metrics for the VBR application based on EGNOS and Local Augmentation Networks in Test Sessions carried out in X2R5-WP6 [5].

For a more comprehensive performance evaluation, additional Key Performance Indicators, supplemented by related figures of merits, can be found in [5]. According to the test conducted and the outcomes reported in [5], the main result is that, although technical approaches may vary, HSTS demonstrator shows that EGNOS SFSC offers promising performance for potential use in rail operational context (refer to Section 2.2).

In addition, findings from the scenarios analyzed on the "Novara-Rho" Pilot line reveal that nearly 70% of the balise groups could potentially be virtualized, about 90% along the line and 50% in the stations. Not all balises can be virtualized since the use of physical balise groups remains necessary to achieve the desired performance levels in areas with more stringent requirements (e.g., the use of physical balises that are related to safety and within stations is essential, but installation and maintenance costs of balises in the stations are expected to be smaller). A significant benefit in terms of balises reduction is also expected in case a sufficient number of physical balises is left (as a minimum according to the constraint on the maximum distance between balise groups reported in ETCS Subset-091 [16]) aiming to allow a flexible upgrade strategy of the fleet. Future services are expected to further reduce ground assets, potentially improving the overall business case.

It is worth emphasising that this section does not intend to claim that the current EGNOS SFSC service is sufficient to achieve SIL4. There are indeed several open points that must be addressed, many of them already highlighted in [2]. Missing those actions, such EGNOS service would be unusable by the railway users. Based on the need presented in Chapter 2, an early SFSC service should be considered as part of the EGNOS roadmap for the rail sector. This approach could potentially allow the introduction of EGNOS without a prolonged wait for future services, provided the necessary issues are addressed to make the current service usable for railway Safety of Life applications. Several open points concerning the use of EGNOS in the railway domain also apply to DFMC, and anticipating their resolution starting from the existing service is considered one of the advantages of the proposed approach.

3.2 ERJU IP LOCALIZATION DEMONSTRATORS

Within the FP2-R2DATO project of EU-Rail, the exploitation of GNSS technology is crucial in the localisation strategies of seven of the eight proposed demonstrators. The objectives of the demonstrators align with the progressive integration of GNSS-based safe train localisation into ERTMS, which represents a substantial step forward in the improvement of the railway system. The key role of EGNOS becomes evident as six of the seven GNSS-dependent demonstrators within the FP2-R2DATO project intend to demonstrate performance of positioning solutions which use EGNOS for SoL applications.

Additionally, Alstom also intends to validate its satellite-based positioning solution, based on augmentation data provided by EGNOS SFSC, on an Italian regional line in the context of FP6-FutuRe demonstrator.

The interest of IP demonstrators in using EGNOS underlines how GNSS is currently considered by railways and the CCS suppliers' community as a very promising solution (albeit not yet fully mature) to be used in the ASTP context.

The EGNOS service to be used for the field test demonstrators cannot be a service directly developed from the specific requirements of the railway sector. This limitation stems from the timeframes associated with developing a new service directly from the user requirements, which is not in line with the time constraints coming from the demonstrators´ needs.

It could be, therefore, worth starting with the provision of SBAS service tailored for railway SoL applications, building on the integrity concepts already existing with EGNOS SFSC. Focusing initially on the qualification and commitment of pseudorange domain performances would allow for the evolution of a service meeting the sector's unique demands while leveraging the groundwork laid by EGNOS SFSC's integrity concepts.

3.3 MIGRATION STRATEGY

An early SFSC EGNOS service for rail SoL applications is supposed to be used in the context of ASTP. This is based on the assumption that ASTP will use GNSS receivers along with other sensors to achieve its main goals, i.e. enhancing train positioning accuracy and reducing the number of physical balises along the track.

In current ETCS implementations, the odometry functionality is part of the monolithic ETCS On-Board Unit. In the future, to improve localization performances while relying on a modular and scalable train positioning system, the odometry functionality could be decentralized from EVC to ASTP. This would mean that ASTP would be responsible for providing localisation information to the EVC (and to other consumers - e.g., class B ATP, ATO-OB, TCMS).

To facilitate the migration towards a CCS system with a modularised ASTP and start getting benefits from the early implementation of GNSS/EGNOS-based positioning solutions, it should be investigated the possibility of following an ASTP stepwise approach starting from a first version of ASTP (“ASTP - Phase 1“) retaining the legacy on-board odometry solutions within the EVC.

The “ASTP – Phase 1” is a new functionality integrated into the ETCS onboard subsystem, conceived as a “black box”, where only the interfaces relevant to interoperability (i.e. the interfaces related to Digital Maps, GNSS and GNSS augmentation) and the performance and safety requirements are standardized. The approach used is similar to that already in place for ETCS odometry.

The “ASTP – Phase 1” makes use of the ETCS odometry, plus GNSS with augmentation and, possibly, other inputs or sensors to provide ETCS with the information needed to enhance the confidence interval for the train position. This solution does not foresee interchangeability, so that each supplier can integrate “ASTP – Phase 1” only into its own ETCS Onboard product.

This type of solution could be already valid to reduce the number of physical recalibration balises for specific lines and operational contexts where a high level of accuracy for train localization is not a priority (as discussed in Section 2.2).

Subsequently, where needed, there may be a phased transition towards “ASTP - Phase 2”.

The “ASTP - Phase 2” concept as resulting from SP, R2DATO WP21 and WP22 (not yet consolidated) would be a subsystem external to the ETCS Onboard, integrating the odometry. Then, the “ASTP - Phase 2” should meet more stringent accuracy requirements and more use cases than “ASTP - Phase 1”. From this, it is quite evident that the impact of “ASTP - Phase 2” on the current ETCS would be much higher than “ASTP - Phase 1”, in term of upgrading the current ETCS Onboard and also in term of standardization timeline, thus resulting less compatible with the RFI strategy already described.

However, it's essential to note that transitioning the trackside infrastructure and the fleet to “ASTP-Phase 2” with independent odometry may not be necessary for all scenarios, especially if the existing systems equipped with “ASTP - Phase 1” adequately meet operational needs. In such cases, additional upgrades may not be necessary, leading to a more cost-effective and pragmatic approach.

For the “ASTP – Phase 1”, the use of a number of physical balise groups remains necessary to achieve the desired performance levels in areas with more stringent requirements (e.g., the use of physical balises that are related to safety and within stations is essential) and for interoperability reasons (according to the constraint on the maximum distance between balise groups reported in ETCS Subset-091 [16]). Leaving a certain number of physical balises installed on the track could also allow a flexible deployment strategy over the fleet and the trackside. Trains equipped with “ASTP - Phase 1” can safely travel on all ETCS lines (being the odometry within the EVC fulfilling the requirements specified in the current CCS-TSI), while it is still to be confirmed that trains not equipped with “ASTP - Phase 1” can safely travel on lines where the number of physical balises has been minimised, albeit with lower performance in terms of positioning accuracy (engineering rules should be properly analyzed).

In the perspective of a migration path allowing for a rapid implementation of GNSS-based systems, initially, the adoption of “ASTP - Phase 1” would only be possible via the ERTMS GSM-R channel. A radio communication system based on TSI compliant GSM-R network has already demonstrated effectiveness in transmitting GNSS augmentation data from trackside to on-board, as evidenced by X2R5 WP6 VB Train Positioning Demonstrators [5]. The dissemination from trackside to on-board over FRMCS will be possible at a later stage. It is out of the scope of this document to match the FRMCS roadmap with the ASTP one.

The outlined migration strategy aims to capitalize on the potential availability of an early EGNOS SoL service for rail based on the needs presented in Chapter 2. The feasibility of this approach will have to be confirmed in v2 of D1.1 "E4R Roadmap and Strategic Plan" [17]. This latter will define a jointly agreed and consolidated roadmap for the introduction of EGNOS in the railway sector, while also guaranteeing synchronization and coherence with the Standardisation and TSI Input Plan, as well as the ASTP roadmap.

4 ADVANTAGES/DISADVANTAGES OF AN EARLY EGNOS SERVICE

An early EGNOS service implies the possibility of starting from the SFSC service once it is suitable for railway SoL applications. The aim of this Chapter is therefore to present an overview of the advantages and disadvantages of a progressive approach based on the development of an early EGNOS service starting from the current available SFSC service.

One of the primary reasons for prioritizing EGNOS SFSC service is its immediate availability, which makes it accessible for testing and integration into railway systems without the need for extensive technical development. Furthermore, as mentioned before, demonstrations in X2Rail-5 (refer to Section 3.1), based on EGNOS SFSC, show performances that are considered sufficient for enabling a substantial reduction in trackside assets.

A first draft of specifications [2] for its application in railways has been developed in the past and will be considered while drafting SARPs+ and MOPS within the E4R WP3 tasks. The availability of the aforementioned draft specifications will provide a solid baseline start, that will facilitate the development of agreed minimum performance standards reducing the complexities of defining entirely new standards or systems.

The safety case for the current version of EGNOS could provide the starting point for developing a methodology and process for certification/authorisation. Once the methodology is defined, applying the process to EGNOS SFSC will also mitigate the risk of unforeseen or blocking issues that may impact the certification/authorisation of future versions of EGNOS. This way, the process can be started without waiting for the DFMC aviation safety case to become available.

In addition to these considerations, another key driver for prioritizing EGNOS SFSC over a completely new service developed on the basis of specific user needs is the cost-effectiveness and efficiency of a progressive approach (this point can also be valid for DFMC currently already under development). Developing an entirely new service tailored to user needs would be a resource-intensive endeavour, both in terms of time and financial investment. On the other hand, deploying the existing EGNOS service for railway applications could be a significantly more cost-effective solution. Reasonably, the effort required to exploit the existing service could be far less, making it a pragmatic choice for expeditious integration in the railway domain.

Prioritizing the current EGNOS service also enables the standardization and provision of services for railway applications that do not demand extremely high levels of accuracy. Initially, the railway SoL Service could take advantage of integrity and performance achievable with EGNOS SFSC. Future services will be developed progressively to meet more stringent needs. Such a cyclic approach will enable the flexibility to manage an evolving set of baselines/needs.

A progressive strategy also allows leveraging the experience gained from the current service to foster and facilitate the development of advanced services, thus optimizing the accuracy and performance incrementally. Many of the technical open points identified will be relevant for future EGNOS services as well, such as DFMC or EGNOS Next. Also, when relying on the DFMC service, the SFSC could be adopted as a degraded service in specific scenarios. Additionally, the integrity performances of EGNOS are unlikely to change significantly in future services.

An early adoption of GNSS for train positioning in the railway sector ensures the prompt availability of all its associated advantages. A progressive strategy allows for the progressive removal of balises, which are costly to install and maintain. Indeed, a solution based on EGNOS SFSC can already bring to a positive business case by reducing investments and operational costs associated with

ERTMS deployment. Many operational scenarios could be covered with the current EGNOS service, as expressed in Chapters 2 and 3. As the service evolves and performance improves, GNSS adoption can then be extended to operational scenarios with more stringent requirements in terms of accuracy, including lines where GNSS can bring even more benefits by saving the installation and maintenance of a greater number of devices and improving the performance of the entire railway system.

Finally, it is worth underlining that a progressive approach does not hinder the different strategies that focus directly on the future evolution of EGNOS; on the contrary, it might facilitate the achievement of more ambitious goals based on EGNOS DFMC and future services, because it anticipates the resolution of technical and non-technical issues.

Among the disadvantages, the adoption of an early service implies the need for possible upgrades when operation requires higher performance as well as the need of delta certifications when moving to future services. However, only SW upgrade from SFSC to DFMC services shall be a necessary precondition. Indeed, a progressive strategy shall ensure a future-proofed approach that can support services as they evolve and provide additional capabilities and commitment and can be de-risked from an on-board equipment supply perspective, considering the development of an ASTP that utilizes a DFMC GNSS receivers. In the current DFMC aviation receiver MOPS (ED-259A), support for EGNOS SFSC is inherent in the design of the DFMC receiver. A similar approach can be considered for the railway MOPS, such that future performance improvements through the use of new railway SoL services based on EGNOS DFMC and EGNOS Next, could be potentially facilitated through software updates (i.e., not requiring retrofitting of equipment on the train including DFMC antennas). This approach minimizes the cost and disruption associated with migration.

The following table summarizes the reasons and the advantages/disadvantages of prioritizing an early service based on the EGNOS SFSC.

Immediate availability	The immediate availability of the current EGNOS service makes it accessible for testing and integration into railway systems without the need for extensive technical development.
Demonstrated suitability	Preliminary evidence for EGNOS SFSC service shows performances that can already be considered sufficient for enabling a substantial reduction in trackside assets.
Efficiency and cost-effectiveness	The effort required to exploit existing EGNOS service requires significantly less effort compared to developing an entirely new service, making the incremental approach a pragmatic choice for expeditious integration in the railway domain.
Anticipated service standardization	A progressive approach may speed up the definition of standard specifications and may even anticipate the provision of future services (EGNOS DFMC and EGNOS next).
Accelerated certification/authorisation of future versions	The safety case for the current EGNOS version provides a starting point for developing a process and methodology for certification/authorisation, mitigating risks for future versions.

Optimization of future service development	A stepwise strategy allows leveraging the experience gained from the current service to foster and facilitate the development of advanced future services.
Early benefits of GNSS in ERTMS	Early adoption in the railway sector ensures the prompt availability of GNSS associated advantages, such as reducing investments and operational costs associated with ERTMS deployment, especially in lines where high train position accuracy is not the priority.
Need for upgrades and delta certifications	The adoption of an early service implies the need for possible upgrades when operation requires higher performances, as well as the need of delta certifications of both EGNOS and deployed rail equipment when moving to future services. This could have non negligible impact on costs.

Table 3: Advantages/disadvantages of prioritizing an early certified service based on EGNOS SFSC

5 CONCLUSIONS

This document presented the need of a part of the railway sector for an early EGNOS service to be used in rail SoL applications. In particular, RFI intends to leverage the benefits of GNSS-based train positioning solutions in the context of the ambitious ERTMS large-scale deployment plan underway in Italy. Indeed, the request that the EGNOS roadmap for railway be structured in such a way as to have EGNOS standards to refer to in the RFI's calls for tender for ERTMS implementation in Italy expected from 2027 onwards. While the need for an EGNOS service is presented from the RFI perspective, it is worth underlining that such a service and standards could potentially be used and needed in other countries as well.

It has been discussed how an early EGNOS service could potentially be suitable for all the operational contexts for which a high level of accuracy for train localization is not a priority. These kinds of lines represent a large part of the Italian railway network and an early EGNOS service could already provide significant benefits in terms of reducing trackside assets and operational costs associated with ERTMS deployment. In supporting this request, several considerations have been provided based on preliminary evidence which have showcased the suitability of EGNOS SFSC to cover relevant rail operational scenarios. A migration strategy to start taking advantage of an early implementation of GNSS/EGNOS-based positioning solutions in the ASTP context has been discussed.

The advantages of a progressive approach based on the development of an early EGNOS service starting from the current SFSC service have been presented, such as immediate availability, efficiency and cost-effectiveness, anticipated service standardization, accelerated certification/authorisation of future versions, optimization of future service development, and early benefits of GNSS in ERTMS. Drawbacks include the need for possible upgrades when operation requires higher performances, as well as the need for delta certifications of both EGNOS and deployed rail equipment when moving to future services.

The document has also highlighted some of the open points that need to be addressed, such as the definition and commitment of pseudorange domain performances for the Railway SoL Service and the resolution of technical and non-technical issues, including the definition of the legal framework, the standardization of interfaces and protocols, and the development of methodology and process for certification/authorisation. Several open points concerning the use of EGNOS for railway SoL applications also apply to future services (DFMC), and "anticipating" their resolution starting from an early service is considered one of the advantages of the approach proposed.

Regarding the introduction of EGNOS service in the TSI, this will come along with the ASTP solution to be introduced in the TSI. For that, ERA is expecting a consensual approach, both for ASTP and EGNOS service, coming from ERJU System Pillar through the Standardisation and TSI Input Plan.

The insights presented in this document will be considered for the drafting of the second version of deliverable D1.1 "E4R Roadmap and Strategic Plan" [17]. This latter will outline a unified and comprehensive strategy for integrating EGNOS in railway for SoL applications, ensuring alignment and consistency with the Standardisation and TSI Input Plan, as well as with the ASTP roadmap.

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