REPORT ON RAIL USER NEEDS AND REQUIREMENTS

OUTCOME OF THE EUSPA USER CONSULTATION PLATFORM

GALILEO EGNOS Copernicus

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01 INTRODUCTION AND CONTEXT OF THE REPORT

GNSS is already widely used for non-safety relevant application in Rail. Since a few years, safety relevant applications based on GNSS have also emerged. GNSS-based solutions can indeed offer safety at lower cost. Thus, all around the world Rail stakeholders are investigating its use for safety relevant application. However, Rail is a highly regulated domain in which the introduction of new technologies can take time. The understanding of Rail user requirements is a key step to support the GNSS market uptake in this segment. Rail and GNSS communities have worked together since many years to this end. The different safety philosophies make the process complex, but notable evolutions have been observed over the past years. This common effort must be pursued.

The User Consultation Platform (UCP) is a periodic forum organised by the European Commission and the EUSPA involving end users, user associations and representatives of the value chain, such as receiver and chipset manufacturers, application developers and the organisations and institutions dealing, directly and indirectly, with Galileo and EGNOS. The event is a part of the process developed at the EUSPA to collect user needs and requirements and take them as inputs for provision of user driven Galileo and EGNOS services. In this context, the objective of this document is to provide a reference for the European GNSS Programmes and for the Rail community reporting periodically the most up-to-date GNSS user needs and requirements in the Rail market segment. This report is considered a "living document" in the sense that it will serve as a key input to the next UCP event where it will be reviewed and subsequently updated. The UCP will be held periodically (e.g. once per year) and this report will be also periodically updated, to reflect the evolution in the user needs, market and technology captured during the UCP.

The report aims to provide the EUSPA with a clear and up-to-date view of the current and potential future user needs and requirements in order to serve as an input to the continuous improvement of the services provided by the European GNSS systems and their evolutions.

Finally, as the report is publicly available, it serves also as a reference for users and industry, supporting planning and decision-making activities for those concerned with the use of location technologies.

It must be noted that the listed user needs and requirements cannot usually be addressed by a single technological solution but rather by combination of several signals and sensors. Therefore the report does not represent any commitment of the European GNSS Programmes to address or satisfy the listed user needs and requirements in the current or future versions of the EGNSS services.

1.1 METHODOLOGY

The following figure details the methodology adopted for the analysis of the Rail user requirements.

The analysis is split into two main steps including a *"desk research"*, to gather main insights, and a *"stakeholders consultation"*, to validate main outcomes.

More in details, the *"desk research"* was based on a secondary research and aimed at providing a preliminary structured analysis:

ALL AROUND THE WORLD RAIL STAKEHOLDERS ARE INVESTIGATING GNSS-BASED SOLUTIONS FOR SAFETY RELEVANT APPLICATIONS.

- Leveraging on the Rail applications' segmentation as included in the EUSPA GNSS market report, additional relevant applications have been identified and included; and
- For each application identified, the function and level of performance required has been determined.

As a result of this activity, a first draft of the Rail User Requirements document has been produced.

In the second step, the "stakeholder consultation" one, main outcomes included in the document have been validated and updated. In this regards, preliminary validation interviews with selected stakeholders have produced the current document to be used as an input for the UCP review and finalisation.

Figure 1: Rail User Requirements Analysis methodology

OVERALL METHODOLOGY

1 Desk Research

Identification of all existing Rail applications along with the function that they perform

- All Rail applications covered in GSA Market Report nº5

User level dimension and characterisation

- Identification of the key GNSS user level dimensions to describe Rail user requirements
- Identification and definition of GNSS performance criteria relevant to Rail

Segmentation of Rail Applications

- Definition and classification of applications
- Focused on GNSS usage (not device-based)

Definition of the functions and level of performance required for each application

- Rail user requirements analysis based on open Secondary research information
- GNSS limitations, market/techno trends and drivers
- Table matching the main applications with the performance criteria

User requirement analysis – *draft 1*

SECONDARY RESEARCH INFORMATION

GNSS magazines - Coordinates, GPS World, Inside GNSS; ESA website; Articles on Google Scholar; Thesis and dissertations on specific database; European regulation or standard; Google

2 Stakeholders Consultation

Validation interviews

- Interview guide
- Selection of the consulted stakeholders
- Primary research: Interviews and reporting

User requirement analysis – *final version*

User Consultation Platform

- User requirements submitted to the first UCP forum for review and finalisation
- Update, validation and expansion of the user requirement analysis at each UCP

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1.2 SCOPE

This document is part of the User Requirements documents issued by the European GNSS Agency for the Market Segments where Position Navigation and Time (PNT) play a key role. Its scope is to cover user requirements on PNT solutions from the strict user perspective and the market conditions, regulations, and standards that drive them. Therefore, the document includes an analysis of the market trends on this particular segment, then performs a detailed analysis including the prospective uses of GNSS in this market finalising with a specification of user requirements in a format that can be used for System Engineering activities.

In more detail, this report is laid out as follows. It starts with a summarised market overview for Rail (**section 4**), where market evolution and key trends, the main market players and user groups are presented.

Then it moves on to the analysis of GNSS user requirements for Rail (**section 5**). Section 5 is organised as follows:

- Section 5.1 presents an overview of the Rail applications extracted from GSA Market Report 5 but also from other sources. It also provides definitions of these applications. They have been typified into different categories according to their usage (safety and non-safety) and a detailed overview of GNSS user requirements is provided.
- Prospective use of GNSS in Rail is addressed in section 5.2. It assesses GNSS technology trends, along with the other technologies that are used in the Rail community.
- GNSS limitations for Rail are described in section 5.3.
- Section 5.4 identifies the drivers for user requirements in Rail.
- Section 5.5 analyses the main relevant policy and regulations.
- Section 5.6 is a conclusion on the GNSS user requirements analysis for Rail applications.

THE DIFFERENT SAFETY PHILOSOPHIES MAKE THE PROCESS COMPLEX, BUT NOTABLE EVOLUTIONS HAVE BEEN OBSERVED.

Finally section 6 summarises the main GNSS user requirements for Rail in the applications domains analysed in this report.

The document is intended to serve as an input to more technical discussions on Systems Engineering and evolution of the European GNSS systems so that space infrastructures are effectively linked to user needs.

02 EXECUTIVE SUMMARY

2.1 EXECUTIVE SUMMARY

The understanding of Rail user requirements as well as their specifications in terms of GNSS is crucial to foster GNSS penetration in this market and subsequently define the European GNSS mission evolution.

There are a larger number of PNT applications in Rail segment. They are divided in two main categories: safety relevant and non-safety relevant applications.
The non-safety relevant category is itself often divided in two sub-categories: liability relevant and non-liability relevant applications.

For safety relevant applications, depending on the applications, GNSS penetration is low, or even nonexistent. For liability relevant applications GNSS penetration is also often low. The only applications where GNSS is widely used are non-safety and non-liability relevant applications, such as passenger information applications.

THE MAIN AXES OF DEVELOPMENT FOR GNSS APPLICATIONS ARE SAFETY AND LIABILITY RELEVANT APPLICATIONS.

The main limitations for GNSS penetration in Rail PNT Applications concern Signal-in-Space obscuration (e.g. stations, tunnels), very high safety integrity and dependability requirements for train position determination in contrast to aviation, excessive position errors due to local effects (e.g. multipath, EMI, spoofing) and also high accuracy requirement for some specific functions (e.g. train positioning on parallel tracks requires a Horizontal Protection Level HPL of 3 m or less. Moreover beyond these "physical" limitations GNSS also faces other issues such as safety demonstration methodologies or certification.

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The main axes of development for GNSS applications in Rail are then safety relevant and liability relevant applications – where European GNSS differentiators can play a key role. Automatic Train Protection (ATP)/Train control is one of the most promising GNSS safety relevant applications.

- Within the context of the European Railway Traffic Management System (ERTMS), GNSS could be used as a mean:
  - To introduce virtual balises in the European Train Control System (ETCS) Level 2;
  - To provide the train integrity monitoring function for the ETCS Level 3.
- Outside the ERTMS context, GNSS is already being deployed for train control most commonly in USA, for Positive Train Control applications.

Over the past years, a lot of effort has been provided by the Rail and GNSS communities to try and understand their respective safety philosophy. However, work is still needed to define user requirements applicable to GNSS, and in particular, quantified requirements.

The work performed by the key Rail stakeholders aims to contribute to the definition of GNSS Rail user requirements for safety relevant applications such as ETCS. The progresses are performed in the framework of working groups or projects funded by H2020, ESA or Shift2Rail. Most of the efforts have focused on the use of GNSS for Virtual Balise in an ERTMS architecture but other applications shall also benefit from GNSS-based positioning.

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However, it is worth noticing that all the current efforts of the Rail community are to include GNSS in ETCS without changing the ERTMS architecture (through in particular the following both applications: virtual balise functionality for ERTMS level 2/3 and train integrity monitoring function for the ERTMS level 3). It cannot be expected from the rail community exclusively to define the GNSS requirements by applying the approach taken by aviation. The Rail scenarios/use cases are much more complex that the aviation ones. The Satellite Navigation community remains a key player to support the definition of GNSS Rail user requirements.

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The user requirements presented hereafter were derived from validation interviews of both key players of the Rail segment: UNIFE (Union des Industries Ferroviaires Européennes) and Ansaldo STS.

The Table 1 summarizes the most recent Rail user requirements expressed for a representative sample of Rail applications (mostly based on [RD4] and [RD27]). Those requirements are mostly expressed by ranges of value or qualitative requirements, and tend to simplify the reality. But as of today, they are the only ones recognized by the Rail community – except for the Time To Alarm requirement. The reality is indeed much more fragmented and work is still required to get realistic reflection of the actual user needs.

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Table 1: Rail GNSS User Requirements

Horizontal accuracy needs to be divided into along-track (ALTE) and across-track (ACTE) errors for some applications. Across-track requirement is defined by "track discrimination" for some applications in the table.

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Application	Accuracy (2Sigma)	Availability	Integrity	SIL	TTA*	Category
Cold Movement Detection	HNSE < 1 m	High	Very High	4	TTA < 10s	Safety relevant
Level Crossing Protection	1 m < HNSE < 10 m	High	Very High	4	TTA < 10s (TBC)	Safety relevant
Train Integrity and train length monitoring	1 m < HNSE < 10 m (TBC)	High	Very High	4	10s < TTA < 30s	Safety relevant
Track Identification	ACTE < 1.9 m	High	Very High	2-4	10s < TTA < 30s	Safety relevant
Odometer Calibration	HNSE < 1 m	High	Low	TBD	TTA < 10s	Non safety relevant
Door Control Supervision	1 m < HNSE < 10 m	High	High	TBD	10s < TTA < 30s	Safety relevant
Door Control Supervision in ATO	HNSE < 1 m	High	High	2	10s < TTA < 30s	Safety relevant
Trackside Personnel Protection	1 m < HNSE < 10 m Track discrimination	High	High	TBD	10s < TTA < 30s	Safety relevant
Management of emergencies	1 m < HNSE < 5 m Track discrimination	High	High	TBD	10s < TTA < 30s	Non safety relevant
Infrastructure surveying	0.01 m < HNSE < 1 m	Low	High (if real time) Low (if post processing)	TBD	TTA ≥ 30s	Liability relevant
Location of GSM Reports	1 m < HNSE < 100 m	Low	High	TBD	TTA ≥ 30s	Liability relevant
Gauging surveys	0.01 m < HNSE < 1 m	Low	Very High	TBD	TTA ≥ 30s	Liability relevant
Structural monitoring	0.01 m < HNSE < 1 m Altitude req. TBD	Low	Low	TBD	TTA ≥ 30s	Liability relevant

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Application	Accuracy (2Sigma)	Availability	Integrity	SIL	TTA*	Category
Fleet management	HNSE ≥ 10 m	High	Low	TBD	TTA ≥ 30s	Liability relevant
Cargo monitoring	HNSE ≥ 10 m	High	Low	TBD	TTA ≥ 30s	Liability relevant
Energy Charging	HNSE ≥ 10 m	High	Low	TBD	TTA ≥ 30s	Liability relevant
Infrastructure Charging	HNSE ≥ 10 m	High	High (charging)	TBD	TTA ≥ 30s	Liability relevant
Hazardous Cargo Monitoring	1 m < HNSE < 10 m	High	High	TBD	10s < TTA < 30s	Liability relevant
Passenger information	HNSE < 100 m (global information) ALTE < 5 m (mass transit)	95%	N/A	TBD	N/A	Non-safety & Non-liability relevant

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03 REFERENCE DOCUMENTS

Table 2: Reference documents

Id.	Reference	Title	Date
[RD1]	SUGAST-INE-5300-D-5310-PU-2.0	Technical note on GNSS performances for rail (not public)	27.05.2011
[RD2]	P1603D003	Rail Positioning Applications (not public)	20.06.2013
[RD3]	EGN-TPZ-01-0011-TNO 1.0	EGNOS V2 applications in Rail logistics and asset management (not public)	29.04.2014
[RD4]	ESSP-TN-12586 v01-00	EGNOS V3 requirements for the rail domain (not public)	20.11.2014
[RD5]		GNSS Market Report issue 4 (available at: https://www.gsa.europa.eu/2015-gnss-market-report)	March 2015
[RD6]	ESSP-TN-11715 v01-00	Report on the use of EGNOS V2 for Railway safety and non-safety applications (not public)	08.05.2014
[RD7]	SUBSET-041 3.1.0	ERTMS/ETCS - Performance Requirements for Interoperability (available at: http://www.era.europa.eu/Document-Register/Documents/Set-2-Index014-SUBSET-041%20v310.pdf)	01.03.2012
[RD8]	SUBSET-091 3.3.0	ERTMS/ETCS - Safety Requirements for the Technical Interoperability of ETCS in Levels 1 & 2 (available at: http://www.era.europa.eu/Document-Register/Documents/Set-1-Index027-SUBSET-091%20v250.pdf)	08.05.2014
[RD9]	(EU) No 642/2014	Council Regulation establishing the Shift2Rail Joint Undertaking (available at: http://eur-lex.europa.eu/legal-content/FR/TXT/?uri=CELEX:52013PC0922)	16.06.2014
[RD10]		Shift2Rail Joint Undertaking - Annual Activity Report 2014 (available at: https://ec.europa.eu/transport/sites/transport/files/modes/rail/doc/s2r-annual-report-2014_final.pdf)	31.03.2015
[RD11]	Version 1.0	Shift2Rail Strategic Master Plan (available at: https://ec.europa.eu/transport/sites/transport/files/modes/rail/doc/2015-03-31-decisionn4-2015-adoption-s2r-masterplan.pdf)	24.09.2014
[RD12]	GSC-D2.2 v1.2	GSC – Identification of Galileo Integrity requirements (not public)	09.2009

[RD13]	GRAIL-WP0-INE-DEL-05	Final Activity Report (available at: https://www.rssb.co.uk/research-development-and-innovation/research-and-development/research-project-catalogue/t511)	10.12.2008
[RD14]	GRAIL-WP3-TIF-DEL-3.1.2	GNSS Subsystem Requirements Specification for Enhanced ETCS Application (available at: https://www.gsa.europa.eu/sites/default/files/virtual_library/2007-06-29_GRAIL_Project_-_GNSS_Subsystem_Requirement_Specification_for_Enhanced_ETSS_Applications.pdf)	08.10.2008
[RD15]	GRAIL-WP3-TIF-DEL-3.1.1	GNSS Subsystem Requirements Specification for Enhanced Odometry Application (available at: https://www.gsa.europa.eu/sites/default/files/virtual_library/2007-08-08_GRAIL_Project_-_GNSS_Subsystem_Requirements_Specification_for_Enhanced_Odometry_Application.pdf)	08.10.2008
[RD16]	SUGAST-FDC-1100-D-1118-PU-1.1	SUGAST Final Report (not public)	13.06.2012
[RD17]		PTC Implementation: The Railroad Industry Cannot Install PTC on the Entire Nationwide Network by the 2015 Deadline (available: https://ohsonline.com/articles/2013/03/01/ptc-implementation-impossible.aspx)	March 2014
[RD18]	DOT-VNTSC-OST-R-15-01	Federal Radionavigation Plan (Available at: https://www.navcen.uscg.gov/pdf/FederalRadionavigationPlan2014.pdf)	May 2015
[RD19]		GNSS for Train Localisation Performance Evaluation and Verification (available at: https://d-nb.info/1059369524/04)	17.06.2014
[RD20]		Impact of the EGNOS and Galileo integrity on the design of railway on board fail-safe positioning equipment George BARBU, UIC (SATLOC project)	2008
[RD21]		A relation among GNSS quality measures and railway RAMS attributes Aleš FILIP, Julie BEUGIN, Juliette MARAIS and Hynek MOCEK (proceedings CERGAL 2008)	2008
[RD22]		Galileo for railway operations: question about the positioning performances analogy with the RAMS requirements allocated to safety applications Julie Beugin, A. Filip, Juliette Marais, M. Bernibeau (available at : https://link.springer.com/article/10.1007/s12544-010-0032-3)	18.01.2011
[RD23]		GRAIL-2: Enhanced Odometry based on GNSS (available at : https://ac.els-cdn.com/S1877042812028017/1-s2.0-S1877042812028017-main.pdf?_tid=9d577528-ca1e-11e7-b3e3-00000aacb361&acdnat=1510762029_958ce5c26297e98f16f53cbaee22ed60)	2011

[RD24]		ERTMS, applications sécuritaires et applications satellitaires, quelles avancées de la recherche ? Juliette MARAIS, Ifsttar (available at : http://docplayer.fr/4695139-Ertms-applications-securitaires-et-applications-satellitaires-quelles-avancees-de-la-recherche.html)	20.11.2014
[RD25]	96S126 02S1266-6	ERTMS/ETCS - RAMS Requirements Specification Chapter 2 – RAM (available at : http://www.era.europa.eu/Document-Register/Documents/B1-02s1266-.pdf)	30.09.98
[RD26]		Simulation-based Evaluation of Dependability and Safety Properties of Satellite Technologies for Railway Localization Julie Beugin, Juliette Marais (available : Simulation-based Evaluation of Dependability and Safety Properties of Satellite Technoligies for Railway Localization)	31.10.2011
[RD27]		Validation Interview – UNIFE (not public)	
[RD28]		Validation Interview – Ansaldo STS (not public)	19.01.2016
[RD29]		GNSS Market Report issue 5 (available at: https://www.gsa.europa.eu/2017-gnss-market-report)	2017
[RD30]		GNSS Technology Report issue 1 (available at: https://www.gsa.europa.eu/european-gnss/gnss-market/2016-gnss-user-technology-report)	2016
[RD31]	GSA-MKD-RL-MOM-246193	User Consultation Platform 2018 – Minutes of Meeting of the Rail Panel	03.12.2018

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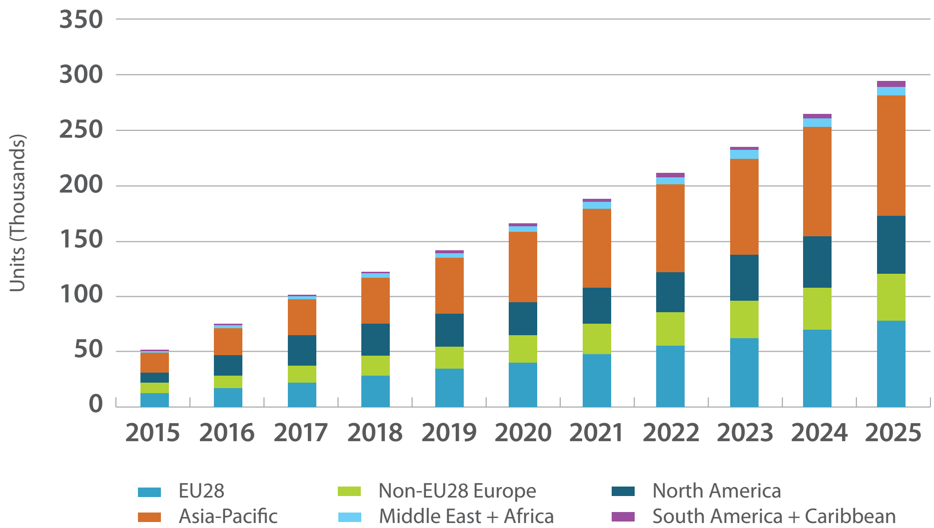
04 MARKET OVERVIEW AND TRENDS

4.1 MARKET EVOLUTION AND KEY TRENDS

According to the GNSS Market Report issue 5 [RD29]. the key GNSS market trends in Rail segment are:

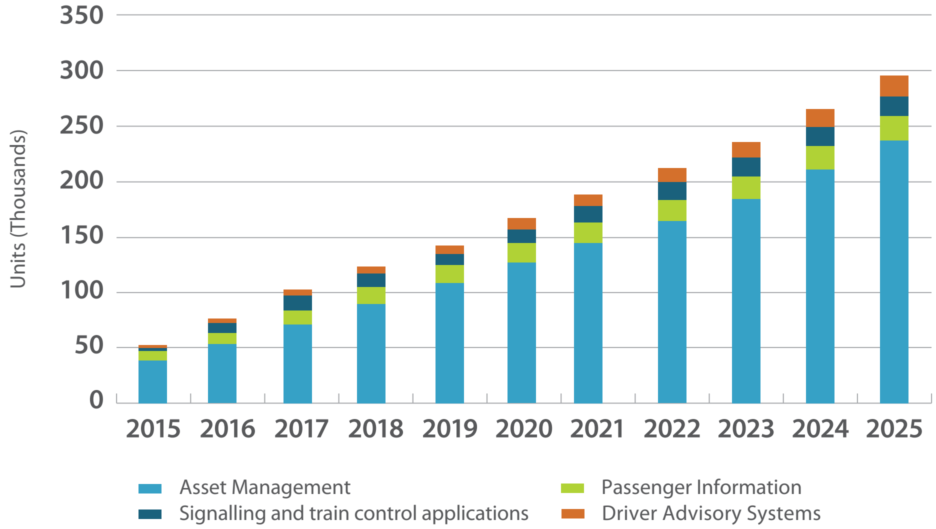
- Non-safety relevant applications in Rail are already widely based on GNSS.
- Safety relevant applications are emerging with different maturity levels depending on region, e.g. in India, China and the Middle East, GNSS is taking up an important position.
- GNSS based solutions can offer safety at a lower cost, e.g. as investigated in railway signaling.

Figure 2: Shipments of GNSS devices by region [RD29]



As a general trend, shipments of GNSS devices have been constantly growing in the last years, with growth significantly intensifying since 2015. **Europe** is the leading region concerning GNSS Rail shipments, due to the high development of non-safety relevant applications related to passenger information.

Figure 3: Shipments of GNSS devices by application [RD29]



Asset management applications are currently driving and expecting to continue to drive GNSS devices shipments.

In the coming years, safety relevant applications (signalling and train control) based on GNSS will be increasingly developed. These applications require a very high level of performance and, depending on the strategy towards them, GNSS may be used as:

- Primary means as foreseen in the US with PTC;
- A back-up solution as planned in Europe; or
- Even one of the means within a hybrid solution.

4.2 MAIN MARKET PLAYERS

The Rail industry is concentrated in Europe and North America. European GNSS companies have a market share of 38%, among components and receivers and the top 3 companies in the continent are Septentrio, Hexagon (Leica Geosystems) and U-blox.

The main industry stakeholders in the Rail GNSS market value chain are system integrators, component manufacturers, train manufacturers, train owners and operators as well as Rail undertakings and infrastructure managers.

- The main **component manufacturers** (receivers and others) are: Trimble, Septentrio, Navis, Garmin, Broadcom, Furuno, Hexagon (Leica Geosystems), Omnicom, U-Blox and Infineon Tech.
- European companies are dominant among **system integrators**, controlling 72% of the market, where key operators have strong exports both to North America and Asia. The top 3 companies are Ansaldo, Alstom and Siemens, but this category also includes: General Electric, Thales, Bombardier, Telespazio and Nottingham.
- We can cite among **train and rolling stock manufacturers:** Siemens, Bombardier, Alstom, Hitachi, and China South Locomotive.
- **Train owners and operators** include: train operating companies and freight operating companies, such as Deutsche Bahn, Trenitalia, SNCF, Arriva, Colas, Renfe, Veolia, Stagecoach and urban transports operators. There are also rolling stock operating companies as investment banks, consortia and national companies.
- The Rail undertakings and infrastructure managers include: Deutsche Bahn, RFI, RFF, Network Rail, ADIF and urban transport operators.

4.3 MAIN USER GROUPS

The analysis of Rail PNT applications (5.1) enabled the identification of the main user communities that are involved in the user requirement definition process. They are identified in the table below.

Table 3: Main Rail user communities

	Group / Bundle	Applications
Safety Critical	Train Control and Signaling	Automatic Train Protection - Enhanced Odometry
		Automatic Train Protection - Absolute Positioning
		Level Crossing Protection
		Cold Movement Detection
		Train Integrity & Train Length Monitoring
		Track Identification
		Odometer calibration
	Protection and Emergency Management Systems	Trackside Personnel Protection
		Management of Emergencies
		Train Warning Systems
		Door Control Supervision
	Hazardous Cargo Monitoring	Hazardous Cargo Monitoring
Non-Safety Critical	Asset Management (Rolling stock)	Fleet Managements
		Cargo Condition Monitoring
		Infrastructure Charging
		Energy Charging
	Asset Management (Fixed asset)	Infrastructure surveying
		Structural Monitoring
	Passenger information	Passenger information

Component manufacturers, system integrators and train manufacturers can also play an important role in the definition of user requirements, in particular for safety relevant applications.

Result	Users			
	Passengers	Train owners / operators	Rail Undertaking / Infrastructure Managers	Others
Provide Location and Speed according to reference point		X	X	
Provides Positioning without integration of Speed		X	X	
Ensure safety when trains cross intersections		X	X	Road users
Confirms validity of the position stored when train is powered off		X		
Ensures trains are complete		X	X	
Determines the current track in which a train is running		X	X	
Provides independant positioning to calibrate train odometer		X	X	
Warns people working near or on the track of an approaching train		X	X	Trackside Personnel
Organizes emergency teams and operations				Rescue teams
Warns passengers when a trains is to pass a platform over a certain speed limit	X		X	
Enables the opening of specific doors at particulier stations		X	X	
Monitors and tracks hazardous cargoes		X	X	
Tracks assets		X		
Allows tracking of freight and planning (e.g. estimation of the arrival at depots)		X		
Charges for specific infrastructure usage			X	
Charges in proportion of energy consumption			X	
Collects located data on the railway infrastructure			X	
Supports the monitoring of railway infrastructure and embankments		X	X	
Provides information on train location to passengers: - customer or staff - on-board or not	X			

05 GNSS USER REQUIREMENTS ANALYSIS

5.1 GNSS USE IN RAIL

5.1.1 RAIL PNT APPLICATIONS

Three separate documents of [RD1], [RD2] and [RD3] describe 63 different Rail PNT applications. These applications are listed in the table below.

[RD2]				[RD1]	[RD3]
	Application Bundle	**Prioriti-sation**	**Applications**	**Applications**	**Applications**
Safety critical applications		1	Low Density Line signalling		
		2	ERTMS Positioning	Absolute Positioning	
		8	Driver route knowledge assistant		
	Autonomous Train Control	5	Automatic Train Protection		
			On-train ERTMS Interface		
			Train Awakening	Train Awakening	
			Cold movement detection	Cold movement detector	
			Train integrity and train length monitoring	Train integrity and train length monitoring	
			Pantograph Control		
			Tilting train control		
			Door Operations		
			On-train Monitoring Recorder		
			Odometer Calibration		
				Track Identification	
				Level Crossing Protection	
				Enhanced Odometry	
	Traffic Management	7	User Worked Crossings		
			Detonator Replacement ("Virtual Detector")		
			Traffic Management & Regulation	Traffic Management Systems (Dispatching)	
			Disruption Management		
			Trackside Personnel Protection	Trackside Personnel Protection	
			Alternative Temporary Block Working		
			Incident Management Response	Management of Emergencies	
				On-board Train Monitoring and Recording Unit	

[RD2]				[RD1]	[RD3]
	Application Bundle	**Prioriti-sation**	**Applications**	**Applications**	**Applications**
Safety critical applications		10	Train Approaching Warnings	Train warnings Systems	
	Maitenance and Survey	11	Possessions Management		
			Digital Route Map creation	Digital Map Creation	Surveying for digital map creation
			Structural Monitoring	Structural Monitoring	Structural monitoring
			Gauging surveys		Gauging surveys
				Infrastructure Data Collection	Infrastructure surveying
			Automated Infrastructure Maintenance		
Non-Safety critical application	Driver assistance	8	Eco-Driving	Energy efficiency	
			Temporary Speed Restrictions & Emergency Speed Restrictions		
			Driver advisory systems (automation stage 1)		
	Autonomous Train Services	6	Centralised clock (GNSS to synchronise multiple on-board devices)		
			Fast and slow line discrimination		
			Automatic Train Operation (automation stage 2)		
			Driverless Trains (automation stage 3)		
			On-train Monitoring		
			Automated Lubrication		
			On-train braking measurement probes		
	Asset Management	3	Location of GSM-R Reports		Location of GSM Reports
			Fleet Management	Fleet Management	Fleet management
			Terminal Management	Multi-modal Terminal Management	
			Passenger Count		
			Infrastructure charges	Infrastructure Charging	Infrastructure Charging
				Energy Charging	Energy Charging
			Delay Attribution		
			Inter-modal transfers		
			On-train CCTV		

Safety critical · Liability critical · Fixed asset Managment (Liability critical) · Rolling stock Managment (Liability critical)

[RD2]				[RD1]	[RD3]
	Application Bundle	Prioriti-sation	Applications	Applications	Applications
Non-Safety critical application	Passenger information	4	On-train ticketing, retail & authentication		
			On-train reservations		
			On-train catering and services		
			Train Crew information services		
			Customer Information Systems		
			On-board Passenger Information systems		
			Personal Journey Assistant		
			Location Based Services & Points of Interest		
			Passenger Broadband (Internet Access Caching)		
		12	Logistics Planning and Monitoring (support vehicles)		
		13	Cargo Monitoring	Cargo Condition Monitoring	Cargo Condition Monitoring
				Hazardous Cargo Monitoring	Hazardous Cargo Monitoring

This document considered only some of these applications. Please refer to reference documents for exhaustive information about Rail PNT application definitions.

The selected applications correspond to the applications considered in [RD4] and [RD5], as well as to the applications considered as "First priority applications" in [RD2]. This panel of applications is a representative sample of the wide range of Rail PNT applications and their associated user requirements.

5.1.2 SAFETY RELEVANT APPLICATIONS

5.1.2.1 AUTOMATIC TRAIN PROTECTION

Automatic Train Protection (ATP) applications are used to ensure that trains run safely and efficiently on the right tracks with appropriate speed. The Rail safety principle is to design and provide controlled safe response of the systems to failures. The main applications included in this group are described in this section.

Automatic Train Protection aims to prevent a train proceeding beyond the point of danger and to prevent the speed of the train exceeding the permissible limit in the event of a driver error. It consists of the safe determination of position, speed and direction of train movement in order to supervise the safe movement of the train up to its stopping point (End of Movement Authority). This application requires the combination of several functions (or lower level applications) which in turn are strongly dependent of the accurate and safe determination of position and speed of the trains:

- Calculation of End of Movement Authority
- Calculation the emergency braking curve to get to the EOA
- Train Location / Train Position Report
- Speed profile calculation
- Train spacing
- Supervision to buffer stops (in particular Calculation on board the release speed for the approach to buffer stop)

ERTMS/ETCS – the European Automatic Train Protection System

The European Rail Traffic Management System (ERTMS) initiative aims to provide a new generation of train control and signalling capabilities (ETCS – European Train Control System), which includes automatic train protection by continuously supervising train speed and braking.

ERTMS has two basic components:

- ETCS, the European Train Control System
- GSM-R, radio system standard for signalling data transmission

The ERTMS technology has different levels of capacity and performance:

- Level 0 is when an ETCS vehicle is used on a non-ETCS route. The trainborne equipment computes the maximum train speed and the train driver must monitor the trackside signals.
- In Level 1, 'Eurobalise' radio beacons transmit trackside signals as a movement authority to the trainborne equipment. There, the maximum speed and braking curve are obtained and automatic train protection is ensured with these data.
- In Level 2, it is possible to remove side light signals as the trains automatically report, on a regular basis, their navigation data to a Radio Block Centre, which transmits back the next movement authority.
- In level 3, no line side signals will be required for delivering movement authorities. A train shall be able to locate itself. All information will be exchanged between the ETCS on-board system and the RBC trackside system (Radio Block Center) through mobile networks. Two data are communicated by the train to the RBC: its location and the confirmation that the train did not lose any wagon. This information is called "integrity" in the railway domain and is an element of the safety. This last level of ETCS shall also improve line capacity by making it possible to manage circulations with moving blocks. In this context, GNSS is investigated to be the basis for new embedded train locator.

ERTMS will intervene if the train over-speeds, to bring it back to safe levels. The system stops a train safely to prevent it from exceeding its movement authority. Precise knowledge of the train speed, thus, is a central topic in the ERTMS developments.

THE RAIL SAFETY PRINCIPLE IS TO DESIGN AND PROVIDE CONTROLLED SAFE RESPONSE OF THE SYSTEMS TO FAILURES.

There are many ATP applications where GNSS could be used, among them: Enhanced Odometry, Absolute Positioning, Cold Movement Detection, Train integrity and train length monitoring, Track Identification, Odometer Calibration, and Level Crossing Protection which are described here after.

5.1.2.1.1 Enhanced Odometry

In ERTMS, train protection is based on the knowledge of train position with respect to a spot to be protected and the supervision of a braking curve. The spots to be protected are referred with respect to balises located on the track. This system implies the need for odometric systems providing current position and speed. One of the traditional odometry systems more widely used calculates the train speed from the number of turns of a wheel of the train with corrective mechanisms for avoiding slide and slip phenomena. The aim of the additional GNSS Enhanced Odometry Subsystem is to support the odometry with accurate position and speed. The GNSS Enhanced Odometry Subsystem could be used as a substitute for/complement of the current odometer sensors (tachometers, INS/IMU, Doppler radar etc.) in the ETCS odometry. However it should be mentioned that if an odometry subsystem should be used as an independent diagnosis (cross-check) of ETCS virtual balise detection based on GNSS, then the enhanced odometry subsystem containing GNSS cannot be used due to a potential Common Cause Failure effect.

5.1.2.1.2 Absolute Positioning

The main purpose of this ATP application is to provide absolute train positioning information for input to the ERTMS system. This application provides a confidence interval on position which is independent of the travelled distance – contrary to the odometry sensors – and can provide location information with a higher and relevant integrity level.

5.1.2.1.3 Cold Movement Detection

Cold Movement detector (CMD) function detects train movements while equipment is in No Power mode (equipment is not powered up). If the Location Unit works independently of train power, CMD function compares train positions when entering and exiting of NP mode. If an external power is supplied to the UT, CMD function detects train movement during NP mode.

5.1.2.1.4 Train integrity and train length monitoring

Train Integrity is the level of belief in the train being complete and not having left coaches or wagons behind. The train

length monitoring could be provided by two positioning systems – satellite positioning system or odometry sensor – at the front and rear end of the train and by a communication system and a computing unit. This function is essential for level 3, and level 2 high density, to increase line capacity.

PERSONNEL WORKING ON OR CLOSE TO THE TRACK MUST BE PROTECTED FROM TRAINS USING THE NETWORK.

5.1.2.1.5 Track Identification

A track identification system would make use of GNSS and other track based infrastructure information to determine the current track on which the train is running.

5.1.2.1.6 Level Crossing Protection

GNSS could be technical solution for Level crossing protection systems.

The protection systems of the level crossing need the location information of a train approaching the level crossing. Besides, information about the location, identification, status and other conditions concerning the level crossing must be transmitted to trains.

The level crossing protection applications is able to send a speed restriction to the train. The value of the speed restriction depends upon the status of the level-crossing, closed detected, closed not detected, and on the line and direction of the movement.

The GNSS subsystem should manage a Digital Map with geographical information: level crossing location, track description in the level crossing surroundings, location activation / deactivation point. This function must be integrated with the ERTMS system to ensure interoperability.

5.1.2.2 PROTECTION AND EMERGENCY MANAGEMENT

5.1.2.2.1 Trackside Personnel Protection

The maintenance and upgrade of the infrastructure is a major activity involving movements of personnel, equipment and materials. Personnel working on or close to the track must be protected from trains using the network. Speed restrictions may apply or the train may be prevented from entering the work zone completely. Alternatively, personnel working must be warned when a train is approaching the working area. Main applications related to the protection and emergency management are described in this section.

GNSS applied to trackside personnel protection will improve current manual or semiautomatic procedures. This application can monitor the location of the working team, the assets (rail construction machinery, etc.) and the trains. The system, knowing the position of the elements, could issue warnings to the trains for slowing speed or event stop, and orders to the working equipment and teams to abandon working areas when trains are approaching.

5.1.2.2.2 Door Control Supervision

The purpose of this application is to enable the opening of specific doors at particular stations. GNSS is used to locate the train within a station.

Some stations have short platforms or platforms on both sides, it is required that only the correct doors (i.e. those with a platform next to them) are opened when a train stops at a station. This application requires knowledge of the train location within the station and identification of the train at a specific platform. Location data can also be used by passenger information systems to alert passengers for the need to move to other vehicles, e.g. long trains at short platforms.

5.1.3 NON-SAFETY RELEVANT APPLICATIONS

5.1.3.1 FIXED ASSET MANAGEMENT (ASSET MANAGEMENT)

Fixed asset management is linked with the railway environment, from the infrastructure to the trackside equipment. Therefore, the accuracy needed for the location of the assets in some cases can be demanding and requiring high precision surveying.

5.1.3.1.1 Infrastructure surveying

The railway is a dangerous environment with a growing demand for shorter journey times (i.e. faster trains) and greater capacity (more trains). This puts severe time and financial constraints for access to working on or near the line. To allow data to be collected on the railway infrastructure, while accommodating the constraints of obtaining access, mobile surveying systems have been developed which combine GPS with digital images, video and laser measurements (data geo-referencing). Some operations that might benefit from this technology include:

- Signal sighting
- Asset data collection
- Site surveys
- Design verification
- Route familiarisation
- Rapid response
- Gauging surveys
- Location of GSM-R reports
- Virtual Inspection

In [RD1], [RD2] and [RD5], this application is considered as a Liability relevant application.

Gauging surveys

This is one sub-application of infrastructure surveying. The purpose is to provide high-precision positioning information to gauging surveys.

Gauging surveys are undertaken on platforms, structures, bridges and tunnels; these operations mainly involve structure clearance and passing clearance assessments when new rolling stock or structures are introduced.

Appropriate loading gauges, with scarce tolerance margins, are needed in the track sections so that the rolling stock can transit without incidents. The ability to move a railway vehicle and its load on a particular part of the network depends on the height and width profile, known as loading gauge, of the route concerned. A railway vehicle must comply with the route loading gauge to ensure that it passes clear of all structures, principally over-bridges and tunnels but also features such as station platforms, canopies and overhead or trackside equipment. The compatibility of rolling stock and infrastructure must be assessed through dedicated structural surveys which use techniques ranging from a conventional wood platform gauge to 3D laser scanning.

GNSS is, as in other topographic applications, an important technology to consider, as it does not only provide appropriate accuracies, but also geo-referenced output.

Location of GSM Reports

This is another sub-application of infrastructure surveying whose accuracy may be lower. This consists of the site survey as part of GSM-R cell planning. As the link budget is not only affected by the accurate placement of GSM-R stations, but also by the track section shape, foliage, multipath and attenuations/gains, the siting accuracy can be consequently moderate.

5.1.3.1.2 Structural monitoring

The industrial driver for the use of GNSS technology in structural monitoring is the increasing need for reliable, accurate and cost-effective condition monitoring systems for bridges and other major structures within the railways.

Monitoring is an important tool in planning the systematic maintenance of the bridge stock in order to preserve adequate levels of structural integrity and maximise operational benefits. In addition to bridges, slope stability is also required to be monitored to ensure that the embankments are stable and the risk of landslide is minimised.

GNSS solutions are supporting both application areas. GNSS is used to provide real-time position sensing of critical locations which can be used to inform infrastructure operators and train operators of any "out of tolerance" behaviour.

In [RD1], [RD2] and [RD5], this application is considered as a Liability relevant application.

2019 update

5.1.3.2 ODOMETER CALIBRATION

The odometer is used for speed, distance, acceleration and running direction measurements by measuring the train's movement along the track. Odometer accuracy is compromised by wheel slips due to rain, ice, snow, and leaves. Independent positioning can be used to calibrate the train odometer for systematic biases that have been introduced through operation. GNSS could be used to assist in the calibration of the train's odometer.

5.1.3.3 MANAGEMENT OF EMERGENCIES

The management of emergencies can be greatly improved if an accurate, continuous location of the train is available, allowing the emergency teams to optimise their operations, thus GNSS is suitable for this kind of application.

In the event of an accident, it is important to know the location of the train in the line, so that rescue teams can reach the place of the accident. For this kind of application the geographical position of the train shall be provided and it shall be expressed in co-ordinates understandable to railway personnel and the emergency services, which normally use different coordinate systems.

THE RAILWAY IS A DANGEROUS ENVIRONMENT WITH A GROWING DEMAND FOR SHORTER JOURNEY TIMES AND GREATER CAPACITY.

5.1.3.4 ROLLING STOCK MANAGEMENT (ASSET MANAGEMENT)

The rolling stock term is usually meaning vehicles that move on a railway including both powered and unpowered vehicles, for example locomotives, railroad cars, coaches, and wagons. The applications identified as interesting involving GNSS are described here after.

In [RD1], [RD3] and [RD5], this application is considered as a Liability relevant application.

5.1.3.4.1 Fleet management

The tracking of assets (rolling stock, wagons) is crucial to achieve an optimised use of an operator fleet. The accurate determination of position and distances covered by a resource can ease the maintenance of a vehicle. The vehicles can be monitored everywhere at every time of their life-cycle.

Long-term management and planning of the use of rolling-stock, the composition of train and the preparations for maintenance are facilitated if a more automated tracking of these resources can be made.

Nowadays some service provider is providing satellite based solutions based on the use of a GNSS receiver integrated with satellite or terrestrial communication installed on each coach.

5.1.3.4.2 Cargo monitoring

The importance of accurate information for freight customers, particularly accurate estimates of the arrival of trains at depots, is inestimable. Unplanned late arrival can result in delays to unloading that seriously disrupt the running of subsequent services.

Complete train, individual containers or even goods can be tracked by radio-navigation systems potentially through multiple modes of transport, thereby requiring the integration of management information from multiple service providers and requiring the interoperability of different systems.

5.1.3.4.3 Infrastructure charging

In the Member States, according to the new directives (First Railway Package European Directive 2001/14/EC) and the liberalisation of the Rail sector, train operators are charged in proportion to use of the infrastructure. Penalties are also imposed according to delays. An independent GNSS-based location/speed/time service could be used within the charging process to determine accurate infrastructure usage according to location and duration and hence generate accurate billing information. Besides, the application allows for transparent process for allocating blame and charges and provision of evidence.

5.1.3.4.4 Energy charging

To monitor the energy consumption of trains and hence users, vehicles can be fitted with GNSS and energy meters. Meter readings will then be available either when borders are crossed or as required. Border crossing events can be registered by GNSS and the reading from the energy consumption meter is forwarded to a recording point for later invoicing.

5.1.3.4.5 Hazardous Cargo Monitoring

Some of the goods carried by Rail freight operators can damage the environment if they are spilt in transit and/or pose a threat to society if they are stolen. These include:

crude petroleum and petroleum products; compressed, liquefied and refrigerated gases; flammable/corrosive/toxic chemicals and chemical/nuclear hazardous wastes.

GNSS can be used to provide an alarm and alert system when used in conjunction with satellite or terrestrial communications and geofencing technologies. This solution allows managers to remotely monitor, track and communicate with their cargoes in real-time. Furthermore, this application provides updates on location, speed, mapping directions, security, etc. It also helps in archiving of vital condition data and an ability to track stolen cargoes.

5.1.3.5 PASSENGER INFORMATION

[RD2] identifies 9 applications that can be included in the application bundle "Passengers information". Please refer to [RD2] for the definition of these applications, including:

- On-train ticketing, retail & authentication
- On-train reservations
- On-train catering and services
- Train Crew information services
- Customer Information Systems
- On-board Passenger Information systems
- Personal Journey Assistant
- Location Based Services & Points of Interest
- Passenger Broadband (Internet Access Caching)

5.1.3.5.1 Train Warning Systems

2019 update

Some railways require a special warning to passengers on a platform when a train is approaching and is expected to pass the platform at a speed greater than a defined level.

This application requires details of train location, speed and other infrastructure data, and may result in an automatic station announcement via a public service broadcast.

5.2 PROSPECTIVE USE OF GNSS IN RAIL

The results presented in this section were consulted with UNIFE and Ansaldo STS (see the reports of the validation interview [RD27] and [RD28]).

Figure 4: Maturity of Application Bundles

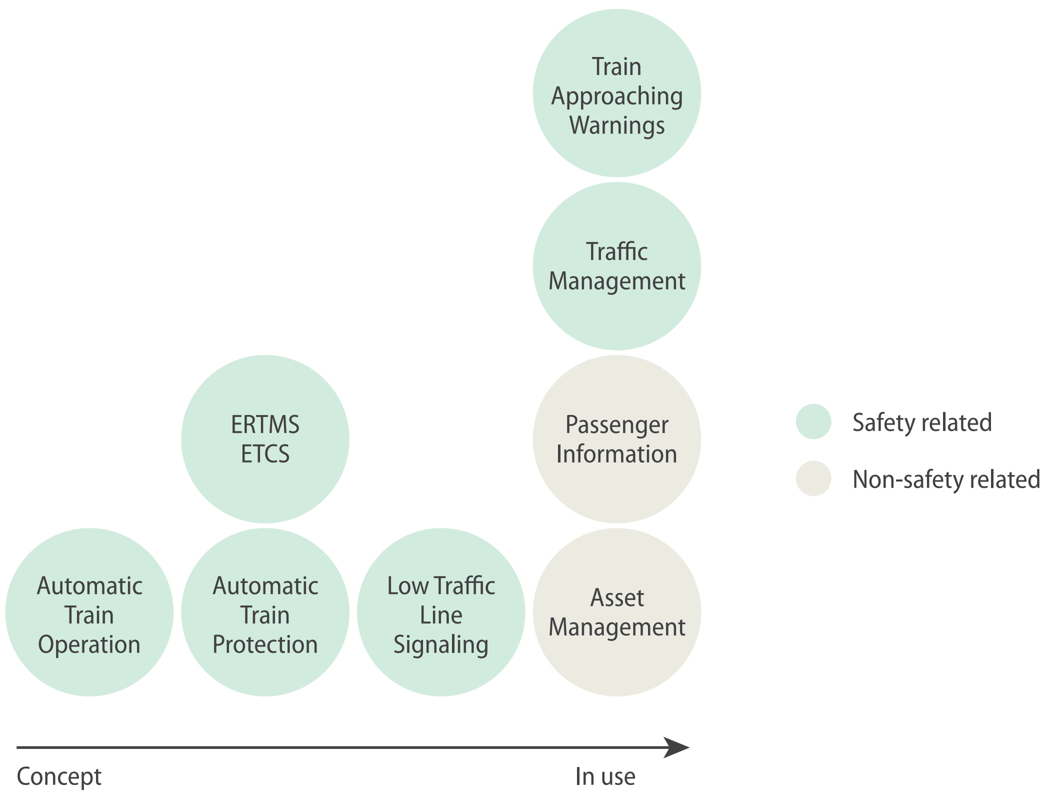


Figure 1 shows the maturity of the different functional groups, this can only be an approximation, since they are groups of individual applications; but it gives an overall impression as to the market readiness of each application grouping. Although the figure shows more groups in use than at a concept stage, it should be noted that the GNSS penetration within these in-use groups is often low and improved location information would offer advantages.

Three application bundles, not addressed as such in the previous part are briefly defined:

- Automatic Train Operation: This application bundle has been identified during UNIFE interview. Automatic Train Operation, or ATO, is an ATC subsystem which performs on-board, non-vital functions normally performed by a train driver, including ensuring a smooth acceleration of the train to the running speed, speed regulation and smoothly stopping the train at the proper position at station platforms or in front of stopping signals. GNSS could be used for ATO but this requires further study as never address before.
- Low Traffic Line Signalling: The purpose is to provide full signalling functionality without interlocking or blocking systems. The train location, speed, direction and identification must be known for every train in the control area.
- Traffic Management: this applications bundle include applications such as Traffic Management Systems[1] (Dispatching), but also Trackside Personnel Protection, Management of Emergencies (see previous section).

1 (please see [RD2])

GNSS is already used in applications in which people's safety isn't at stake, such as passenger information applications, which are mainly mature applications.

The main axes of development for GNSS applications in Rail are safety relevant and liability relevant applications. The European GNSS differentiators can play a key role in these applications.

Automatic Train Protection is one of the most promising GNSS safety relevant applications. It can be seen under two perspectives: inside and outside the ERTMS framework.

- Within the ERTMS framework, GNSS could be used as a means:
  - To introduce the virtual balise in the ERTMS ETCS Level 2/3
  - To provide the train integrity monitoring function for the ETCS Level 3
- Outside the ERTMS framework, GNSS is already being deployed for train control most commonly in USA, for Positive Train Control applications.

As it comes to Galileo system, it could bring increased availability and accuracy to train control, low traffic line and level crossing management, rolling stock management and other applications, even in difficult environments. With other constellations, it could help increase integrity via advanced technology at receiver level.

5.3 GNSS LIMITATIONS FOR RAIL USE

Rail is a very safety-sensitive environment and this why there are still limitations to use GNSS technology in Rail applications.

The main limitations for Rail GNSS applications concern obscuration, which might take place in tunnels, deep cuttings and in the shade of high hills/mountains, and at high latitudes or out of coverage for EGNOS obscuration. Another limitations is GNSS accuracy regarding positioning a train on parallel tracks or in train stations (HPL ≤ 3 m required).

AUTOMATIC TRAIN PROTECTION IS ONE OF THE MOST PROMISING GNSS SAFETY RELEVANT APPLICATIONS.

This section highlights the challenges related to the satellite positioning in the Rail domain. This section is based on [RD20], [RD21], [RD22] as input documents.

The train location determination is a primary function in the railway activity management. Indeed, it contributes not only to the traffic management, but also to the train control. The train control aims to avoid collision or other accident.

Currently, odometric sensors are used to measure the train speed and the relative train position in the European Train Control System, computed by integration of the speed. Balises are regularly spaced out along the railway track. The train assesses its position thanks to two tachometers and two Doppler radars, whose errors are reset periodically by the beacons. The operating and maintenance costs of this type of equipment are very high. This leads sometimes to the closure of low traffic lines.

The use of satellite positioning systems in the ETCS could resolve the economic issues and meet the interoperability requirements, as the current train control equipment differs from country to country.

However, some railway specificities have to be considered, when taking in to account using GNSS in Rail applications.

First of all, the train moves along the track, and so along one axis – horizontal. It involves that:

- the train driver can only brake but not avoid
- but, the train can stop in response to a failure

The railway safety problematic is thus very different to the aeronautical one.

Secondly, the train location is determined upon only one coordinate: the distance from the last balise to the train. Each track has its own coordinate system. Taking into account the railway network map the general three-dimensional positioning principle can be reduce to a one-dimensional model: the distance travelled by the train from its departure place (assuming that an accurate and reliable map is available).

For the positioning systems the railway applications require variable safety levels:

- A very high level for safety relevant applications. For instance, the train control function which ensures the non-collision of trains requires SIL4
- A very low level for the others.

At last, when a failure occurs a train has to immediately stop. The railway community wants to take no risk. Therefore, the notion of Time-To-Alarm in the railway domain dissents from the aeronautical one.

Today, the used railway location systems are more determinist. The potential use of GNSS systems in the ETCS involves the use of its statistical parameters.

5.4 DRIVERS FOR RAILWAY USER REQUIREMENTS

5.4.1 THE RAILWAY SAFETY PHILOSOPHY

According to [RD20], The Railway Safety philosophy is based on three main principles:

- **Avoidance**, and as far as possible exclusion, the transformation of the inherent human non-intended errors into wrong-side failures (= failures, technical or human, susceptible to develop into hazards, to produce harm). Prevention of imaginable non-intended failures of the human operator to become wrong-side failures => the railway system is not designed to protect against intended wrong-side human failures.
- The **controlled reliability**, mainly applicable to the vital components.
- Detection and identification of any possible random critical technical failure (= any technical non functionality which has the potential to produce a non-safe response) and immediate enforcement of a safe state. The **safety integrity risk** is given below:

$$SIr = P(2f) + P(syf) + P(false\_if)$$

- *P(2f)* the probability that during the imposed and designed time of failure detection, identification and enforcement to safe response (1s) a second failure occurs.
- *P(syf)* the probability of systematic failures for which the system is not designed to the detection.
- *P(false_if)* the probability that bad information is not detected and the system uses a false information.

The railway safety standards (EN 50126...EN 50129) clearly prescribe the methodology to be followed over the whole life cycle of a sub-system or component to assure that its safety integrity risk is controlled and maintained under the prescribed level.

The classification of the safety integrity is prescribed on 5 levels (from EN 50129):

Table 4: SIL Classification

Safety integrity	On Demand Mode (Low demand mode)		Continuous Mode (High demand mode)	Consequence of a failure
Level	Availability	Probability of failure on Demand (failure/demand)	Tolerable Hazard Rate per hour and function	
SIL4	> 99.99%	$\geq 10^{-5}$ to $<10^{-4}$	$\geq 10^{-9}$ to $<10^{-8}$	Several possible dead people in surrounding community
SIL3	99.99%	$\geq 10^{-4}$ to $<10^{-3}$	$\geq 10^{-8}$ to $<10^{-7}$	Several possible dead people
SIL2	99% -99.99%	$\geq 10^{-3}$ to $<10^{-2}$	$\geq 10^{-7}$ to $<10^{-6}$	Possible serious wounded people or one dead person
SIL1	90% -99%	$\geq 10^{-2}$ to $<10^{-1}$	$\geq 10^{-6}$ to $<10^{-5}$	Possible minor wounds
SIL0	No requirement			N/A

This table indicates the probability of failure, the safety integrity risk allocated to each of the levels (the figures represent probabilities expressed in events/hour).

The classification of SIL makes a distinction between the continuous (high demand) mode of operation and the operation on demand. This distinction takes into account that the operation on demand shall be preceded by an initial check of the element's fail-less state. In this study we will be interested exclusively in the continuous mode.

Note:

- The "on demand mode" is reserved for systems used in intermittent/sporadic way.
- The "continuous mode" concerns systems permanently used for a period of time.

5.4.2 SAFETY AND DEPENDABILITY PARAMETERS = RAMS

The Railway quality attributes differ from the GNSS quality criteria.

Railway definitions according to the EN 50126 standard are:

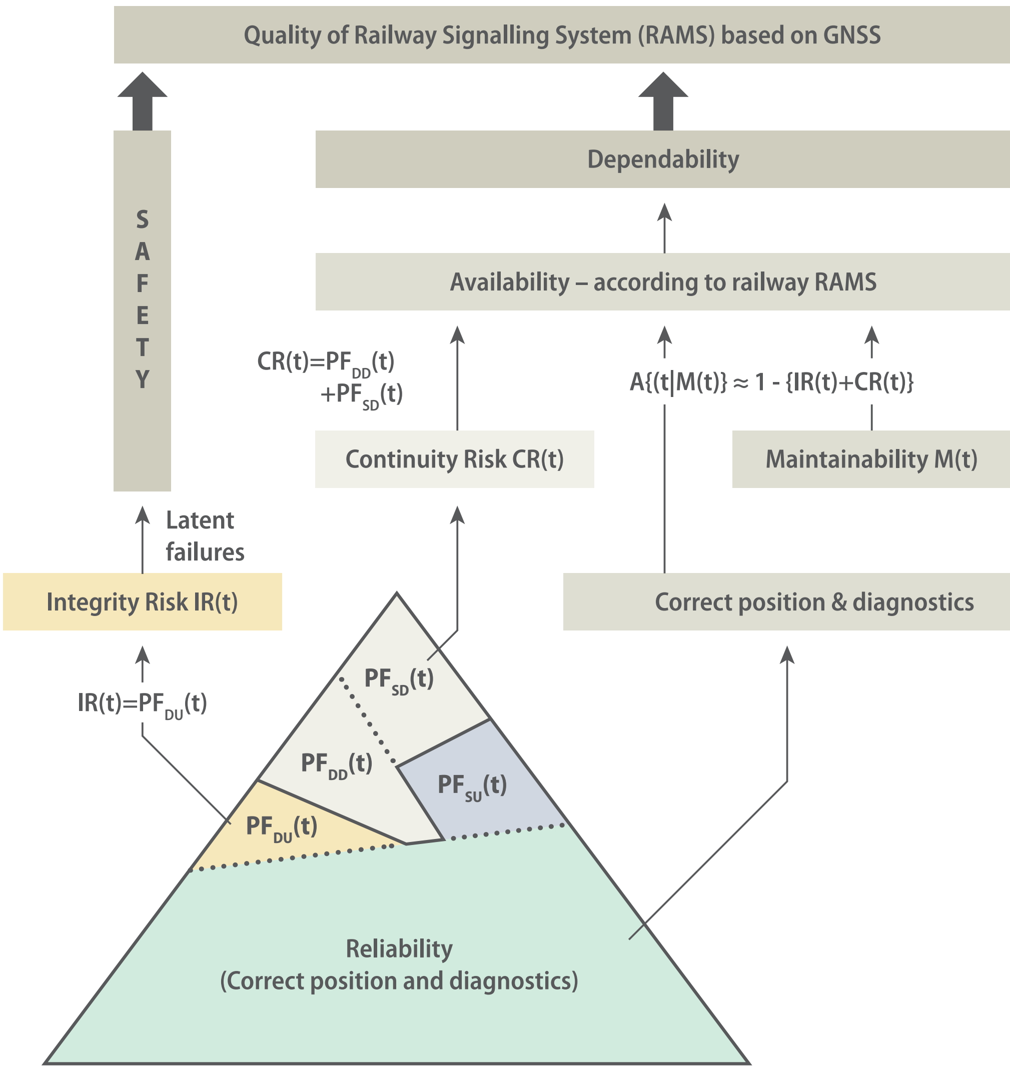
- **Reliability:** the probability that an item can perform a required function under given conditions for a given time interval.
- **Availability:** the ability of a product to be in state to perform a required function under given conditions at a given instant in time or over a given time interval assuming that the required external resources are provided.
- **Maintainability:** the probability that a given maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources. It means the ability of a system being maintained or restored after a failure to operational status over a given time interval assuming that the maintenance is made under given conditions with prescribed procedures and means.
- **Safety integrity:** the probability of a system satisfactory performing the required safety functions under all stated conditions within a stated period of time.

5.4.3 RELATION BETWEEN GNSS PERFORMANCE PARAMETERS AND RAILWAY QUALITY MEASURES

The scope of this part is to explain the relation between the GNSS performance parameters and railway quality measures. A number a research work on this topic has been carried out since more than 15 years. In spite of different safety philosophies, the GNSS performance parameters can be described by means of RAMS terminology according to railway standards.

For more information please refer to [RD22].

Figure 5: GNSS quality criteria within railway RAMS



Besides, [RD20] states that GNSS parameters relevant and impacting to the fail-safe design in compliance with the railway principles and standards are:

- The Position Accuracy,
- The HAL (and consequently the AL),
- The Integrity Risk computed when the HAL and IR threshold are considered in the computation.

The other parameters of GNSS (such as the continuity risk) are not directly relevant to the safe design in the railway applications in contrast to aviation, given the random obstruction / visibility environment a continuity condition cannot be applicable. For completeness' sake it should be mentioned that GNSS SoL service continuity does not only depends on SIS visibility. Continuity in aviation is the hardest requirement of all.

5.5 POLICY AND REGULATORY FRAMEWORK

5.5.1 POLICY AND REGULATORY STAKEHOLDERS

The main policy and regulatory European stakeholders involved in the user requirement definition process are the European Railway Agency (ERA) and the UNion Industry of SIGnalling (UNISIG).

European Railway Agency

The European Railway Agency was set up to help create this integrated railway area by reinforcing safety and interoperability. The Agency also acts as the system authority for the European Rail Traffic Management System (ERTMS) project, which has been set up to create unique signalling standards throughout Europe.

UNISIG

UNISIG is the main entity involved in the definition of user requirements for safety relevant applications, and in particular for ERTMS user requirements.

UNISIG is an industrial consortium, which was founded in 1998/99 at the specific request of the EU Commission with the task of drafting the technical specifications for ERTMS/ETCS.

Its role today is to develop, maintain and update the ERTMS specifications in close cooperation with the ERA, which has been made the "system authority" for ERTMS. To do so, UNISIG actively contributes, together with the railway representative bodies, to the various related working groups of the agency. Whilst the final version of the ERTMS specifications is published by the European Commission following the approval of the Member States, it is based on a recommendation from ERA. This recommendation is widely discussed with the railway sector, including UNISIG, and considerable work is undertaken by the consortium to define these specifications.

The UNISIG Consortium is an Associated Member of UNIFE. Seven companies now known as **Alstom**, **Ansaldo STS**, **Bombardier**, **Siemens**, **Thales**, **CAF** and **AŽD Praha** are its Full Members. **MERMEC** became Associated Member in 2010.

The **UNISIG Satellite Positioning Working Group** was created (June 2012) to specify and standardize the application of the satellite positioning to ERTMS.

Background: In 2011 UNIFE launched a market analysis of the new requirements coming from Customers outside and inside Europe.

The result of the analysis showed that Customers worldwide are strongly interested in the application of ERTMS, and that they would also be interested in some new features, such as (partial) elimination of balises in ETCS Level 2 through the use of satellite positioning functionality.

CUSTOMERS WORLDWIDE ARE STRONGLY INTERESTED IN THE APPLICATION OF ERTMS.

The UNISIG Satellite Positioning WP objectives are the following ones:

- To develop a basic concept for train localization through the use of satellite positioning
- To define, how the new functionality influence the current ETCS architecture
- To ensure that the impact on the existing system architecture and existing products can be kept minimal.

5.5.2 REGULATIONS TOWARDS GNSS USER REQUIREMENTS

5.5.2.1 EUROPEAN RAIL USER REQUIREMENTS SPECIFICATION – ERTMS/ ETCS RAM

Further specifications on ERTMS are provided by UNISIG on the design, certification and application of ERTMS equipment. Those considered to be more related to GNSS applications are commented in this section. These specifications are related to a function in which GNSS receivers can be included but to the GNSS receiver itself.

For more information about ERTMS/ETCS RAM requirements specification, please refer to [RD25].

Reliability requirements consist of quantitative requirements in terms of Mean Time Between Failures (MTBF); and differentiates in reason of the criticality (Immobilizing, Service or Minor) of such failures. They are also called ERTMS RAM (for Reliability, Availability and Maintenance) requirements and are stated as follows (these are all defined for on-board equipment) [RD25].

- The MTB Immobilizing hardware Failures shall be not less than $2{,}7\text{x}10^6$ hours.
- The MTB Service hardware Failures MTBF-SONB shall be not less than $3{,}0\text{x}10^5$ hours.
- The MTB Minor hardware Failures MTBF-MONB shall be not less than $8{,}0\text{x}10^3$ hours.

Availability must be not less than 99.973%, in order to assure compatibility with the ERTMS availability.

Maintainability is also standardized by European Standards. Apart being designed in order to minimize periodical maintenance and to control hazard levels, the equipment installation must not interfere with the access to other systems and devices on-board the train. The system supplier must specify the needed and forbidden maintenance procedures, it must also present auto test systems to verify periodically the correct operation and include a "maintenance mode" for the maintenance operation, including interfaces maintenance.

THE RAILWAY SAFETY PROBLEMATIC IS VERY DIFFERENT TO THE AERONAUTICAL ONE.

5.5.2.2 PERFORMANCE REQUIREMENTS

For more information about performance requirements, please refer to [RD6].

Performance Requirements for Interoperability define possible values for technical performance requirements of ERTMS on-board equipment.

This section contains an analysis of the required technical performances of ERTMS/ETCS equipment that could include a GNSS component inside.

Accuracy

- **Position accuracy** measured on-board: For every traveled distance s the accuracy shall be better or equal to **± (5m + 5% s)**. The fixed ± **5m tolerance is intended to cover the longitudinal uncertainty of the balise reader in detecting the balise reference location.** Also in case of malfunctioning the on-board equipment shall evaluate a safe confidence interval.
- **Accuracy of speed** known on-board: **± 2km/h for speeds lower than 30km/h, then increasing linearly up to ± 12km/h at 500km/h.**
- Age of location measurement for position report to trackside: The location of the train head indicated in a position report shall be estimated less than 1 sec before the beginning of sending of the corresponding position report.

Clock

- Safe clock drift: 0.1 %. This value is not only a performance but also a safety related requirement as it refers to clock information used for time-stamping of messages and for supervision of time-outs, the magnitude of which is a few minutes.

5.5.2.3 SAFETY REQUIREMENTS

For more information about safety requirements, please refer to [RD6].

These requirements refer to generic high-level quantitative safety requirements for ETCS operating either in Level 1 or Level 2. They are presented here in order to illustrate the magnitude order of Tolerable Hazard Rates of the transmission systems. This information is important if we consider that, in order to replace balises by virtual balises, the GNSS-based equipment must provide a performance as good as the existing equipment.

A dangerous failure is an undetected failure of the positioning system leading to the position provided being out of the accuracy range.

Only the safety requirements for the ETCS onboard equipment are addressed in this report.

The safety integrity level will be derived from the different tolerable hazard rates, taking into consideration the specified environment. For Hazard Rates of < 10-9 failures/hour, a SIL 4 process will be applicable. It is important to notice only failures that cause the ETCS hazard need to be considered.

Considering ETCS onboard equipment without the transmission system, the hazard rate for the ETCS onboard system excluding those parts forming part of the transmission paths shall be shown not to exceed a THR of $\mathbf{0.67x10^{-9}}$ **dangerous failures/hour**. The process of confirmation that the train data is correctly stored on-board must be of a quality commensurate with **a SIL 4** system.

Table 5: ERTMS User requirements

Application	Position Accuracy	Speed Accuracy	Safety Level
ERTMS UNISIG Specifications	5m + 5% s s is the distance travelled from the last calibration of the odometric device	±2km/h for speed ≤ 30km/h increasing linearly up to ±12km/h at 500km/h	SIL 4

5.5.2.4 USA SITUATION – PTC AND USER REQUIREMENTS

One of the most important applications for GNSS in the USA is Positive Train Control, which is a set of highly advanced technologies designed to automatically stop a train before certain types of accidents occur. It includes a GPS and communications-based system to monitor and control trains' movements in order to provide increased safety. PTC main functions are train separation or collision avoidance, line speed enforcement, temporary speed restrictions and rail worker wayside safety.

According to the Association of American Railroads ([RD17]), PTC systems are composed of three main elements integrated by a wireless communications system, which are:

- **Onboard or Locomotive System:** Monitors the train's position and speed and activates braking as necessary to enforce speed restrictions and unauthorized train movement into new sections of track.
- **Wayside System:** Monitors railroad track signals, switches and track circuits to communicate authorization for movement to the locomotive.
- **Back Office Server:** The storehouse for all information related to the rail network and trains operating across it – speed limits, track composition, speed of individual locomotives, train composition, etc. – and transmits the authorization for individual trains to move into new segments of track.

As stated by the Federal Radionavigation Plan ([RD18]), in the USA, the railroad industry does not have any specific short-term need for satellite systems based on the performance of current GPS and non-NDGPS differential systems. The GPS dependent Positive Train Control systems currently being deployed do not depend on differential systems availability. Some other applications require more accurate positioning information and therefore use differential systems.

Since the train is constrained to be located on a track, the location in the railroads context is a one-dimensional problem, with well-defined discrete point where the potential to diverge exists, where the interval between locations at which a train may diverge from its current route over a switch is considerably small, not reaching 20m.

The most stringent requirement for the location determination system in PTC is to determine which parallel tracks a train is occupying with a probability of 99,999% with a minimum track spacing of 3,5m.

Aside from position and timing needs for safety critical PTC system operations, some other potential uses for railroad functions are infrastructure surveying and mapping, track defect location, weather forecasting, locomotive control and high capacity communications. These position and timing needs can also rely on a variety of GPS based and non GPS based systems.

5.5.2.5 RUSSIAN SITUATION - KLUB-U

Russia developed an Integrated Train Protection System called KLUB-U, using both GPS and GLONASS technologies for train positioning.

This system determines train movement qualitative values (coordinates, speed) by the data from satellite navigation devices, the digital track map of a railway section and distance-and-speed sensors/meters, which are installed on a wheel-set journal box[2]. Different issues shall be addressed by this modern train control system: this is on the one hand the low visibility of signals at difficult environmental conditions like fog, rain and snow; on the other hand the targeted high speeds where driving at sight to signals is not possible. This technology still needs to be improved for extreme environments.

KLUB-U[3] in-cab signaling systems are able to decode the track-side ALSN codes (Continuous Automatic Train Signalization). In the most recent block control system, the KLUB-U systems decode signals by digital radio including a remote initiation of a train stop. In those areas the train position is

Table 6: Rail User Requirements (USA)

Requirements	Measures of minimum performance criteria to meet requirements					
	Accuracy (Meters, 2 drms)	Availability	Continuity	Integrit (alert limit)	Time to alert	Coverage
Positive Train Control (PTC)	1.0	99.9%	N/A	2 m	6 s	Railroad right of way in all 50 states and District of Columbia
Track Defect Location (TDL)	0.3	99.9%	N/A	0.6 m	30 s	Railroad right of way in all 50 states and District of Columbia
Automated Asset Mapping (AAM)	0.2	99.9%	N/A	0.4 m	30 s	Railroad right of way in all 50 states and District of Columbia
Surveying	0.02	99.7%	N/A	0.04 m	30 s	Railroad right of way in all 50 states and District of Columbia
Bridge and Tectonic Monitoring for Bridge Safety	0.002	99.7%	N/A	0.004 m	30 s	Railroad right of way in all 50 states and District of Columbia
Telecommunications Timing	340 nsec	99.7%	N/A	680 nsec	30 s	All 50 states and District of Columbia

2 http://en.irz.ru/products/20/70.htm
3 https://en.wikipedia.org/wiki/KLUB-U

derived from a satellite navigation system (GPS or GLONASS). KLUB-U is connected to an in-cab system via GSM-R digital radio with the ERMTS Level 2 RBC block control. The KLUB-U systems are capable for high-speed tracks.

KLUB-U[4] is at the center of an expanded concept EKS (ЕКС - единая комплексная система управления тяговым подвижным составом - Single Unified Train Control System). This will be able to decode signals from Eurobalises and display the information in an extended version that allows representation of signals according to European railway standards. For cross-border transport to Finland, cooperation with Ansaldo STS was created in 2007, which developed the Italian-Russian train control system ITARUS-ATC being compatible with ETCS. It is similar to ERTMS Level-2 (being able to use GSM-R to communicate with its Radio Block Center) but adds satellite navigation to the system. The system combines inertial navigation and wheel sensors to measure distance and turns to enhance safety for passenger service in the Russian Federation.

Ansaldo was contracted in January 2010 to deploy the ITARUS-ATC on the test track for a later rail connection to Sochi up to the 2014 winter games. Belarus wants to license the system to use this ETCS- and KLUB-compatible train control system on the Pan-European transport corridors 2 and 9. At the end of November 2010 Finmeccanica (parent company of Ansaldo) and Russian Railways (Mother Company of VNIIAS) have signed a Memorandum of Understanding to found a joint venture to develop the ITARUS-ATC system. The deal includes a project to use the train control system to equip 100 stations, 100 trains and 50 lines until 2020 - estimations find the deal to be worth about 2 billion Euro.

No user requirements were identified in public literature.

5.6 CONCLUSIONS

Over the past years, a lot of effort has been provided by the Rail and GNSS communities to try and understand their respective safety philosophy (see Annex 1). However, work is still needed to define user requirements applicable to GNSS, and in particular, quantified requirements.

The results presented hereafter are derived from validation interviews of both key players of Rail market: UNIFE (Union des Industries Ferroviaires Européennes) and Ansaldo STS (see [RD27] and [RD28]).

They represent the most recent Rail User Requirements expressed for a representative sample of Rail applications. Those requirements are mostly expressed by ranges of value or qualitative requirements, and tend to simplify the reality. But as of today, they are the only ones recognized by the Rail community– except for the Time To Alarm requirement. The Rail community is indeed not able to express any requirement in terms of TTA.

2019 update

The following sections summarize the requirements applicable to the rail applications considered in section 1.1.1. These requirements are mainly derived from:

- The ESSP Technical Note “EGNOS v3 requirements for the rail domain”, mainly based on SUGAST project results (see [RD4]);
- The validation interview of UNIFE ([RD27]).

Parameters describing user requirements for Rail applications

Safety Integrity Levels are defined in section 1.4.1. It is worth noticing that according to rail community:

- No SIL allocation is needed for non-safety relevant applications (see Annex 1).
- For the applications “Protection and Emergency Management”, no SIL allocation is needed ([RD27]).

RAIL IS A VERY SAFETY-SENSITIVE ENVIRONMENT AND THIS WHY THERE ARE STILL LIMITATIONS TO USE GNSS TECHNOLOGY.

Recommendations for future works

The reality is much more fragmented and work is still required to get realistic reflection of the actual user needs. The ATC example is a good illustration: There are plenty of ATC implementations, trying to match the operational and other needs of specific applications (urban, mainline, high-speed, regional, etc.). Within ATC systems itself, there are more modes and functionalities, where the requirements for GNSS will differ.

It can be expected that current initiatives (see Annex 2), where major players in the sector are cooperating, such as UNISIG WG on Satellite Navigation, NGTC project and H2020 ERSAT EAV project as well as (in the close future) Shift2Rail TD2.4 and H2020 STARS project, that are going to contribute in a significant way in the definition of GNSS rail user requirements for safety relevant applications such as ETCS. The activities of these initiatives should be closely monitored.

4 http://www.eav.ru

However, it is worth noticing that all the current efforts of the Rail community are to include GNSS in ETCS without changing the ERTMS architecture (through in particular the following both applications: virtual balise functionality for ERTMS level 2/3 and train integrity monitoring function for the ERTMS level 3). It cannot be expected from them the tremendous work required to express rail user requirements in terms of GNSS requirement by applying e.g. the aviation approach. The rail scenarios/use cases are much more complex that the aviation ones. The Satellite Navigation community remains a key player to support the definition of GNSS Rail user requirements.

Both following additional points should be considered for future analyses:

- An important request from the Rail community is to closely refer to applications as they are defined in Rail segment,
- The applications defined in the context of "Autonomous Train Operations" should be further analyzed.

Last but not least, an important descriptive work on the Rail PNT applications is still required, in particular the operational descriptions.

Table 7: Parameters definition for rail applications requirements

Parameter	Description
Accuracy	Accuracy is a statistical value and is defined as the degree of conformance between the measured position and its true position, at a given level of confidence, at any given instant in time, and at any location in the coverage area. When specifying accuracy it is essential to specify the statistical context, which is usually assumed to be Gaussian. It is usually expressed as a confidence interval which is associated to probability (normally 95%). Only horizontal accuracy is considered in rail applications.
Availability	According to EN 50126, availability is the ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided. In the present document the availability is defined as the intrinsic availability of location information fulfilling its performance requirements at the location unit output. In railways, where the relative unavailability of Signal in Space (SiS) owing to limited visibility is a natural condition, lack of SiS is not a cause of non-availability for highly demanding applications (other sensors will compensate for this fact through hybridization).
Integrity	Integrity relates to the trust that can be placed in the correctness of the information supplied by the Location Unit to the application. Integrity is defined here as the ability of the Location Unit equipment to provide timely warnings to the user when data provided by the system should not be used.
Time to Alert (TTA)	Maximum allowable time between the occurrence of the failure in the system (e.g. satellite fault) and its presentation to the user. The failure can be due to an excessive inaccuracy being detected (see alert limit) or that a particular satellite is untrustworthy.
Integrity risk	Appears when location is out of the tolerance limit (false), but the Location Unit reports "information available" and no "alarm" is triggered within the time to alarm. For safety applications, the integrity risk can be described by the tolerable hazard rate which is derived from a risk analysis of the application. A Safety Integrity Level shall be then allocated to the Location Unit according to the application.

06 USER REQUIREMENTS SPECIFICATION

The requirements have been gathered according to the groups of applications described in paragraph Error! Reference source not found.. When a requirement is common to one or two groups the same nomenclature reference is used.

6.1 REQUIREMENTS FOR SAFETY

Table 8: Requirements for Automatic Train Protection

Id	Description	Type	Source
~~**GSA-MKD-USR-REQ-RAI-0010**~~	~~The PNT solution shall provide the train position with a horizontal accuracy within a range of 1-10m for High Speed Line.~~	~~Performance (Accuracy)~~	~~[RD4], [RD27]~~
~~**GSA-MKD-USR-REQ-RAI-0020**~~	~~The PNT solution shall provide the train position with a horizontal accuracy of 10m or even more for Low Traffic Line.~~	~~Performance (Accuracy)~~	
~~**GSA-MKD-USR-REQ-RAI-0030**~~	~~The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.~~	~~Performance (Availability)~~	
~~**GSA-MKD-USR-REQ-RAI-0040**~~	~~The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Very High.~~	~~Performance (Integrity)~~	
~~**GSA-MKD-USR-REQ-RAI-0050**~~	~~The PNT solution shall achieve a Safety Integrity Level 2-4.~~	~~Performance (Safety Integrity Level)~~	
~~**GSA-MKD-USR-REQ-RAI-0060**~~	~~The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be less than 10s.~~	~~Performance (Time To Alarm)~~	

2019 update

Table 9: Requirements for Cold Movement Detection

	Id	Description	Type	Source
2019 update	**GSA-MKD-USR-REQ-RAI-0070**	The PNT solution shall provide the train position with a horizontal accuracy lower than 1m	Performance (Accuracy)	[RD4] [RD27] [RD31]
	GSA-MKD-USR-REQ-RAI-0080	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
	GSA-MKD-USR-REQ-RAI-0090	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Very High.	Performance (Integrity)	
2019 update	**GSA-MKD-USR-REQ-RAI-0100**	The PNT solution shall achieve a Safety Integrity Level 4.	Performance (Safety Integrity Level)	[RD4] [RD27] [RD31]
	GSA-MKD-USR-REQ-RAI-0110	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be less than 10s.	Performance (Time To Alarm)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016

Table 10: Requirements for Level Crossing Protection

	Id	Description	Type	Source
	GSA-MKD-USR-REQ-RAI-0120	The PNT solution shall provide the train position with a horizontal accuracy within a range of 1-10m.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
	GSA-MKD-USR-REQ-RAI-0130	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	
	GSA-MKD-USR-REQ-RAI-0140	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Very High.	Performance (Integrity)	
2019 update	**GSA-MKD-USR-REQ-RAI-0150**	The PNT solution shall achieve a Safety Integrity Level 4.	Performance (Safety Integrity Level)	[RD4] [RD27] [RD31]
	GSA-MKD-USR-REQ-RAI-0160	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be lower than 10s.	Performance (Time To Alarm)	

Table 11: Requirements for Train Integrity and train length monitoring

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0170	The PNT solution shall provide the train position with a horizontal accuracy within a range of 1-10m.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0180	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	
GSA-MKD-USR-REQ-RAI-0190	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Very High.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0200	The PNT solution shall achieve a Safety Integrity Level 4.	Performance (Safety Integrity Level)	[RD4] [RD27] [RD31] 2019 update
GSA-MKD-USR-REQ-RAI-0210	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alarm)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016

Table 12: Requirements for Track Identification

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0220	The PNT solution shall provide the train position with a horizontal accuracy lower than 1.9m for track discrimination.	Performance (Accuracy)	[RD4] [RD27] [RD31] 2019 update
GSA-MKD-USR-REQ-RAI-0230	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0240	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Very High.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0250	The PNT solution shall achieve a Safety Integrity Level 2-4.	Performance (Safety Integrity Level)	
GSA-MKD-USR-REQ-RAI-0260	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alarm)	

Table 13: Requirements for Door Control Supervision

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0320	The PNT solution shall provide the train position with a horizontal accuracy within a range of 1-10m.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
2019 update **GSA-MKD-USR-REQ-RAI-0321**	When using ATO, The PNT solution shall provide the train position with a horizontal accuracy within a range of 1m.	Performance (Accuracy)	[RD4] [RD27] [RD31]
GSA-MKD-USR-REQ-RAI-0330	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0340	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0350	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alarm)	

Table 14: Requirements for Trackside Personnel Protection

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0360	The PNT solution shall provide the train position with a horizontal accuracy within a range of 1-10m.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0370	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	
GSA-MKD-USR-REQ-RAI-0380	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0390	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alarm)	
2019 update **GSA-MKD-USR-REQ-RAI-0391**	For ATO application, the PNT solution shall achieve a Safety Integrity Level 2.	Performance (Safety Integrity Level	[RD4] [RD27] [RD31]

6.2 REQUIREMENTS FOR NON-SAFETY RELEVANT APPLICATIONS

6.2.1 LIABILITY RELEVANT APPLICATIONS

Table 15: Requirements for Odometer Calibration

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0270	The PNT solution shall provide the train position with a horizontal accuracy lower than 1m.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0280	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	
GSA-MKD-USR-REQ-RAI-0290	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used is low.	Performance (Integrity)	[RD4] [RD27] [RD31]
~~**GSA-MKD-USR-REQ-RAI-0300**~~	~~The PNT solution shall achieve a Safety Integrity Level 2-4.~~	~~Performance (Safety Integrity Level)~~	
GSA-MKD-USR-REQ-RAI-0310	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be less than 10s.	Performance (Time To Alarm)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016

2019 update

Table 16: Requirements for Management of emergencies

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0400	The PNT solution shall provide the train position with a horizontal accuracy within a range of 5m and track selectivity is needed.	Performance (Accuracy)	[RD4] [RD27] [RD31]
GSA-MKD-USR-REQ-RAI-0410	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0420	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0430	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alarm)	

2019 update

Table 17: Requirements for Train warning systems

2019 update

Id	Description	Type	Source
~~GSA-MKD-USR-REQ-RAI-0440~~	~~The PNT solution shall provide the train position with a horizontal accuracy within a range of 1-10m.~~	~~Performance (Accuracy)~~	~~[RD4] [RD27] [RD31]~~
~~GSA-MKD-USR-REQ-RAI-0450~~	~~The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.~~	~~Performance (Availability)~~	
~~GSA-MKD-USR-REQ-RAI-0460~~	~~The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.~~	~~Performance (Integrity)~~	
~~GSA-MKD-USR-REQ-RAI-0470~~	~~The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.~~	~~Performance (Time To Alarm)~~	

Table 18: Requirements for Infrastructure surveying

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0480	The PNT solution shall provide the train position with a horizontal accuracy within a range of 0.01-1m.	Performance (Accuracy)	[RD4] : ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0490	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be Low.	Performance (Availability)	
GSA-MKD-USR-REQ-RAI-0500	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0510	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 30s or even more.	Performance (Time To Alarm)	

2019 update

Table 19: Requirements for Location of GSM Reports

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0520	The PNT solution shall provide the train position with a horizontal accuracy within a range of 100m.	Performance (Accuracy)	[RD4] [RD27] [RD31]
GSA-MKD-USR-REQ-RAI-0530	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be Low.	Performance (Availability)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0540	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0550	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 30s or even more.	Performance (Time To Alarm)	

Table 20: Requirements for Gauging surveys

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0560	The PNT solution shall provide the train position with a horizontal accuracy within a range of 0.01-1m.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0570	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be Low.	Performance (Availability)	
GSA-MKD-USR-REQ-RAI-0580	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Very High.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0590	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 30s or even more.	Performance (Time To Alarm)	

Table 21: Requirements for Structural monitoring

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0600	The PNT solution shall provide the train position with a horizontal accuracy within a range of 0.01-1m.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0610	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be Low.	Performance (Availability)	
GSA-MKD-USR-REQ-RAI-0620	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Low.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0630	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 30s or even more.	Performance (Time To Alarm)	

Table 22: Requirements for Fleet management

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0640	The PNT solution shall provide the train position with a horizontal accuracy of 10m or even more.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 irements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0650	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	
GSA-MKD-USR-REQ-RAI-0660	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Low.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0670	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 30s or even more.	Performance (Time To Alarm)	

Table 23: Requirements for Cargo monitoring

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0680	The PNT solution shall provide the train position with a horizontal accuracy of 10m or even more.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0690	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	
GSA-MKD-USR-REQ-RAI-0700	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Low.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0710	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 30s or even more.	Performance (Time To Alarm)	

Table 24: Requirements for Energy Charging

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0720	The PNT solution shall provide the train position with a horizontal accuracy of 10m or even more.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0730	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	
GSA-MKD-USR-REQ-RAI-0740	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Low.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0750	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 30s or even more.	Performance (Time To Alarm)	

Table 25: Requirements for Infrastructure Charging

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0760	The PNT solution shall provide the train position with a horizontal accuracy of 10m or even more.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0770	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	
GSA-MKD-USR-REQ-RAI-0780	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0790	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 30s or even more.	Performance (Time To Alarm)	

Table 26: Requirements for Hazardous Cargo Monitoring

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0800	The PNT solution shall provide the train position with a horizontal accuracy within a range of 1-10m.	Performance (Accuracy)	[RD4]: ESSP-TN-12586 v01-00 "EGNOS V3 requirements for the rail domain", 20.11.2014 [RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0810	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	
GSA-MKD-USR-REQ-RAI-0820	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.	Performance (Integrity)	
GSA-MKD-USR-REQ-RAI-0830	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alarm)	

6.2.1 NON-LIABILITY RELEVANT APPLICATIONS

The only non-safety and non-liability relevant application considered in this document is passenger information. The actual existing GNSS performances are meeting the user requirements.

Table 27: Requirements for passenger information

Id	Description	Type	Source
GSA-MKD-USR-REQ-RAI-0840	The PNT solution shall provide the train position with a horizontal accuracy of less than 100m.	Performance (Accuracy)	[RD27]: UNIFE validation interview, 13.01.2016
GSA-MKD-USR-REQ-RAI-0850	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be of 95%.	Performance (Availability)	

07 ANNEX 1: PAST INITIATIVES REGARDING GNSS REQUIREMENTS IN RAIL

GNSS RAIL ADVISORY FORUM

In 2000, the GNSS Rail Advisory Forum proposed some possible common requirements for different safety and non-safety related applications. But at that time the way in which the performances are described was not understandable and consequently not recognized by the railway actors (see [RD26]).

GRAIL

This section corresponds to a summary of the outcomes of GRAIL project carried out from [RD6], [RD12], [RD13], [RD14]and [RD15].

Introduction

This project was aimed at supporting the introduction of GNSS in the Rail market. It was carried out from the 31st August 2005 to the 31st July 2008.

GRAIL proposed a strategy consistent with the current deployment process of ERTMS/ETCS in Europe, for a smooth integration of GNSS into control and command applications and particularly in signaling. Its objectives were:

- To achieve a common specification for the GNSS subsystem for:
  - Enhanced Odometry application
  - Enhanced ETCS applications (absolute positioning)
- To develop and test a prototype of the GNSS subsystem for the Enhanced Odometry and the Enhanced ETCS applications:
  - Tests in a real ERTMS/ETCS line
  - Tests in a lab environment
- To study the complementary aspects:
  - economic issues
  - legal issues
  - development of GNSS local elements specific for railways consistent with the objectives 1 and 2

Table 28: GNSS requirements for Rail from the GNSS Rail Advisory Forum

Application	Horizontal accuracy (m)	Integrity	
		Alert limit (m)	Time to alarm (s)
Safety related applications			
ATC on high density line/station/parallel track	1	2.5	<1.0
Train Control on medium density lines	10	20	<1.0
Train Control on low density lines	25	50	<1.0
Mass commercial/information and management – operational applications			
Tracing & Tracking of vehicules	50	125	<10
Cargo monitoring	100	250	<30
Dispatching	50	125	<5
Passenger information	100	250	<30
Infrastructures & civil engineering, professional applications			
Positioning of machines	1 cm	N/A	<5
Infrastructure survey	1 cm	0.1 cm	<10
Fix point applications	5 mm	N/A	<30

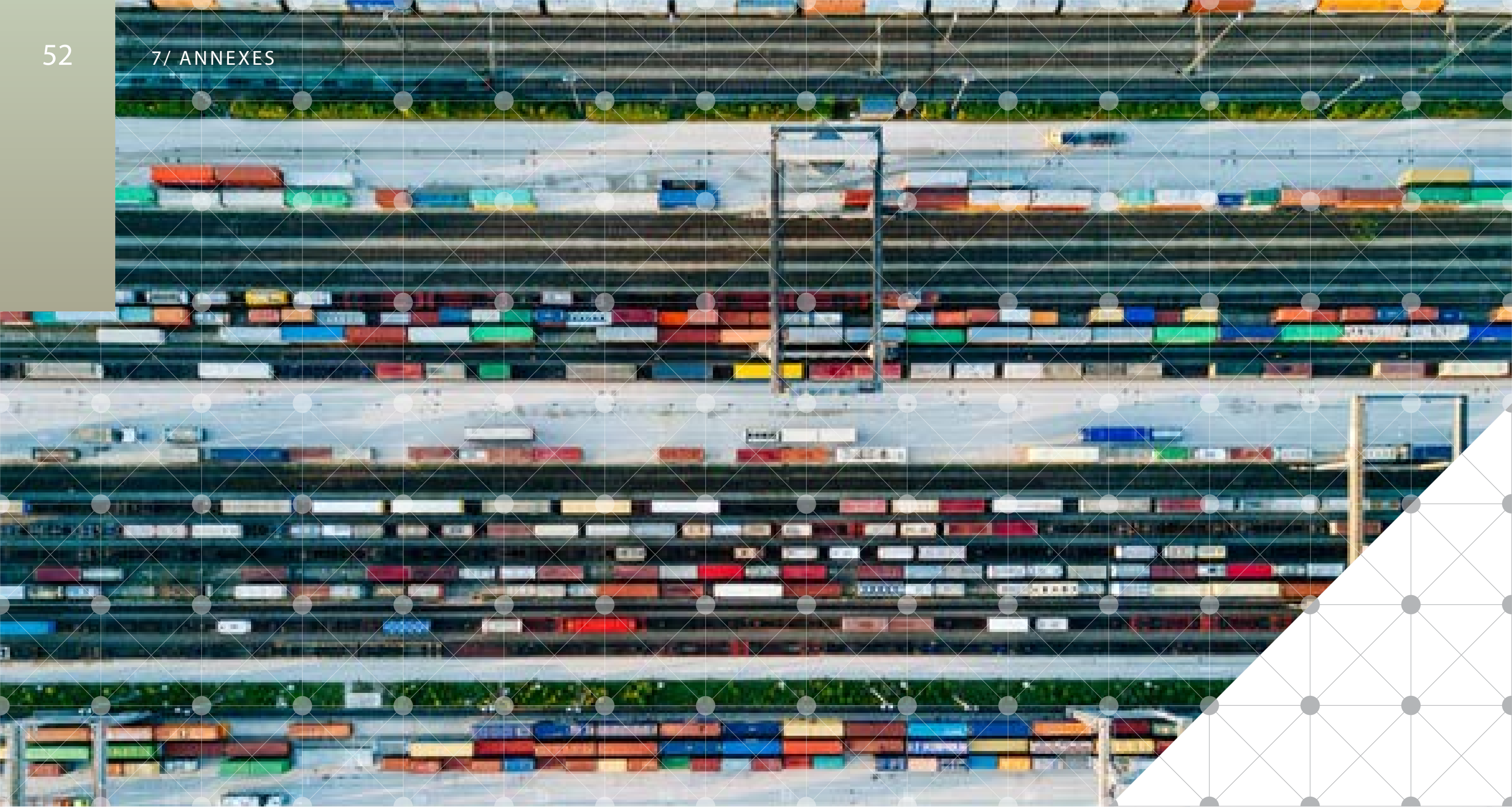
Interruption (% of mission time)	Interruption of service (s)	Continuity of service (%)
>99.98	<5	>99.98
>99.98	<5	>99.98
>99.98	<5	>99.98
>99.9	N/A	N/A
>99.5	N/A	N/A
>99.9	N/A	N/A
>99.5	N/A	N/A
99.5	N/A	N/A
99	N/A	N/A
99	N/A	N/A

GRAIL PROPOSED A STRATEGY CONSISTENT WITH THE CURRENT DEPLOYMENT PROCESS OF ERTMS/ ETCS IN EUROPE.

Table 29: GRAIL User Requirements

<table>
<tr><th>Application</th><th colspan="4">Accuracy</th><th>Speed Accuracy</th><th>Availability</th></tr>
<tr><td rowspan="3">Enhanced Odometry</td><td colspan="4">Travelled Distance Accuracy for main lines (urban and rural scenarios) and for low visibility scenarios (tunnels, covered stations)
REQ-GNSSUT-EO-PER-170</td><td>Independently of operational conditions
REQ-GNSSUT-EO-PER-190</td><td>In any place within the Service Volume, when operating in the Nominal SIS Constellation state
REQ-GNSSUT-EO-PER-200</td></tr>
<tr><td>Appr.1</td><td colspan="3">± (5m + 5% of the distance since last beacon)</td><td>2 km/h</td><td rowspan="2">95%</td></tr>
<tr><td>Appr.2</td><td colspan="3">± (5m + 2% of the distance since last beacon)</td><td>1 km/h</td></tr>
<tr><td rowspan="2">Cold Movement Detection & Train Awakening</td><td colspan="4" rowspan="2">Position Accuracy: 1m
REQ-GNSSUT-EE-TA-250</td><td rowspan="2"></td><td>In any place within the Service Volume, when operating in the Nominal SIS Constellation state
REQ-GNSSUT-EE-TA-280</td></tr>
<tr><td>95%</td></tr>
<tr><td rowspan="9">Absolute Positioning</td><td colspan="4">Position accuracy with a SIL 4 integrity level
REQ-GNSS-EE-AP-490
REQ-GNSS-EE-AP-500</td><td>Velocity accuracy with a SIL 4
REQ-GNSS-EE-AP-510
REQ-GNSS-EE-AP-520</td><td>In any place within the Service Volume, when operating in the Nominal SIS Constellation state
REQ-GNSSUT-EE-AP-530</td></tr>
<tr><td rowspan="4">Zone 1</td><td rowspan="2">Short term</td><td>Rural</td><td>≤ 100m</td><td>≤ 1.5 m/s</td><td rowspan="8">99%</td></tr>
<tr><td>Urban</td><td>≤ 150m</td><td>≤ 3 m/s</td></tr>
<tr><td rowspan="2">Long term</td><td>Rural</td><td>≤ 50m</td><td>≤ 1m/s</td></tr>
<tr><td>Urban</td><td>≤ 100m</td><td>≤ 2 m/s</td></tr>
<tr><td rowspan="4">Zone 2</td><td rowspan="2">Short term</td><td>Rural</td><td>≤ 30m</td><td>≤ 1.5m/s</td></tr>
<tr><td>Urban</td><td>≤ 40m</td><td>≤ 3 m/s</td></tr>
<tr><td rowspan="2">Long term</td><td>Rural</td><td>≤ 20m</td><td>≤ 1 m/s</td></tr>
<tr><td>Urban</td><td>≤ 25m</td><td>≤ 2 m/s</td></tr>
<tr><td>Train Integrity Length Monitor</td><td colspan="4">Train Length confirmation Accuracy: ≤ 10m
REQ-GNSSUT-EE-TI-370</td><td></td><td>99.98% main lines
95% low traffic lines
(final report)</td></tr>
</table>

Continuity	Integrity	TTA	Alert Limit	Train Length Confidence Interval Accuracy
Assuming the SoL core system performance requirements (without receiver contribution) of 8x10⁻⁶/15s. REQ-GNSSUT-EO-PER-210	>TBD% REQ-GNSSUT-EO-PER-220	< 5s REQ-GNSSUT-EO-PER-230		
< 8x10⁻⁵/15s.				
Assuming the SoL core system performance requirements (without receiver contribution) of 8x10⁻⁶/15s. REQ-GNSSUT-EE-TA-290	Independently from environmental influences topography and buildings (REQ-GNSSUT-EE-TA-320)			
< 8x10⁻⁵/15s.	SIL 4 (final report)			
	SIL 4 (final report)			
Assuming the SoL core system performance requirements (without receiver contribution) of 8x10⁻⁶/15s. REQ-GNSSUT-EE-TI-390	Independently from environmental influences topography and buildings (REQ-GNSSUT-EE-TI-440)		≤ 2L for high speed lines (headway 3′) ≤ 37.8%L for mixed traffic lines (headway 4′) REQ-GNSSUT-EE-TI-370	
< 8x10⁻⁵/15s.	SIL 4 (final report)			



The project developed works on the following selected applications:

- Enhanced Odometry,
- Train Awakening / Cold Movement Detector,
- Absolute Positioning,
- Train Integrity.

User Requirements

One of the main objectives of the GRAIL project was to define the performance requirements for the GNSS system for some selected relevant applications in the railway sector. Two main applications classes were defined: the Enhanced Odometry applications and the Enhanced ETCS applications. Within the Enhanced ETCS applications three applications have been distinguished: the Absolute Positioning, the Integrity Length Monitor, and the Train Awakening and Cold Movement Detector.

In the GRAIL document each performance requirement refers to an acronym (REQ-GNSSUT-XX-XX). These acronyms will be used in the present document as references.

The following tables summarizes the requirements specified for each Rail application.

Comment:

Two different approaches are proposed for the Enhanced Odometry.

- The Approach 1 is a short term solution: the User Terminal (UT), or GNSS receiver, is used as a complement of the current odometry sensors and with the current ETCS performance requirements.
- The Approach 2 is a mid-term solution: a more advanced UT is used as a complement or substitute of the current odometry sensors, with a public interface and with enhanced ETCS Odometry performances.

Analysis of GRAIL user requirements

In the GRAIL documentation, most requirements are expressed according to the GNSS parameters. Some efforts were provided by the railway community. The use of GNSS in Rail seems to become a real need.

For most applications, a very stringent integrity requirement is specified. A SIL 4 corresponds to THR comprised between 10-9/h and 10-8/h, which is pretty much equivalent to an Integrity Risk in the order of 10^{-11}/150s.

Although a number of requirements were expressed, some of them are not yet mature or complete enough.

GRAIL-2

This section corresponds to a summary of the outcomes of GRAIL project carried out from [RD6], [RD23], and [RD23]. Reports of GRAIL-2 being not public, the level of information given in this report is very limited.

GRAIL-2 project aimed at defining, developing and validating a GNSS-based ETCS application in high- speed railway lines. Starting from the work done in the GRAIL project, GRAIL-2 went further in the implementation and testing of the Enhanced Odometry so that a real validation of the application against user needs can be performed, thus achieving a system closer to a final product.

The GRAIL-2 Consortium carried out the project in the period from 1st September 2010 to 31st December 2013.

The main objectives of this project were:

- Definition of user and system requirements,
- Development of a GNSS-based EO system prototype,
- Validation of the prototype by means of an extensive test campaign,
- Demonstration that the safety requirements for the application can be met by the system, by means of simulation, testing, modeling, etc.,
- Roadmap towards certification.

GNSS-based Enhanced Odometry for Rail

In ERTMS, the odometry is a function that determines the location of a train, related to a reference point and the distance from that point as measured by counting wheel rotations. As the measurement is based on a reference point, the accuracy decreases with the distance travelled from the last reference point, so the position errors are reset periodically by eurobalises, whose location is known from a preloaded database.

The aim of the GNSS 'enhanced odometry' subsystem was to support the odometry function (speed measurement) with accurate location information. This subsystem aimed at replacing conventional sensors such as Doppler radars, which have shown to cause some operational problems under some conditions and whose maintenance costs are high, enabling at the same time a cost-effective way to implement this function and paving the way for the introduction of other ERTMS functions which may rely also on the GNSS signals.

In parallel, comprehensive safety studies were performed, whose goal within GRAIL-2 was to demonstrate that the safety requirements for the application can be fulfilled, according to current rail standards and procedures. First, it was analysed if the original development concept would meet the safety requirements imposed on the odometry functionality. Then, a second iteration was performed to assess what parts of the design should be revised so that the adequate level of safety is reached for the application. Finally, in parallel to the collection of evidences for the completion of the application safety case, an independent safety analysis started, with the aim of ensuring the correct use of the methodology set out by European norms to demonstrate safety.

Main outcomes of the safety studies

Based on an existing development made in GRAIL, the core activities of the GRAIL-2 sequel consisted of making the necessary evolutions in such a prototype so that a resulting odometry function was as much as possible consistent with the safety requirements imposed on a commercial system of these characteristics.

GRAIL-2 AIMED AT DEFINING, DEVELOPING AND VALIDATING A GNSS-BASED ETCS APPLICATION IN HIGH-SPEED RAILWAY LINES.

These requirements can be grouped in a single requirement: a Safety Integrity Level of four (SIL 4), which means that a systematic failure in the full function, originating fatal consequences, must have a probability less than 10^{-8} per hour.

The first safety iteration in the project consisted of analysing the SIL level achievable by the GNSS User Terminal (which included an inertial unit), legacy from GRAIL. As SIL 4 was not achievable by such sensor, the original aim of replacing all conventional sensor types by the UT alone was abandoned and a more pragmatic approach was decided: the odometer architecture would retain some conventional sensors, but remove the Doppler radars, whose maintenance costs and some reported availability problems were the first motivation for choosing this application.

The independent safety analysis carried out by Veritas showed that **the SIL level achieved by the GNSS User Terminal is SIL 2.**

SUGAST

This section corresponds to a summary of the outcomes of SUGAST WP5000 project carried out from [RD1] and [RD16].

The SUGAST project aimed at carrying on the standardization process already started for EGNOS and Galileo in key application areas. It was carried out from the 23rd March 2010 to the 30th June 2012. WP5000 general objectives were to improve the common understanding of Galileo use for safety related applications in railways and to provide technical support to standardisation of safety applications in ERTMS. In particular, the objective of WP5300 was to conduct technical studies to define the required GNSS performances for relevant Rail communities.

The main output of the WP consisted on deliverable D-5310, "Technical Note on GNSS performances for Rail" ([RD1]). The first draft of the D-5310 document started the definition of the minimum operating performance standard for the most promising Rail applications classified in different groups of applications which require similar performances. These performances are defined at Locator Unit (LU) level, that is, the minimum performances needed at the output of the LU to fulfill the application requirements. Therefore, performances for different classes of locator units suitable for each group of applications were proposed, based upon the previous experience and other R&D projects, trying to settle a guideline for the GNSS locator unit's designers.

SUGAST AIMED AT CARRYING ON THE STANDARDIZATION PROCESS ALREADY STARTED FOR EGNOS AND GALILEO.

The Technical Note (TN) contained, first, information and assumptions needed to understand the rationale for equipment characteristics and requirements stated throughout the document. It described typical GNSS-based application and operational goals including a brief description of the applications and an overview of the railway environments, from the points of view of both visibility and operation.

Then, the TN described different groups of GNSS based applications, classified according to their required performances. A quantitative summary of performances was set out in order to find similar characteristics which would lead to outline a group.

Different proposals for LU classes were described then, beginning with an overview of the different augmentation and hybridisation techniques which can be used to improve a LU. It also presented a selection of different groups of applications whose requirements could be fulfilled by the same LU, concluding with the proposed LU class for each of these selections.

Then, the general required performance for a LU was described, as well as the specific performances for each of the classes proposed in the previous section.

Finally, the document presented a proposal of roadmap that the document should follow to become a real standard.

The final version of D-5310 included tests data from previous experiments, i.e. RSSB Projects T510 and T892 and the GSA project GRAIL-2, to justify the performance characteristics in D-5310 regarding the locator unit classes developed there, either directly or by extrapolation.

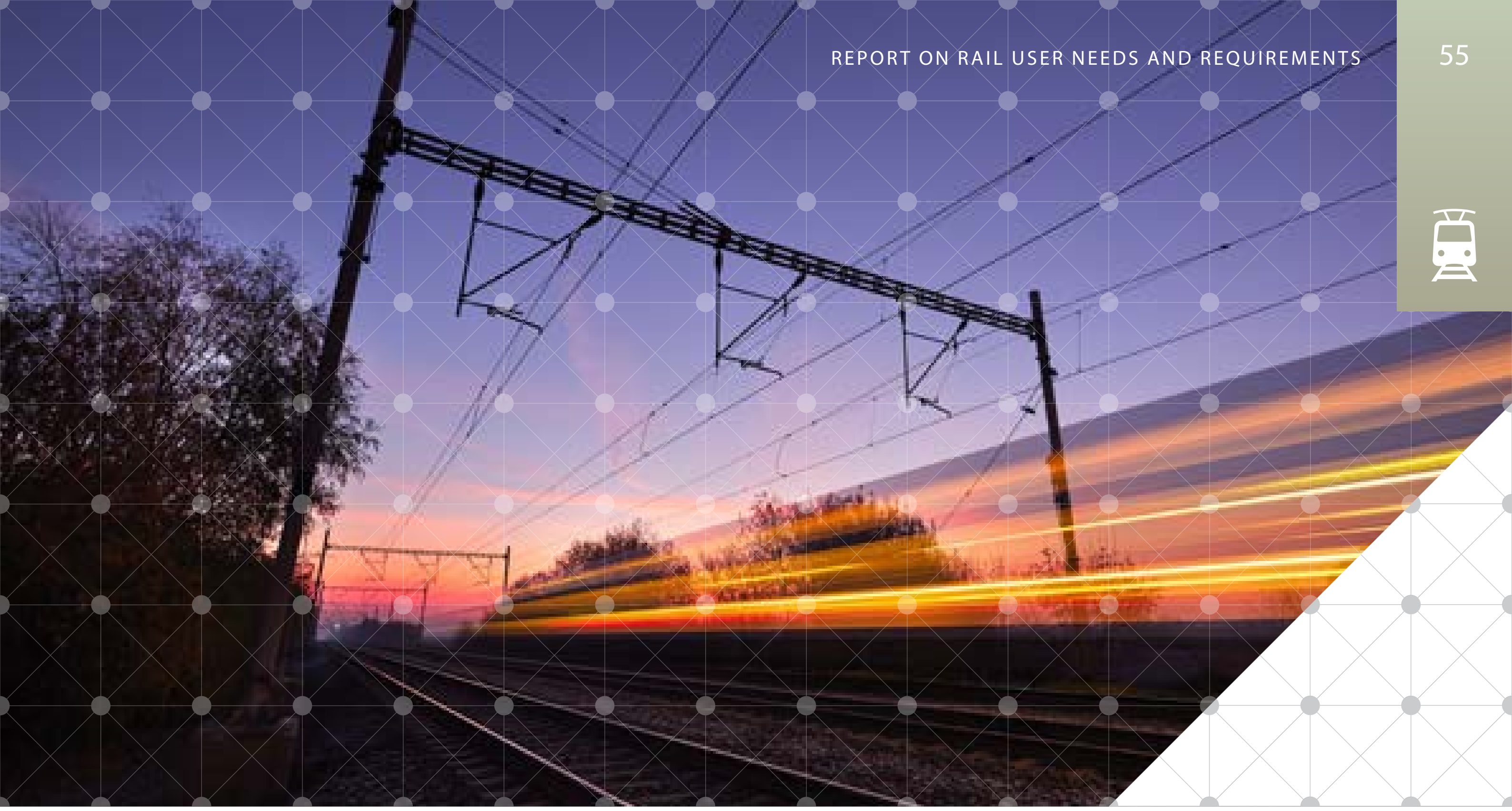
Rail Operational Environments

The performances of the applications can be affected by several factors, which some of the main important are cited below:

- Masking level
    - Open sky: 10° elevation has been used. This is a typical 'best practice' masking angle for many GNSS applications.
    - Medium masking: A variable mask scheme has been created that reflects a rail track environment with across-track masking of 30° and along-track of 10°.
    - High masking: In this case, the across-track masking is of 60° on both sides and the along-track masking is of 10°.
- Obscuration
- Multipath
- Alternative Path
- Interference

However, the environmental conditions also depend on several factors such as the line constructions and the intended features of the lines. This leads do the definition of two operational scenarios: Low Traffic Lines and High Speed Lines, which differ mainly in terms of block sections' needs, once both lines require high accuracy when approaching a danger point:

- Low Traffic Lines: A LDL is a national, regional or local line with low traffic: about 1 to 10 trains per day. Most of them are single tracks with no train detection system installed along the track, but side signaling could be installed. Telephone Block Systems are widespread in



this kind of lines, while ATP systems are not, due to the limited budget dedicated to these lines.

- High Speed Lines: High speed rail is a system of rolling stock and infrastructure which regularly operates at or above 200 or 250km/h. An important aspect of this environment is the use of continuous welded rail to reduce track vibrations and discrepancies between rail segments, which is very important to allow trains to pass at high speeds. Almost all of these lines are electrically driven via catenary and have in-cab signaling as well as no level crossings.

User Requirements

The table below describes the requirements needed for each Rail application.

Applications marked with "LE" are the ones which require very high accuracy services and almost all are extremely local. Besides, they all need coverage in adverse visibility environments.

The "DM" column refers to applications which require a Digital Map for their intended function.

Safety related applications need SoL services as shown in column "SoL". For the ERTMS, a SIL 4 is required while for safety related applications outside ERTMS the safety studies have not been carried out and no SIL has been yet determined. On the other hand, no SIL allocation is needed for non-safety applications (SIL 0).

The accuracy is expressed in "meters" reflecting the horizontal accuracy (including cross accuracy for some cases such as in the Train Awakening in order to differentiate parallel tracks) while the integrity is expressed in "seconds" reflecting the Time To Alarm needed. To be noted is that the integrity is also related to the Safety Integrity Level for safety related applications. On the other hand, there are some liability relevant applications which are not safety related (SIL 0) but need high integrity, so there is not direct relationship between the integrity and the SIL. Therefore TTA has been chosen to quantify the integrity requirement instead of SIL.

Then GNSS based applications were classified according to their required performances.

The groups are made based on the required performances needed by each application and performance requirements are expressed by the three standard Required Navigation Parameters, these are "accuracy", "integrity" and "availability" (please find the related definitions in section Annex 4 Error! Reference source not found.). In addition the need of using digital map, Local Elements (LE) and the SIL is indicated.

Table 30: SUGAST User Requirements

			Operational Environment	Horizontal Accuracy	
Safety Critical Applications	Train control and signaling applications	Enhanced odometry	HSL	High (5m + 5%s)	6 - 50m
			LDL	High (5m + 5%s)	6 - 50m
		Absolute positioning	HSL	High (block sections)	6 - 50m
				Very High (approaching a danger point)	1 - 5m
			LDL	Low (block sections)	6 - 50m
				Very High (approaching a danger point)	1 - 5m
		Train awakening	HSL	Very High (to distinguish between parallel tracks)	1 - 5m
			LDL	High (single track)	6 - 50m
		Cold movement detector	HSL	Very High (to differentiate between parallel tracks)	1 - 5m
			LDL	Low (single track)	> 50m
		Track identification	N/A	Very High	1 - 5m
		Level crossing protection	N/A	High	6 - 50m
		Train integrity and train lenght monitoring	HSL	High	6 - 50m
			LDL	Low	> 50m

Features and qualitative performances for applications

Integrity		Availability	LE	DM	SoL	SIL	Group
Very High	< 10s	High	No (TBC2)	No	Required	4	4
Very High	< 10s	High	No (TBC2)	No	Required	4	4
Very High	< 10s	High	Required (TBC)	Required	Required	4	4
Very High	< 10s	High	Required (TBC)	Required	Required	4	1
Very High	< 10s	High	Required (TBC)	Required	Required	4	4
Very High	< 10s	High	Required (TBC)	Required	Required	4	1
Very High	< 10s	High	Required	Required	Required	4	1
Very High	< 10s	High	Required	Required	Required	4	4
Very High	< 10s	High	Required	No	Required	4	1
Very High	< 10s	High	Required	No	Required	4	7
Very High	< 10s	High	Required	Required	Required	TBD	1
Very High	< 10s	High	No	Required	Required	4 (TBD)	4
Very High	< 10s	High	No	No	Required	4	4
Very High	< 10s	High	No	No	Required	4	7

			Operational Environment	Horizontal Accuracy	
Liability Critical Applications	Protection and emergency management systems	Trackside personal protection	N/A	High	6 - 50m
		Management of emergencies	N/A	Low	> 50m
		Train warning systems	N/A	High	6 - 50m
	Traffic management and information systems	Infrastructure charging	N/A	Low	> 50m
		Hazardous cargo monitoring	N/A	High	6 - 50m
		On-board train monitoring and recording unit	N/A	High	6 - 50m
		Traffic management systems (dispatching)	N/A	High	6 - 50m
	Asset tracking systems	Fleet management	N/A	Low	> 50m
		Cargo condition monitoring	N/A	Low	> 50m
		Multi-modal terminal management	N/A	High	6 - 50m
	On-board information systems	Energy efficiency	N/A	Low	> 50m
		Energy charging	N/A	Low	> 50m
	Infrastructure management and operations	Infrastructure data collection	N/A	High	6 - 50m
		Digital map creation	N/A	Very High	1 - 5m
		Structural monitoring	N/A	Very High	1 - 5m

Features and qualitative performances for applications

Integrity		Availability	LE	DM	SoL	SIL	Group
Very High	< 10s	High	No (TBC)	No	Required	TBD	4
High	10 - 30s	High	No	No	Required	TBD	8
High	10 - 30s	High	No	No	Required	TBD	5
Low	> 30s	High	No	No	No	0	9
High	10 - 30s	High	No	No	Required	TBD	5
High	10 - 30s	High	No	No	No	0	5
High	10 - 30s	High	No	No	No	0	5
Low	> 30s	High	No	No	No	0	9
Low	> 30s	High	No	No	No	0	9
High (transaction)	10 - 30s	High	No	No	No	0	5
Low	> 30s	Low	No	No	No	0	9
Low	> 30s	High	No	No	No	0	9
Low	> 30s	Low	No (TBC)	No	No	0	6
High	10 - 30s	Low	Required	No	No	4 (TBC)	2
Low	> 30s	Low	Required	Required	No	0	3

It is, therefore, possible to define 9 groups of applications with similar requirements for horizontal accuracy and integrity:

- Group 1 requires very high accuracy in order to distinguish between parallel tracks or to approach the Danger Point at the appropriate speed. Techniques to assure availability over large coverage areas (rail networks) are required. All applications require a digital map to operate properly and need very high integrity as they are all SIL 4 applications.
- Groups 2 and 3 do not require high availability. They present very high horizontal accuracy requirement but not very high integrity, since they are not SoL applications.
- The difference between groups 4 and 7 is that for LDL the accuracy needed in block sections is less demanding than in HSL. Both groups required very high integrity since a non-detected failure may lead to a catastrophic accident.
- Groups 5, 6 and 8 do not require very high integrity nor accuracy.
- Applications in Group 9 are non-safety related applications and are the less demanding applications in terms of accuracy and integrity. No digital map needed although route and/or network data may be required.

Comment:

- Applications highlighted in green do not require high availability.
- The use of a Digital Map is essential to perform the applications highlighted in orange. A DM is used to translate absolute coordinates and to provide location infrastructure data, for example.

From these groups, a selection can be made grouping applications with similar performances needed for the definition of reference locator units (see Annex 3):

Class A: Applications in **Group 1** are the most demanding in terms of accuracy and integrity. This group includes applications in frame of ERTMS, which require that the data coming from the receiver is processed and in the adequate

Table 31: SUGAST Application Groups

	Integrity Requirement (TTA)		
Horizontal Accuracy Requirement	**Very High (<10s)**	**High (10-30s)**	**Low (>30s)**
Very High (1-5m)	**GROUP 1** Train Awakening (HSL) Cold Movement Detector (HSL) Track Identification Absolute Positioning (approach to danger point)[1]	**GROUP 2** Digital Map Creation[2]	**GROUP 3** Structural Monitoring[2]
High (6-50m)	**GROUP 4** Train Awakening (single LDL) Enhanced Odometry Absolute Positioning Train Integrity and Train Length Monitoring (HSL) Level Crossing Protection Trackside Personnel Protection	**GROUP 5** Train Warning Systems Hazardous Cargo Monitoring Traffic Management System (Dispatching) Multimodal Terminal Management On-board Train Monitoring and Recording Unit	**GROUP 6** Infrastructure Data Collection
Low (>50m)	**GROUP 7** Train Integrity and Train Length Monitoring (LDL) Cold Movement Detector (LDL)	**GROUP 8** Management of Emergencies	**GROUP 9** Infrastructure Charging Cargo Condition Monitoring Fleet Management Energy Efficiency Energy Charging

1 No relocation balises are installed in the line (See section 1.5.1.1.2)
2 No Locator Unit will be defined for this application because is offline and no continuity is needed.

format to be used as input to the on-board / trackside system. Therefore it is recommended to search a specific LU able to accomplish these specific requirements.

Class B: Groups 4 and 7 also include some applications in frame of ERTMS and hence require very high integrity since the applications considered are safety relevant. However, the accuracy requirement is more relaxed than for group 1 applications. A LU designed satisfying the needs of Group 4 will also meet the needs of Group 7 since both of them have the same integrity requirement and that is what is going to determine the kind of augmentations and hybridizations needed.

Class C: Groups 5, 6 and 8 do not include any applications in frame of ERTMS, but it has to be noted that the integrity required in some cases is high as well as the accuracy. It is worth proposing a LU which meets the requirements of Group 5 so it also may be used for applications in Group 6 and 8.

Class D: Finally, the least demanding applications in terms of integrity and accuracy are contained in Group 9, so the simplest and at the same time the cheaper LU could be thought to meet the needs of this group.

Analysis of SUGAST user requirements

User requirements expressed in SUGAST project are still qualitative requirements or requirements expressed by range of value. However they constitute a very relevant basis to progress.

Table 32: Locator Units Functions and Performances

	Locator Unit Class A	Locator Unit Class B	Locator Unit Class C	Locator Unit Class D
Functions	• Provide valid position to the train when the stored position is invalid or unknown • Detect train movement when ETCS on-board equipment is powered off • RBC ID • Compute PVT • Train orientation • Standstill (absence of movement) • Translation of coordinates • Absolute Positioning Reference Point (APRP) • Track ID • DM manage	• Provide valid position to the train when the stored position is invalid or unknown • Detect train movement when ETCS on-board equipment is powered off • RBC ID • Compute PVT • Train orientation • Standstill (absence of movement) • Translation of coordinates • Absolute Positioning Reference Point (APRP) • Train Integrity status • Train length confirmation • Level Crossing status (ID, distance to level crossing) • Generate flags/ alarm (optional) • DM manage (if needed)	• Provide PVT • Generate flags/alarm (optional)	• Provide PVT
I/F	PROFIBUS	PROFIBUS	TBD	TBD
Horizontal accuracy	1m	10m	25m	50m
AL	2,5m	25m	62,5m	125m
SIL	4	4	TBD	0
Availability	99,98%	99,98%	99%	95%
TTFF	120s	120s	TBD	TBD
TTA	<7s	<7s	<20s	<30s

The application groups were made based on the required performances needed by each application and performance requirements are expressed by the three standard Required Navigation Parameters, these are "accuracy", "integrity" and "availability" – which include GNSS parameters relevant and impacting to the fail-safe design in compliance with the railway principles and standards. Their definitions are given here after.

Besides, the link between GNSS performance requirements and Rail performance requirements is clearly stated.

Accuracy is a statistical value and is defined as the degree of conformance between the measured position and its true position, at a given level of confidence, at any given instant in time, and at any location in the coverage area. When specifying accuracy it is essential to specify the statistical context, which is usually assumed to be Gaussian. It is usually expressed as a confidence interval which is associated to probability (confidence level, K). In SUGAST document, the accuracy is specified as the position error at 95%.

According to EN 50126 [RD24] **availability** is the ability of a product to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided.

In SUGAST document the **availability** is defined as the intrinsic availability of location information fulfilling its performance requirements at the LU output. In the current circumstances when the relative unavailability of Signal in Space (SiS) owing to limited visibility shall be accepted as a natural condition for designing a Location Unit with a highly-available positioning output at all locations - so for highly-demanding applications, lack of SiS shall not be a cause of non-availability.

Integrity relates to the trust that can be placed in the correctness of the information supplied by the Location Unit to the application. Integrity is defined here as the ability of the GNSS LU equipment to provide timely warnings to the user when data provided by the system should not be used. It is a measure that is applied only when the application is safety-related or safety relevant. Integrity is described by three parameters:

- **Alert Limit** (AL): Maximum allowable error in the estimated position, measured by integrity monitoring, before an alarm is triggered. The value is greater than the nominal accuracy required of the LU to avoid excessive false alarms. A factor of 2.5 times required accuracy in normally set by GNSS system designers.
- **Time To Alert (TTA):** Maximum time allowable between the occurrence of the failure in the User Terminal and its presentation to the user. The failure can be due to an excessive inaccuracy being detected (see alert limit) or that a particular satellite is untrustworthy.
- **Integrity Risk:** Appears when location is out of tolerance limit (false), but the LU reports "information available" and no "alarm" is triggered within the time to alarm.
  - For safety applications the integrity risk can be described by the tolerable hazard rate which is derived from a risk analysis of the application. A Safety Integrity Level shall be then allocated to the LU according to the application.
  - The integrity risk of the GNSS LU is strongly dependent on implementation. GNSS System and GNSS Receiver are only two of the components whose integrity risk contributes to the Global LU integrity risk value.

OTHER PROJECTS

The following table gathers together a number of EU projects related to GNSS Rail applications.

Table 33: EU Project related to GNSS application in Railways

2019 update

Project Name	Start	End	Funding	Comments
Gate4Rail	2018	2020	Shift2Rail	GNSS Automated Virtualized Test Environment for Rail
CAPRESE	2018	2020	ESA	Assess, design and test techniques for improving the robustness of carrier phase measurements for use in GNSS positioning for virtual balise detection in the European Rail Traffic Management System (ERTMS).
STEMS	2018	2020	ESA	Suitability of SBAS corrections for the use in ERTMS system
ASTRAIL	2017	2019	Shift2Rail	Applicability of requirements and solution from the aviation domain to the railway sector, with a particular focus on the application of Fail-Safe train positioning to moving block signaling. Definition of a possible GNSS architecture

Project Name	Start	End	Funding	Comments
X2Rail2	2017	2020	Shift2Rail	Development of an absolute and safe train positioning system based on a multi-sensor concept, where GNSS is the preferred technology.
ERSAT GGC	2017	2019	H2020	Certify EGNSS resources according to the ERTMS standard Methodology for characterization of GNSS reception along a line
DB4Rail	2016	2018	ESA	DB4Rail (Digital Beamforming for Rail), consists to develop of a digital platform for rejecting GNSS interference signals, jamming and spoofing / meaconing, by a conventional array antenna to be used to support evolution GNSS based LDS in ERTMS / ETCS
STARS	2015	2018	H2020	Characterization of GNSS local effects represented in rail environment
EGNOS for rail (E4R)	2015	2015	France	Feasibility study by Railenium for SNCF
ERSAT EAV	2015	2017	H2020	GNSS in ERTMS
SBS RAILS	2014		ESA	Feasibility Study is to determine the technical feasibility and economic viability of an integrated satellite navigation and satellite communication solution complementing the European Rail Traffic Management System (ERTMS)
SafeRail	2013	2015	ESA ARTES 20 IAP	Satellite based train positioning system which enables continuous train detection and safe operation of level crossings Technical feasibility and business viability
LeCross	2013	2014	ESA ARTES 20 IAP	Feasibility of an integrated service solution to improve the safety at railway level crossings by supporting prevention of accidents and improving emergency operations.
EATS	2012	2016	FP7	Smart Train Positioning System (STPS) Concept - Low cost ETCS
GaLoROI	2012	2015	FP7	Development of a eddy current GNSS Unit
SATLOC	2012	2014	FP7	Development of a reliable and competitive satellite-based rail transport operation and management system for low-traffic rail lines
3inSat/ ERSAT	2012	2014	ESA	Development and Validation of a new satellite-based platform (both for navigation and communications) suitable for the Train Control and Management System
TR@IN-MD	2006	2009	France, ANR	Dangerous Goods survey
LOCASYS	2006	2009	UK	Dependability
GIRASOLE			FP6	Receiver Safety Of Life
M-TRADE	2005	2007	FP6	Multimodal Transport
GEORAIL	2004		UIC	
ECORAIL	2001	2005	ESA	Safe use of EGNOS for level crossing protection
GADEROS	2001	2004	FP5	Demonstration of the use of GNSS integrity and SoL characteristics for defining a satellite-based system to perform train location for safe railway applications
LOCOPROL	2001	2004	FP5	Definition of a low-cost satellite-based train location solution for low traffic lines
LOCOLOC			Belgium	Complementary activity to LOCOPROL
INTEGRAIL	2001	2004		EGNOS in ERTMS, multi-sensors system
APOLO	1999	2001		Train location system using GNSS and other sensors to facilitate improvements in supervision systems for dispatchers and to support signalling systems for low traffic lines

ANNEX 2: CURRENT INITIATIVES REGARDING GNSS REQUIREMENTS IN RAIL

It can be expected that NGTC project and Shift2Rail are going to contribute in a significant way in the definition of user requirements for safety relevant applications such as ATP. This section introduces both initiatives.

NGTC

NGTC Overview

New Generation of Train Control project (NGTC) is a 7th Framework programme project (DG RTD) and correspond to the pilot project of Shift2Rail.

- Duration: September 2013 – August 2016 (36 months)
- Budget: 10.9 M EUR (EC funding: 6.4 M EUR)
- Coordinator: UNIFE

- Partners: Alstom Belgium, Ansaldo STS, AŽD Praha, Bombardier Transportation Sweden, CAF Signalling, D'Appolonia, ERTMS Users Group, Ineco, London Underground, NAVECOM, RATP, Siemens AG Germany, Siemens Rail Automation – Spain, SNCF, Technische Universitat Dresden, THALES Canada, THALES Communications & Security – France, THALES Transportation Systems – Germany, TMB, UITP

NGTC objective was to develop specifications for train control systems for urban and mainline domains, by evolving ETCS functionality based on CBTC system solutions in order to achieve maximum synergies towards a single scalable system. The intention was to provide interoperability and interchangeability based on standardised interfaces for the entire rail spectrum from urban to high-speed applications, even in the case where interoperability between networks is not needed.

GNSS in NGTC "WP7: Satellite positioning"

The NGTC project included research work on the further development of standardized satellite positioning functionality on Railway applications.

The objectives of NGTC WP7 were:

- to define standardized procedures for GNSS signals quality determination in railway environment,
- to perform safety analyses on potential impact of satellite navigation.

NGTC WP7 results are:

- Engineering rules and test specifications to ensure interoperable use of satellite positioning functionality.
- Technical analysis of the possible architectures, including interoperable interfaces.

NGTC Partners involved in WP7 were: UNISIG Members [Alstom, AnsaldoSTS, AZD, Bombardier, CAF, Siemens, Thales Transportation Systems], Dimetronic, INECO and D'Appolonia (engineering consultancy)

Table 34: NGTC WP7 Deliverables

Reference	Deliverable
D7.1	Report about current GNSS performances in railway environment and impact analysis of GNSS performances on virtual balise functionality and on possible functional architectures
D7.2	Definition and quantification of the GNSS parameters to be measured in railway environment
D7.3	Specification about standard process for measurement of the coverage and the accuracy delivered by GNSS
D7.4	Engineering rules specification
D7.5	Database Operational Management specification
D7.6	Study about other applications of satellite positioning functionality, e.g. train integrity, cold movement
D7.7	Results of the safety analysis (Restricted access)

SHIFT2RAIL INITIATIVE

Shift2Rail Overview

The Shift2Rail Joint Undertaking[5] (the S2R JU) - set up under the Horizon 2020 Framework Programme – is a public-private partnership in the rail sector, providing a platform for the rail sector to work together with a view to driving innovation in the years to come. The Council Regulation No 642/2014 establishing the Shift2Rail Joint Undertaking came into force on 16 June 2014 ([RD9]).

Activities focus around five key areas, corresponding to the five "Innovation Programmes" defined in the Regulation:

- IP1: developing a new generation of high-quality reliable rolling stock that substantially reduces the cost of rail services, drastically improves the quality of rail services and facilitates the use of trains throughout various Member States;
- IP2: developing intelligent traffic management and control systems, beyond signalling, building on current ERTMS, to optimise capacity, reliability and minimise life-cycle cost;
- IP3: delivering a new railway infrastructure system that will radically improve capacity and performance and reduce costs related to development, maintenance and renewals;
- IP4: developing innovative IT solutions and services to make railway services more attractive;
- IP5: developing sustainable and attractive freight solutions, helping rail to enter into new market segments and become an integrated part of advanced logistic solutions.

The S2R Joint Undertaking shall seek to develop, integrate, demonstrate and validate innovative technologies and solutions that uphold the strictest safety standards.

5 http://europa.eu/rapid/press-release_MEMO-13-1143_en.htm

Shift2Rail Members

There are two Shift2Rail membership categories:

- Founding Members:
  - Industry: Alstom, Ansaldo STS, Bombardier, Construcciones Y Auxiliar De Ferrocarriles (CAF), Siemens, Thales
  - Rail Undertaking, Infrastructure Managers: Network Rail, Trafikverket
- Associated Members:
  - AERFITEC, Amadeus, AZD Praha, CFW, Deutsche Bahn, DIGINEXT, EUROC, Faiveley, HaCon, Indra, Kapsch, Knor-Bremse, Mermec, Smart Demain, SmartRaCon, SNCF, Swi'Tracken, Talgo, VVAC+.

GNSS in Shift2Rail "IP2"

Research and demonstration activities within IP2 focus on the different areas and activities, including ([RD11]):

- Develop a fail-safe, multi-sensors train positioning system (e.g. by applying in demonstrator GNSS to the ERTMS/ETCS core),
- boosting the quality of train localisation and integrity information while reducing the overall cost, namely by enabling a significant reduction in all track-side conventional train detection systems (balises, track circuits, axle counters, etc.).

Shift2Rail IP2 leader is AnsaldoSTS.

The European Railway Agency, the ERTMS User Group and UNISIG are the key entities involved to ensure that innovative solutions developed in Shift2Rail are compatible with ERTMS.

In September 2017, the X2Rail2 project started. Its WP3 focuses on the development of a fail-safe train positioning system; leaded by Ansaldo. In parallel, as a result of the Open Call, the ASTRail project started, leaded by ISMB.

ANNEX 3: SUGAST LOCATOR UNITS

Three kinds of GNSS augmentation are considered:

- **Regional** augmentation, which uses SBAS such as EGNOS;
- **Local** augmentation, through GBAS (DGPS + pseudo-lites);
- **Onboard** augmentation called RAIM (Receiver Autonomous Integrity Monitoring) which takes place inside the LU and uses measurements from redundant GNSS satellites to detect faults.

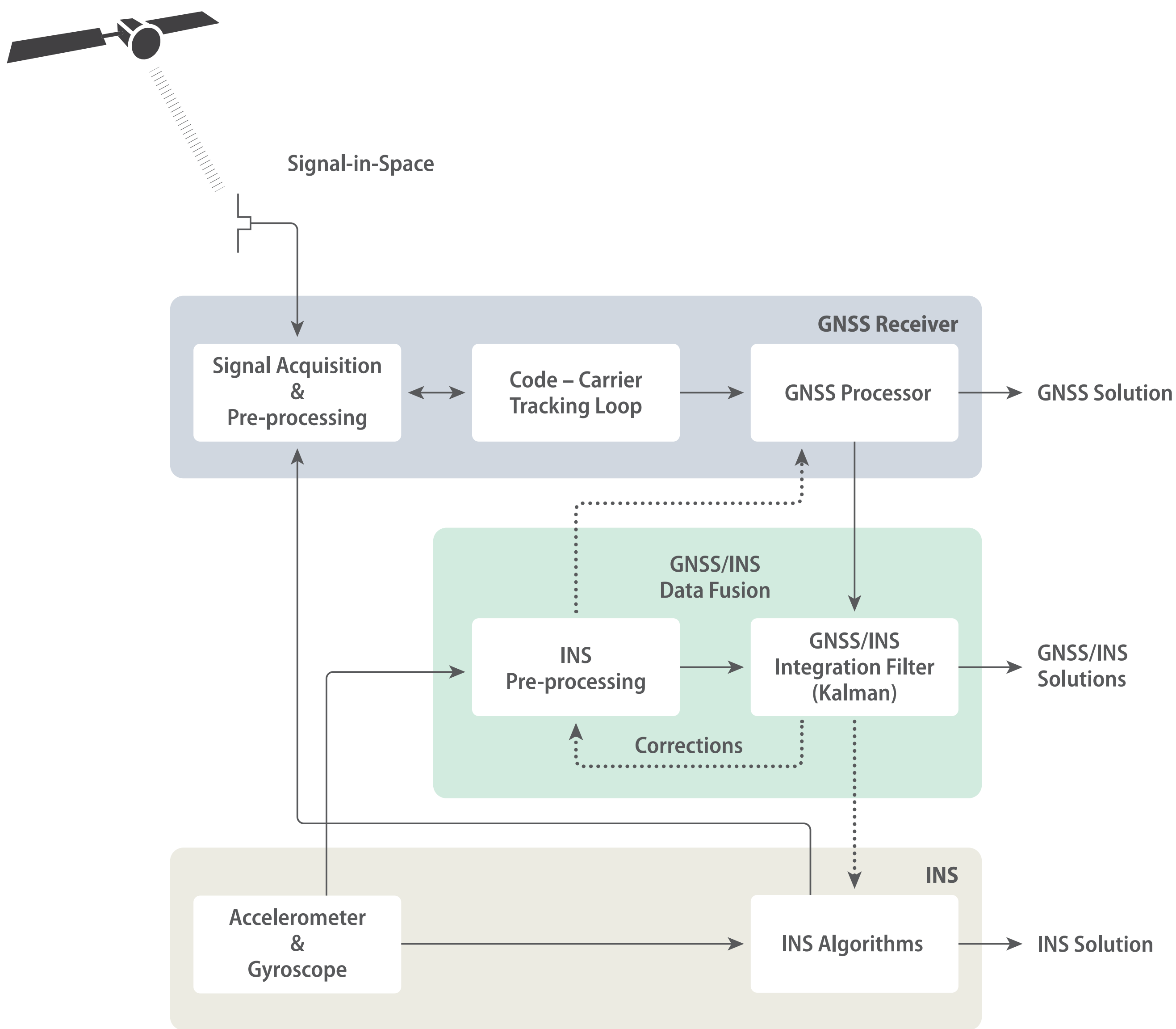
The introduction of satellite systems can significantly reduce investments and operational costs, while significantly contributing to railway safety. In this context, awareness of the potential and schedules of GNSS is still needed.

There are three coupling schemes considered for **hybridization:**

- **Loosely coupling scheme:**

In this scheme INS and GNSS solutions are redundant and independent, what gives a faster acquisition of code and carrier phase, improved navigation performance and better calibration and alignment, resulting in improved navigation accuracy during jamming or satellite loss.

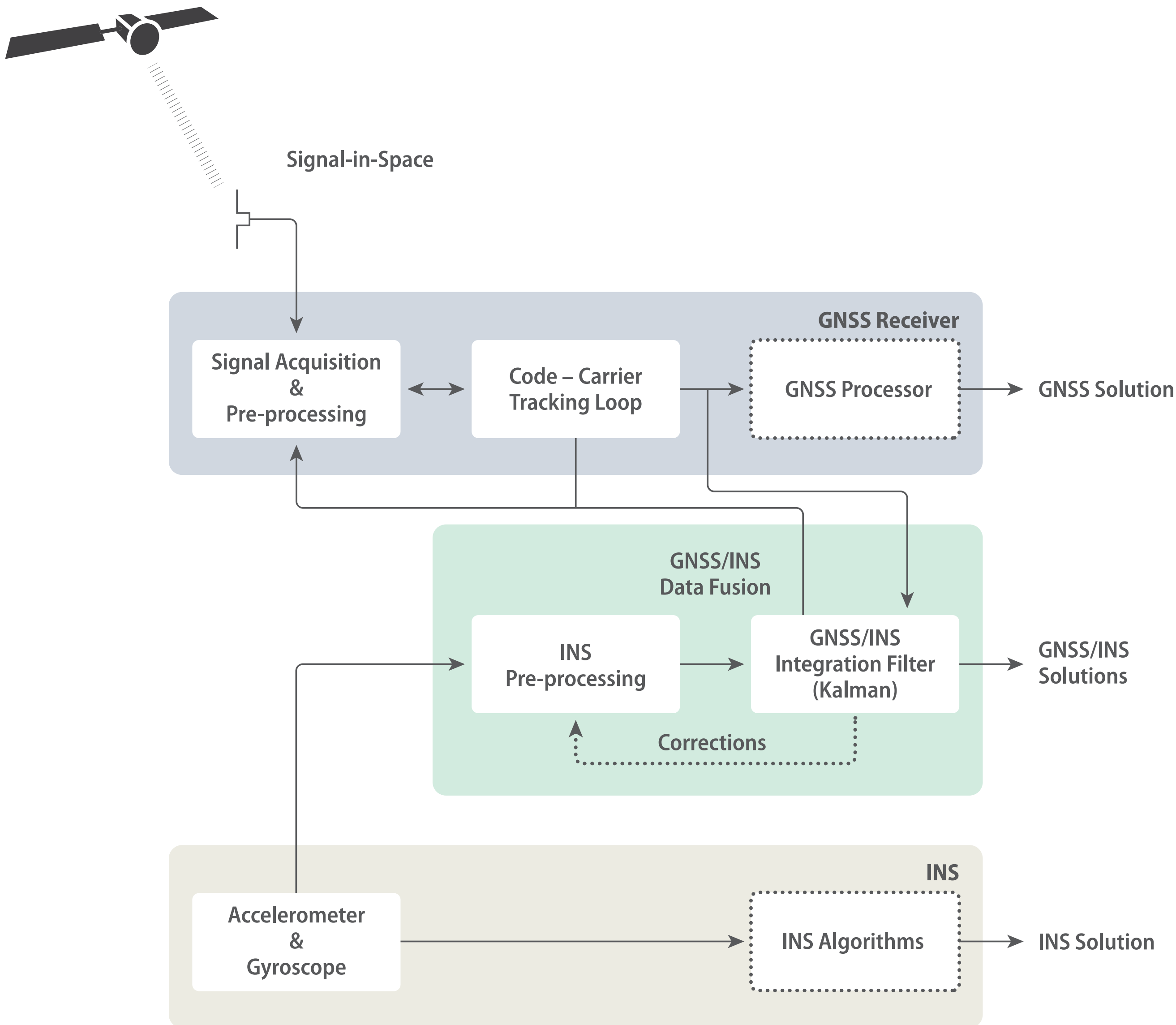
Figure 6: Loosely coupling scheme



- **Tightly coupling scheme:**

While this scheme loses redundancy, it provides more accurate results than the loosely coupled or the separate architectures. It is capable of providing a navigation solution even with less than four satellites, due to its integration filter and has increased jamming resistance.

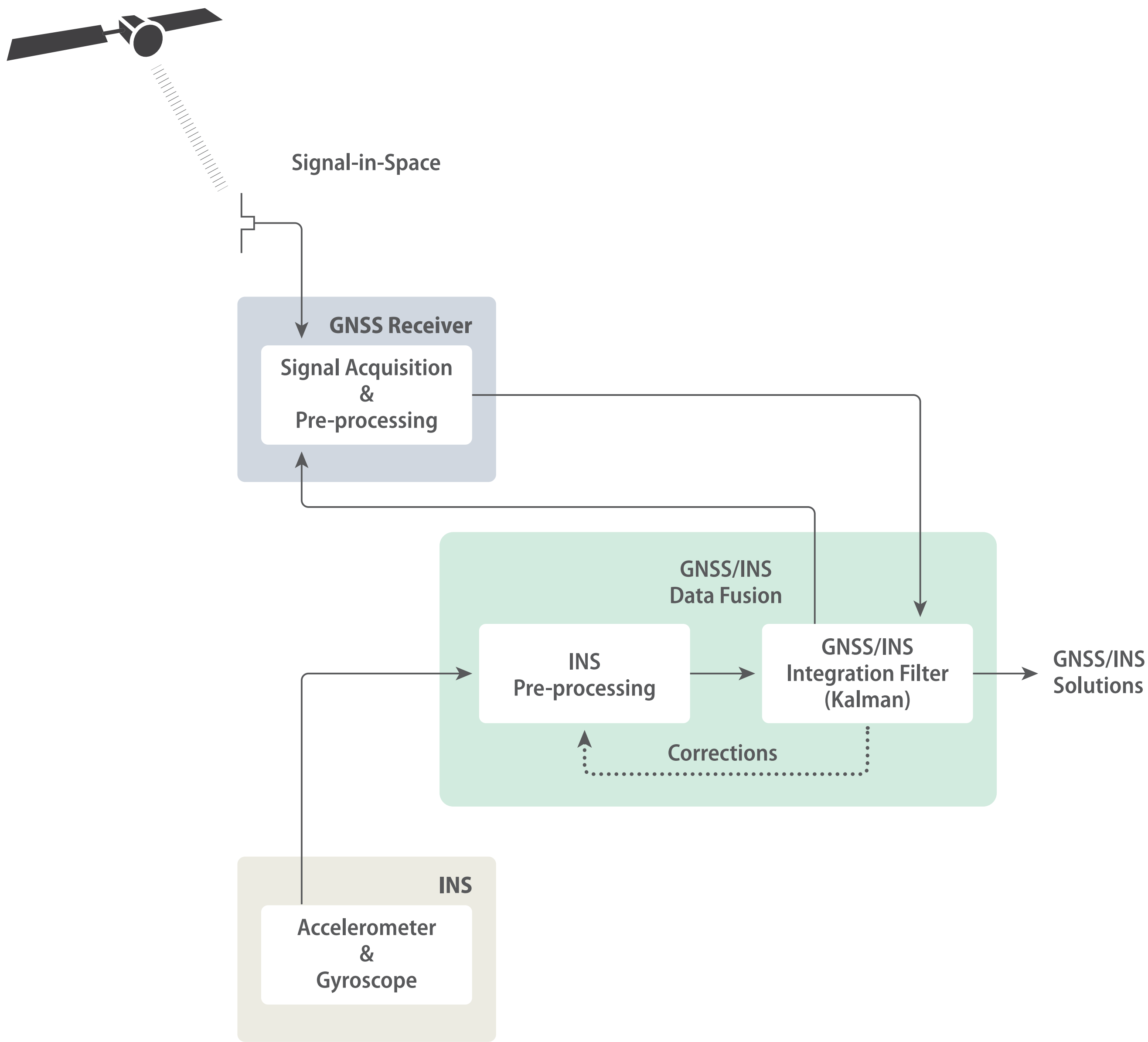
Figure 7: Tightly coupling scheme



- **Ultra-tightly coupling scheme:**

This scheme loses in independency to avoid correlation between GNSS receiver and INS errors, and therefore, obtain more accurate measurements. It is also more complex and presents immunity enhancement to interference and jamming.

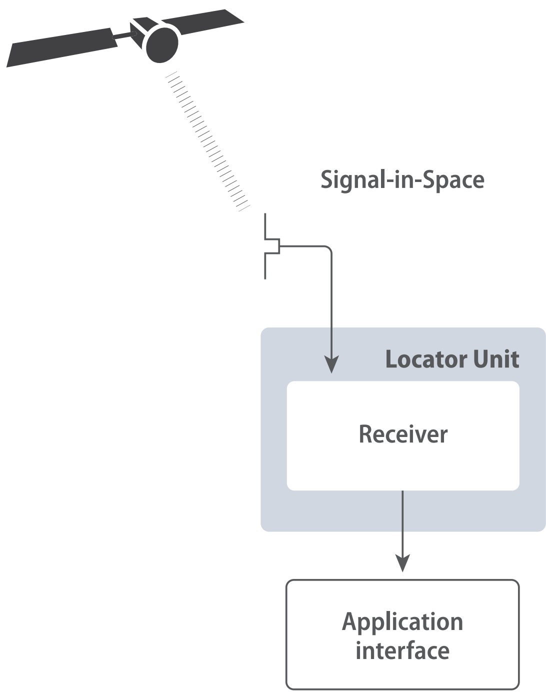
Figure 8: Ultra-tightly coupling scheme



Locator Unit Class D

This is the simplest solution, but it does not fit all applications. In this Locator Unit, the receiver works alone with the antenna on the roof, with neither augmentation nor hybridisation. This model assumes discontinuity in SiS and provides low accuracy and low integrity. However, it is the solution currently in use for fleet management and the best suited for other non-safety applications such as Infrastructure Charging, Cargo Condition Monitoring, Fleet Management, Energy Efficiency and Energy Charging. This Locator Unit provides Position, Speed and Time information.

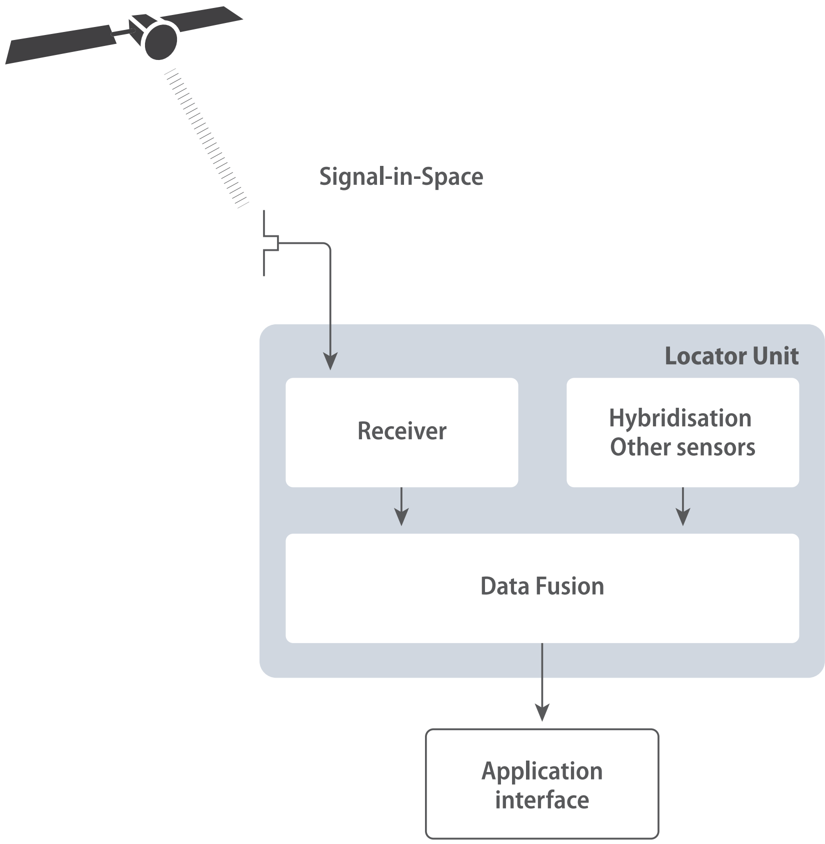
Figure 9: Locator Unit Class D



Locator Unit Class C

This receiver is composed by the antenna placed on the roof, presenting also hybridization with other sensors, in order to increase service availability while providing position, speed and time. . When the SiS is obscured, the system can use information from the INS, and if the latter is also unavailable, there is still the possibility of using the tachometer. The better receiver associated with hybridization techniques also improves accuracy and integrity.

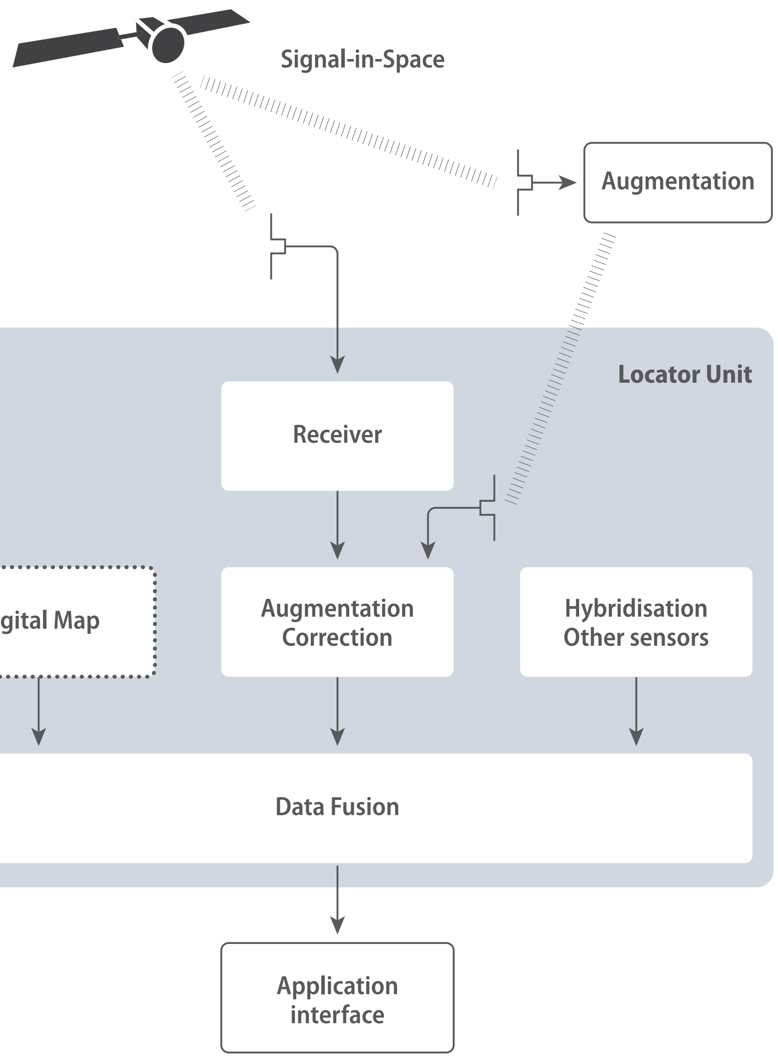
Figure 10: Locator Unit Class C



Locator Unit Class B

As addition to the receiver, the antenna on the roof and the hybridisation with other sensors, this locator unit also presents augmentation chosen according to specific values of accuracy and integrity in order to provide very high integrity. There is the possibility of using 2 antennas and 2 receivers to provide availability and train orientation. The use of a Digital Map is optional. This Locator Unit provides not only position, speed ant time data, but also confidence levels, making it applicable to safety applications such as Train Awakening (for single LDL), Enhanced Odometry, Absolute Positioning (block sections), Train Integrity and Train Length Monitoring, Level Crossing Protection, Trackside Personnel Protection and Cold Movement Detector (LDL).

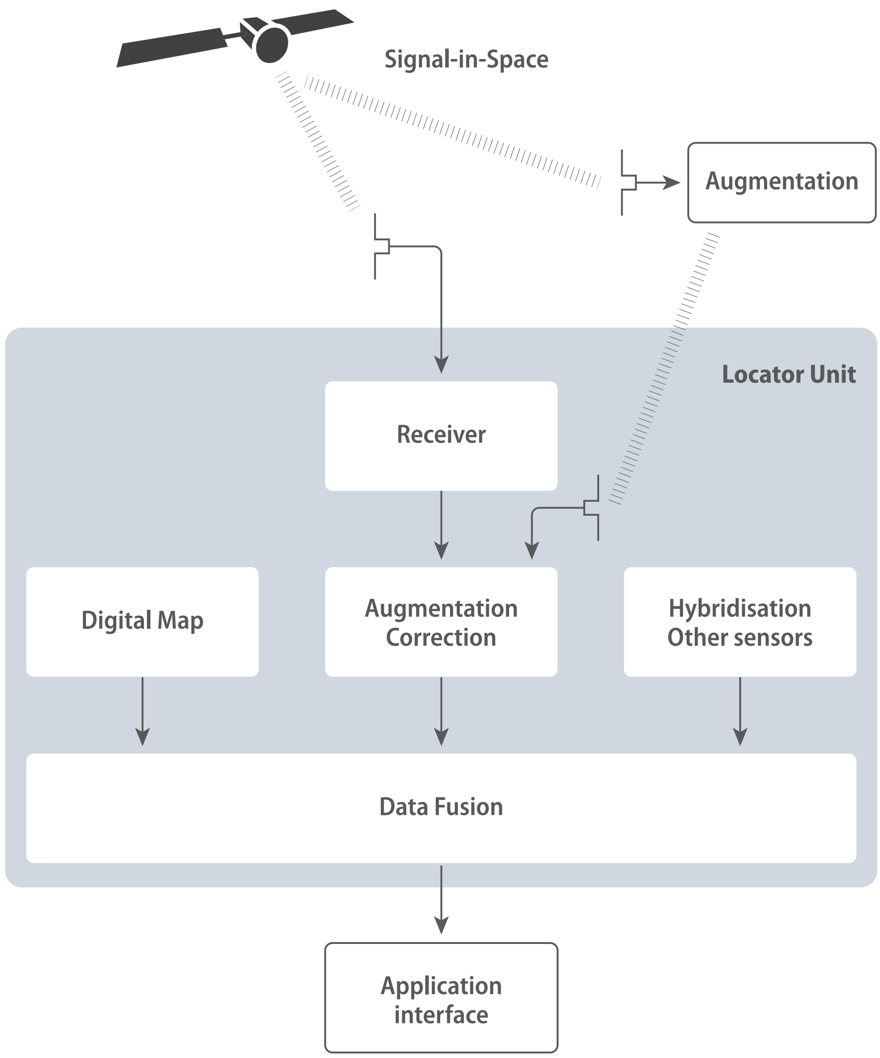
Figure 11: Locator Unit Class B



Locator Unit Class A

This is the most complete class of Locator Units: it counts with a receiver, an antenna on the roof, hybridisation with other sensors, augmentation and a Digital Map. It is possible to use 2 antennas and 2 receivers in order to provide availability (through the use of different GNSS signal frequencies or constellations) and train orientation. Augmentation is chosen depending on specific values of accuracy and integrity, making it capable to provide very high integrity and accuracy. This receiver provides position, speed, time and confidence levels for the most stringent safety applications such as: Train Awakening (for HSL), Cold Movement Detector (for HSL), Track Identification and Absolute Positioning even when approaching a danger point.

Figure 12: Locator Unit Class A



Applications and Locator Units Mapping

Table 35: SUGAST – Applications and Locator Units Mapping

			Performance Requirements for different LU Classes							
			LU Class	I/F	Horizontal Accuracy	AL	SIL	Availability	TTFF	TTA
Safety Critical Applications	Train control and signaling applications	Enhanced odometry	B	PROFIBUS	10m	25m	4	99.98%	120s	< 7s
			B	PROFIBUS	10m	25m	4	99.98%	120s	< 7s
		Absolute positioning	B	PROFIBUS	10m	25m	4	99.98%	120s	< 7s
			A	PROFIBUS	1m	2,5m	4	99.98%	120s	< 7s
			B	PROFIBUS	10m	25m	4	99.98%	120s	< 7s
			A	PROFIBUS	1m	2,5m	4	99.98%	120s	< 7s
		Train awakening	A	PROFIBUS	1m	2,5m	4	99.98%	120s	< 7s
			B	PROFIBUS	10m	25m	4	99.98%	120s	< 7s
		Cold movement detector	A	PROFIBUS	1m	2,5m	4	99.98%	120s	< 7s
			B	PROFIBUS	10m	25m	4	99.98%	120s	< 7s
		Track identification	A	PROFIBUS	1m	2,5m	4	99.98%	120s	< 7s
		Level crossing protection	B	PROFIBUS	10m	25m	4	99.98%	120s	< 7s
		Train integrity and train lenght monitoring	B	PROFIBUS	10m	25m	4	99.98%	120s	< 7s
			B	PROFIBUS	10m	25m	4	99.98%	120s	< 7s
Liability Critical Applications	Protection and emergency management systems	Trackside personal protection	B	PROFIBUS	10m	25m	4	99.98%	120s	< 7s
		Management of emergencies	C	TBD	25m	62,5m	TBD	99%	TBD	< 20s
		Train warning systems	C	TBD	25m	62,5m	TBD	99%	TBD	< 20s
	Traffic management and information systems	Infrastructure charging	D	TBD	50m	125m	0	95%	TBD	< 30s
		Hazardous cargo monitoring	C	TBD	25m	62,5m	TBD	99%	TBD	< 20s
		On-board train monitoring and recording unit	C	TBD	25m	62,5m	TBD	99%	TBD	< 20s
		Traffic management systems (dispatching)	C	TBD	25m	62,5m	TBD	99%	TBD	< 20s

			Performance Requirements for different LU Classes							
			LU Class	I/F	Horizontal Accuracy	AL	SIL	Availability	TTFF	TTA
Liability Critical Applications	Asset tracking systems	Fleet management	D	TBD	50m	125m	0	95%	TBD	< 30s
		Cargo condition monitoring	D	TBD	50m	125m	0	95%	TBD	< 30s
		Multi-modal terminal management	D	TBD	25m	62,5m	TBD	99%	TBD	< 20s
	On-board information systems	Energy efficiency	D	TBD	50m	125m	0	95%	TBD	< 30s
		Energy charging	D	TBD	50m	125m	0	95%	TBD	< 30s
	Infrastructure management and operations	Infrastructure data collection	C	TBD	25m	62,5m	TBD	99%	TBD	< 20s
		Digital map creation	N/A	-	-	-	-	-	-	-
		Structural monitoring	N/A	-	-	-	-	-	-	-

ANNEX 4: DEFINITION OF KEY GNSS PERFORMANCE PARAMETERS

This Annex provides a definition of the most commonly used GNSS performance parameters based on [RD30] and is not specifically focusing on the Rail community.

Availability: the percentage of time the position, navigation or timing solution can be computed by the user. Values vary greatly according to the specific application and services used, but typically range from 95-99.9%. There are two classes of availability:

- **System:** the percentage of time the system allows the user to compute a position – this is what GNSS Interface Control Documents (ICDs) refer to;
- **Overall:** takes into account the receiver performance and the user's environment (for example if they are subject to shadowing).

Accuracy: the difference between true and computed position (absolute positioning). This is expressed as the value within which a specified proportion of samples would fall if measured. Typical values for accuracy range from tens of meters to centimeters for 95% of samples. Accuracy is typically stated as 2D (horizontal), 3D (horizontal and height) or time.

Continuity: ability to provide the required performance during an operation without interruption, once the operation has started. Continuity is usually expressed as the risk of a discontinuity and depends entirely on the timeframe of the application (e.g. an application that requires 10 minutes of uninterrupted service has a different continuity figure than one requiring two hours of uninterrupted service, even if using the same receiver and services). A typical value is 1x10-4 over the course of the procedure where the system is in use.

Integrity: the measure of trust that can be placed in the correctness of the position or time estimate provided by the receiver. This is usually expressed as the probability of a user being exposed to an error larger than alert limits without warning. The way integrity is ensured and assessed, and the means of delivering integrity related information to the user are highly application dependent. For safety-of-life-critical applications such as passenger transportation, the "integrity concept" is generally mature, and integrity can be described by a set of precisely defined and measurable parameters. This is particularly true for civil aviation. For less critical or emerging applications, however, the situation is different, with an acknowledged need of integrity but no unified way of quantifying or satisfying it. Throughout this report, "integrity" is to be understood at large, i.e. not restricted to safety-critical or civil aviation definitions but also encompassing concepts of quality assurance/quality control as used by other applications and sectors.

Robustness to spoofing and jamming: robustness is a qualitative, rather than quantitative, parameter that depends on the type of attack or interference the receiver is capable of mitigating. It can include authentication information to ensure users that the signal comes from a valid source (enabling sensitive applications).

Note: for some users robustness may have a different meaning, such as the ability of the solution to respond following a severe shadowing event. For the purpose of this document, robustness is defined as the ability of the solution to mitigate interference or spoofing.

Indoor penetration: ability of a signal to penetrate inside buildings (e.g. through windows). Indoor penetration does not have an agreed or typical means for expression. In GNSS, this parameter is dictated by the sensitivity of the receiver, whereas for other positioning technologies there are vastly different factors that determine performance (for example, availability of Wi-Fi base stations for Wi-Fi-based positioning).

Time To First Fix (TTFF): a measure of a receiver's performance covering the time between activation and output of a position within the required accuracy bounds. Activation means subtly different things depending on the status of the data the receiver has access to:

- **Cold start:** the receiver has no knowledge of the current situation and thus has to systematically search for and identify signals before processing them – a process that typically takes 15 minutes.
- **Warm start:** the receiver has estimates of the current situation – typically taking 45 seconds.
- **Hot start:** the receiver knows what the current situation is – typically taking 20 seconds.

Latency: the difference between the time the receiver estimates the position and the presentation of the position solution to the end user (i.e. the time taken to process a solution). Latency is usually not considered in positioning, as many applications operate in, effectively, real time. However, it is an important driver in the development of receivers. This is typically accounted for in a receiver, but is a potential problem for integration (fusion) of multiple positioning solutions or for high dynamics mobiles.

Power consumption: the amount of power a device uses to provide a position. The power consumption of the positioning technology will vary depending on the available signals and data. For example, GPS chips will use more power when scanning to identify signals (cold start) than when computing position. Typical values are in the order of tens of mW (for smartphone chipsets).

ANNEX 5: LIST OF ACRONYMS

AL	Alert Limit
AP	Absolute Positioning
APRP	Absolute Positioning Reference Point
ATC	Automatic Train Control
ATP	Automatic Train Protection
BTM	Balise Transmission Module
CER	Community of European Railway
DGPS	Differential Global Positioning System
DGNSS	Differential GNSS
DM	Digital Map
DMI	Driver Machine Interface
DR	Dead Reckoning
EC	European Commission
EEIG	European Economic Interest Group
EGNOS	European Global Navigation Overlay System
EIM	European Infrastructure Managers
EMC	Electromagnetic Compatibility
EoT	End of Train device
ERA	European Railway Agency
ERTMS	European Railway Management System
ESA	European Space Agency
ETCS	European Train Control System
FD	Fault Detection
FDE	Fault Detection and Exclusion
GBAS	Ground Based Augmentation System
GEOs	Geostationary Earth Orbit satellite
GLONASS	Global Orbiting Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile communications
GSM-R	GSM for Railways
HoT	Head of Train device
HPL	Horizontal Protection Level
HSL	High Speed Line
HNSE	Horizontal Navigation System Error
ICD	Interface Control Document
ID	Identification
IMU	Inertial Measurement Unit

INS	Inertial Navigation System
ITU	International Telecommunication Union
L3	ERTMS level 3
LAAS	Local Area Augmentation System
LCP	Level Crossing Protection
LTL	Low Traffic Line
LE	Local Elements
LU	Locator Unit
MASPS	Minimum Aviation System Performance Specifications
MOPS	Minimum Operation Performance Standards
NSA	National Safety Authority
OBU	On-Board Unit
OCS	Operational Control System
ODO	Odometry
OS	Open Service
PDMU	Partial Digital Map Unit
PNT	Position, Navigation and Time
PVT	Position, Velocity, and Time
R&D	Research and Development
RAIM	Receiver Autonomous Integrity Monitoring
RBC	Radio Block Centre
RF	Radio Frequency
RFI	Rete Ferroviaria Italiana
RHCP	Right Hand Circular Polarization
RNP	Required Navigation Performance
RNSS	Radio Navigation Satellite Service
SAR	Search And Rescue
SARPs	Standards And Recommended Practices
SBAS	Satellite Based Augmentation System
SIL	Safety Integrity Level
SiS	Signal in Space
SNR	Signal to Noise Ratio
SoL	Safety of Life
SPS	Standard Positioning Service
TBC	To Be Confirmed
TBD	To Be Defined
THR	Tolerable Hazard Rate
TI	Train Integrity
TTA	Time To Alert
TTFF	Time To First Fix
UCP	User Consultation Platform
UIC	International Union of Railways
UNISIG	Union of Industry of Signalling
USAF	United States Air Force
UTC	Universal Time Coordinated

ANNEX 6: UPDATES FOLLOWING THE USER CONSULTATION PLATFORM 2018

As per EUSPA document reference GSA-MKD-AGR-UREQ-250286 available here.

ANNEX 7: UPDATES FOLLOWING THE USER CONSULTATION PLATFORM 2020

As per EUSPA document reference EUSPA-MKD-AGR-UREQ-250286 available here.

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