EPICURE

D030 Final Report

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CHANGE RECORDS

ISSUE	DATE	§ CHANGE RECORDS	AUTHOR
1	23/02/22	First issue of the document for Final Review	DELFOUR-CORMIER Hélène
2	24/05/22	Final Report updated according to FR RIDs: FR-JO-01: overall check done about the meaning of “today” in the document FR-JO-02: - §3.3 title updated - Figure 3 updated to add EUSPA logo - §3.4 added to report the list of stakeholders involved in the project - §4 simplified to refer to §3.4 FR-JO-03: Former section 1.2 moved in §3.1 FR-JO-04: §4 and §1.5 updated to detail definitions involved in Table 2 FR-JO-05: §4 updated to convey a more positive message FR-JO-07: former paragraph 4.1.1 (Background on aviation integrity concept) removed, which supersedes other actions decided in the frame of discussion of this RID and RID FR-JO-06 FR-JO-08: Former sections 4.1.2 (Specificities of road applications) and 4.1.3 (Main features of EPICURE integrity concept) merged in the new section 5.1.2 and justification added related to the interest to offer an integrity linked to billing FR-GDP-01: Formulations improved all along the document FR-GDP-02: Readability of figures improved as much as possible FR-GDP-04: geographical presence of stakeholders highlighted in §3.4 FR-GDP-05: no dedicated action implemented since superseded by modifications according to FR-JO-05 FR-GDP-06: "Medium"/"High" target value meaning	DELFOUR-CORMIER Hélène

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		clarified in a footnote FR-GDP-08: §5.1.5 updated for better sentence wording FR-GDP-07: Expected performances of INS sensors are available in D220 table 2 : this is clarified in §5.1.2 FR-GDP-09: - Section 7.3 added to describe the actual set-up used during data collect. - Section 7.5.3 updated with justification of the choice of COTS. - Comparison of EPICURE algorithm with verifiable requirements added in Table 8 FR-JO-13 / FR-GDP-10: Experimentation moved to a new section 7, sentence in §7.4 updated to reflect the necessity to perform pseudo-range level analysis. FR-GDP-11: Justification added in §7.5.3 (Empirical value to derive protection level from accuracy computation) FR-GDP-12: “TAS” replaced by “EPICURE algorithm” in §7.5 FR-JO-08: §5.1.3 updated to clarify the threats considered in EPICURE and §5.1.4 updated to clarify their management FR-JO-09: §5.1.5 updated to restrict the list of algorithms FR-JO-10: §1.5 created to gather the definitions and §5.2 updated to refer to these definitions and to clarify some points. FR-JO-12: §7.1 added to describe the environmental scenarios of interest for the real data collection FR-JO-14: Section 7.4 updated to include the dates in the headers of all performance figures, a clarification on expected SFI values and their evolution according to GIVE, a table of KPIs assessed in the experimentation FR-JO-15 / FR-JO-39: Section 7.5 updated to	

ISSUE	DATE	§ CHANGE RECORDS	AUTHOR
		include a description of scenarios urban#1, urban#2 and tunnel#2, to include section 7.5.8 with the conclusions and way forward, and refer to other parts of the document rather than D230. Section 10 also added at the end of the report. FR-JO-16: Section 7.5.3 updated to list the KPIs monitored in §7.5.4 to 7.5.6. Section 7.3 added added to describe the actual set-up used during data collect. Section 7.5.3 updated to explain availability and xPL computation for COTS (when available) FR-JO-17: §6.1 updated to report EDAS requirements FR-JO-19: Figure 10, Figure 11 and Figure 12 added to represent overall RITS architecture changes associated to the roadmap. FR-JO-21: Service area definition updated in §6.2 and definition of EGNOS contributing countries added in §1.5. A footnote is added about backward compatibility in the “step 2” column of Table 6: EPRIS Performance Requirements FR-JO-23: §8 updated according to the updated CBA document and to better define the base case scenario FR-JO-24: Service provision scheme reflected in §6.4 FR-JO-25: Recommendation from the stakeholders taken in to account in the updated roadmap (prototype available 2 years before EPRIS FOC), see §6.3) FR-JO-26: CBA assumptions reflected in §8.1 FR-GDP-19: §6 updated to reflect the simplified roadmap as per FR discussions. This supersedes the action related to FR-GDP-14. FR-JO-27 / FR-JO-28: Section 9 updated to reflect up-to-date status of dissemination activities FR-JO-31: Acronyms table completed FR-JO-34: §5.1.1 added	

<table>
<tr><th>ISSUE</th><th>DATE</th><th>§ CHANGE RECORDS</th><th>AUTHOR</th></tr>
<tr><td>3</td><td>16/06/22</td><td>FR-JO-35: Comment column re-introduced in Table 5

FR-JO-36: §5.1.7 added

FR-JO-38: §5.1.6 added

FR-JO-53: Explanatory note added in §6.2

FR-JO-56: WP V2.4.3 mentioned in §6.2

Update for Final Review close out

FR-JO-04: footnote added related to integrity value in Table 2. Misleading sentence updated at the beginning of §4 and legend of Table 2 updated to clarify that it relates to end-to-end solution.

FR-JO-06:
- Introduction of section 5 updated to reflect the link between the integrity concept and the EGNOS service definition
- §5.1.1 updated to remove the details on the different definitions after Table 3.
- §5.1.5 updated to remove trade-off elements
- Table 5 now integrated as a picture in the document

FR-GDP-10: Reference to §6 added in §5 when talking about EPRIS

FR-GDP-19:
- Clarification on EPRIS availability and Ranging Accuracy added in Table 6 in §6.2
- Clarification of the origin of the troposphere model added in §5.1.6

FR-JO-81:
- harmonisation of tenses employed in the document
- §6.5.1.X changed to §6.5.X
- §6.3 updated to remove the former figure 17 and 18 and explain the main activities on the critical paths.

FR-JO-82: Executive summary created</td><td>DELFOUR-CORMIER Hélène</td></tr>
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1. INTRODUCTION

1.1. SCOPE AND PURPOSE

This document is the deliverable **D030 – Final Report** of the EPICURE project. It presents an executive summary of the project results.

The document is structured as follows:

- Section 1 is the current introduction of the document;
- Section 2 provides an executive summary of the project.
- Section 3 recalls the breakdown of the project into tasks;
- Section 4 and 5 provides an executive summary of tasks 1 and 2 respectively.
- Section 6 summarizes the outcomes of tasks 3 and 5.
- Section 7 gives the outcomes of the experimentation performed as part of task 2.
- Section 8 and 9 provides an executive summary of tasks 4 and 6 respectively.
- Section 10 concludes this final report and proposes a way forward.

1.2. APPLICABLE DOCUMENTS

Local ID	Title
[AD1]	Tender specifications, No GROW/2019/OP/0003
[AD2]	Service Contract, No GROW/2019/OP/0003

1.3. REFERENCE DOCUMENTS

Local ID	Title
[D110]	Road Domain Analysis and User Needs for Payment/Liability Critical Applications
[D210]	0005-0012873351 - D210 User Integrity concept analysis
[D220]	0005-0012874600 - D220 Receiver model requirements
[D230]	0005-0012871863 - D230 Test campaign plan & Results
[D310]	0005-0013446097 - D310 EGNOS Service Definition for Payment/Liability Critical Applications in the Road Sector
[D410]	Task 4: Cost-Benefit Analysis
[D510]	0005-0013841099 - D510 EGNOS Service Roadmap for Payment/Liability Critical Applications in the Road Sector
[1]	ICAO SARPS “International Civil Aviation Organization Standard and Recommended Practices Annex 10 - Aeronautical Telecommunications - Volume I - Radio Navigational Aids”
[2]	MOPS DO-229F “Minimum Operational Performance Standards for Global Positioning System/Satellite-Based Augmentation System Airborne Equipment”
[3]	Space — Use of GNSS-based positioning for road Intelligent Transport Systems

Local ID	Title
	(ITS) — Part 3: Assessment field tests for security performances of GNSS-based positioning terminals "CEN_CLC_TC5_WG1_N081 - EN_16803-3_(E) – draft"
[4]	Juan Blanch et al., "An Optimized Multiple Hypothesis RAIM Algorithm for Vertical Guidance", Proceedings of ION GNSS 2007, Fort Worth (TX) September 2007
[5]	Miguel Azaola et al., "Isotropy-Based Protection Levels: a Novel Method for Autonomous Protection Level Computation with Minimum Assumptions", NAVITEC 2008, Noordwijk (The Netherlands), Dec 2008.
[6]	Miguel Azaola et al., "Autonomous Integrity: An Error Isotropy–Based Approach for Multiple Fault Conditions", InsideGNSS, Jan-Feb 2009
[7]	Patrick Y. Hwang et al., "From RAIM to NIORAIM: Applying a New Integrity Approach to the Integrated Multi-GNSS System Problem", InsideGNSS, May/June 2008
[8]	R. Grover Brown et al., "GPS RAIM: Calculation of Threshold and Protection Radius Using Chi-Square Methods – A Geometric Approach", Global Positioning System: Inst. Navigat., vol. V, pp. 155–179, 1997.
[9]	Lee, Young C, Investigation of Extending Receiver Autonomous Integrity Monitoring (RAIM) to Combined Use of Galileo and Modernized GPS, Proceedings of ION GNSS 2004, Long Beach, CA, September 2004, pp. 1691-1698
[10]	Groves, P., "Principles of GNSS, Inertial, and Multisensor Integrated Navigation Systems", ARTECH HOUSE,ISBN-13: 978-1-58053-255-6
[11]	Clark, B. et al., "FDE Implementations for a Low-Cost GPS/INS Module", 22nd International Meeting of the Satellite Division of The Institute of Navigation, Savannah, GA, September 22-25, 2009
[12]	Walter, T et al., "Worldwide Vertical Guidance of Aircraft Based on Modernised GPS and New Integrity Augmentations". Proceedings of the IEEE Vol. 96, No.12, December 2008
[13]	Lee, Y, "Optimization of Position Domain Relative RAIM", ION GNSS 21st International Technical Meeting of the Satellite Division, Savannah, GA, September 16-19, 2008
[14]	Gratton, L. et al., "Carrier Phase Relative RAIM Algorithms and Protection Level Derivation", The Journal of Navigation, Vol. 63, No.2, April 2010
[15]	Domínguez, E. et al., "ESA's Multi-Constellation Regional System Land Users Test-Bed Integrity Algorithms Experimentation Results,", Proc. ION GNSS+ 2013, Nashville, TN, September 2013, pp. 2672-2689."
[16]	EGNOS SDD "EGNOS Safety of Life (SoL) Service Definition Document", https://egnos-user-support.essp-sas.eu/new_egnos_ops/sites/default/files/documents/egnos_sol_sdd_in_force.pdf
[17]	GSALOT3-SC2-D4_1 Analysis of the most promising road payment/liability critical applications for EGNOS adoption in 2025-2035
[RD3]	DO 178B: Software considerations in airborne systems and equipment certification
[RD4]	DO 278 A: Software integrity assurance considerations for communication, navigation, surveillance and air traffic management (CNS/ATM) systems
[RD12]	3GPP TR 38.857: Study on NR positioning enhancements
[RD13]	ETSI SES TS 103246 : Satellite Earth Stations and Systems; GNSS based location systems; Parts 1, 2, 3, 4, 5
[RD14]	ISO/PRF TS22591: Space systems — Space-based services for a high accuracy positioning system with safety requirements
[RD15]	ISO/TS 21176:2020: Cooperative intelligent transport systems (C-ITS) — Position, velocity and time functionality in the ITS station
[RD16]	EN16803 series: Use of GNSS-based positioning for road Intelligent Transport Systems (ITS)

1.4. ACRONYMS

Acronym	Description
AD	Applicable Document
A-GNSS	Assisted GNSS
C/A	Coarse/Acquisition
CBA	Cost Benefit Analysis
CFI	Customer Furnished Item
COTS	Commercial-Off-The-Shelf
CSP	Constellation Service Provider
DF	Dual Frequency
DFMC	Dual Frequency and Multi-Constellation
DOP	Dilution Of Precision
E-GNSS	European GNSS
EC	European Commission
EDAS	EGNOS Data Access Service
EGNOS	European Geostationary Navigation Overlay Service
ENT	EGNOS Network Time
EPICURE	EGNOS service for Payment and lIability Critical applications for Users in Road
EPRIS	EGNOS Pseudo-Range Integrity Service
EU	European Union
EUSPA	European Union Agency for the Space Programme
ESP	EGNOS Service Provider
ETC	Electronic Toll Collection
FDE	Fault Detection and Exclusion
FOC	Full Operational Capability
FF	Fault-Free
FR	Final Review
FRD	Final Report Document
GEO	Geostationary Earth Orbit
GIVD	Grid of Ionosphere Vertical Delay
GIVE	Grid Ionospheric Vertical Error
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
H2020	Horizon 2020
HPE / HPA	Horizontal Position Error / Accuracy

HVPL	Horizontal Velocity Protection Level
HW	Hardware
IBPL	Isotropic Based Protection Level
IGP	Ionospheric Grid Point
IR	Integrity Risk
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
ITS	Intelligent Transport Systems
ITT	Invitation to Tender
J/S	Jammer-to-Signal-power-ratio
KFMI	Kalman Filter Measurement Innovation
KOM	Kick-Off Meeting
KPI	Key Performance Indicator
LEO	Low-Earth Orbit
MEO	Medium-Earth Orbit
MHSS	Multiple Hypotheses Solution Separation
MIR	Misleading Information Rate
MS	Microsoft
MTR	Mid Term Review
NAP	National Access Point
NLOS	Non-Light Of Sight
NRE	Non-Recurring Expenses
OBU	On-Board Unit
OS	Open Service
PAYD	Pay-As-You-Drive
PCA	Payment Critical Applications
Pd	Probability of detection
PDF	Portable Document File
Pfa	Probability of False Alert
PHYD	Pay-How-You-Drive
PL	Protection Level (HPL for Horizontal, VPL for Vertical)
PM	Progress Meeting
PMP	Project Management Plan
POI	Point of Interest
PPK	Post-Processed-Kinematic mode

PR	Progress Report
PRN	Pseudo-Random Noise code (GPS satellite identifier)
PST	Progress Status Teleconference
PVT	Position Velocity and Timing
RAIM	Receiver Autonomous Integrity Monitoring
RRAIM	Relative RAIM
RD	Reference Document
RM	Review Meeting
RITS	Road Insurance Telematics Service
RTMeS	Reference Trajectory Measurement System
Rx	Receiver
SAP	Service Access Point
SBAS	Satellite-Based Augmentation Systems
SFI	SaFety index
SiS	Signal-In-Space
SF	Single Frequency
SOA	Start Of Activities
SoL	Safety of Life
SPS	Standard Positioning Service
SQM	Signal Quality Monitoring
SREW	Signal Ranging Error Worst user location
SV	Satellite Vehicle
SW	Software
TSP	Telematics Service Provider
TTA	Time To Alarm
TTFF	Time To First Fix
UBI	Usage-Based Insurance
UDRE	User Differential Range Error
UK	United Kingdom
US	United States
VERT	Vehicle for Experimental Research on Trajectories
WBS	Work Breakdown Structure
WP	Work Package
WPD	WP Description

1.5. DEFINITIONS

The following definitions are used related to key performance indicators characterizing the defined service.

- **Availability** - percentage of time the position, navigation or timing solution can be computed by the user. The time used in user needs and requirements tables refers to monthly availability
- **Integrity Availability** - percentage of time the protection level (linked to integrity definition below) can be computed by the user and is below the alarm limit. The time used in user needs and requirements tables refers to monthly integrity availability
- **Positioning horizontal (respectively vertical) accuracy** (2-sigma, 95%) - a statistical measure of the difference between the true horizontal (respectively vertical) position and the horizontal (respectively vertical) position estimated by the GNSS receiver;
- **Positioning horizontal velocity accuracy** (2-sigma, 95%) - a statistical measure of the difference between the true horizontal velocity and the horizontal velocity estimated by the GNSS receiver;
- **Timing accuracy** (2-sigma, 95%) - a statistical measure of the difference between the true time and the time estimated by the GNSS receiver;
- **Time to First Fix -** the time taken by the Navigation Subsystem to provide location-related data, upon the reception of a request or a triggering event and is defined for a cold-start condition, i.e. the GNSS receiver has no information concerning its Position, Velocity, and Time, and no information on the GNSS satellite positions
- **Integrity** - measure of trust that can be placed in the correctness of the position estimate provided by the receiver; More generally in the context of insurance telematics, integrity could be defined as the measure of trust that can be placed in the correctness of the estimate of any indicator involved in billing. When focusing on the integrity of the position, the notion of integrity is associated to:
    - **PL** = Protection level is the indicator computed to bound the position error. This bound should be below a threshold, also called **alarm limit** (e.g. 25 m) to allow reliable billing;
    - **IR** = Integrity Risk is the probability that the protection level fails in bounding the real position error;
- **Time-To-Alert** (not applicable in the frame of this study because linked to safety of life applications) - the maximum allowable time interval between when the navigation system exceeds the tolerance limit and when the user receives the alarm informing about this situation

- **Robustness vs spoofing -** capacity of a GNSS receiver to detect a false manipulation of signal; This is characterised quantitatively via the probability of detection of spoofing (Pd) and the probability of false alert of the detection mechanism (Pfa).
- **Robustness vs interference -** capacity of a GNSS receiver to resist to intentional or unintentional GNSS interferences. This is characterised quantitatively via the range of jammer-to-signal-power-ratio (J/S) which shall be assumed by the GNSS sensor.

In addition, the following definition has to be noted :

- **EGNOS contributing countries:** they are the countries not part of EU member states but which contribute to the programme and are targeted to be covered by the EGNOS service (part of the service area), ie Norway, Switzerland and Iceland

2. EPICURE PROJECT EXECUTIVE SUMMARY

The EPICURE project has studied the basic principles and concepts for a future EGNOS integrity service, EPRIS (EGNOS Pseudo-Range Integrity Service), specifically to fit in the road insurance telematics applications. In this framework, the market's stakeholders played an important role in the project, as they were consulted in key points of the project and were asked to provide inputs and feedbacks concerning various aspects.

They contributed in particular as follows through three interactions:

- The first interaction for gathering user needs and requirements concerning the GNSS positioning components and functionalities, through dedicated interviews
- The second interaction (still through dedicated interviews) for validating the service definition related to the designed integrity concept and for collecting inputs for the economic analyses and impact assessment;
- The third interaction through a webinar for having feedbacks on the elaborated roadmap, and possibly further recommendations and guidelines to be considered for the refinement of the roadmap.

From the first interaction, with the own values and ideas indicated by the respondents, a table of consolidated requirements was compiled for feeding the design of a possible new EGNOS integrity concept (and associated functionalities, features and services). The performance parameters involved in this table (see Table 1 below) are defined in §1.5:

Performance parameters	Targeted value
Availability	99.9 %
Horizontal accuracy	1m – 5m
Vertical accuracy	NA
Time accuracy	10ms - 1s
Integrity	None – 25m[1]
Robustness to spoofing	"Medium"[2]
Robustness to GNSS interferences	"High"[3]

Table 1: Performances requirements (end-to-end solution) after stakeholder's consultation

[1] The value 25m corresponds to the so-called alarm limit involved in integrity performance (see definition given in §1.5)

[2] According to [17]: *Low* - a spoofing attack would have very little impact (operational, liability or economic) on the application service provision scheme; *Medium* - a spoofing attack would have impact (operational, liability or economic) on the application service provision scheme but may remain marginal; *High* - a spoofing attack would have huge impact (operational, liability or economic) on the application service provision scheme.

[3] According to [17]: Low - the application can endure an interference without being disrupted; Medium - the application can endure an interference during a certain period while providing a sufficient level of service; High - an interference would be critical for the application proper functioning.

Starting from this table of requirements, a preliminary service definition was proposed (EPRIS : EGNOS Pseudo-Range Integrity Service), with performance targets recommended to be further consolidated in particular in the WP EGNOS V2.4.3 for the maritime applications.

A roadmap for EPRIS service introduction was also proposed with progressive service introduction in two steps:

- Step V1 (2025) : Single Frequency Single Constellation (GPS) service
- Step V2 (2029) : Dual Frequency Dual Constellation (GPS / Galileo) service

This EPRIS service fits into an overall user level integrity concept, with the following main characteristics :

- Adaptation to road environments, which are affected by harsh conditions (threats), where:
  - Local errors are predominant (due to multipath more particularly)
  - Direct path may be less numerous than indirect paths, and their distribution is not well known
  - Environment is changing, with frequent signal outage, signal reflection
- Threats are either tackled locally by advanced GNSS antenna and receiver technologies or by the EPRIS service when adequate
- A Multi-sensor on-board unit (OBU) is proposed: GNSS is coupled with other sensor(s) within the on-board unit to cope with frequent GNSS signal blockage in terrestrial environment (at least Inertial Navigation System – INS)

As a summary, the following figure gives an overview of the functional architecture considered for the OBU, in line with the EPICURE proposed user-level integrity concept.

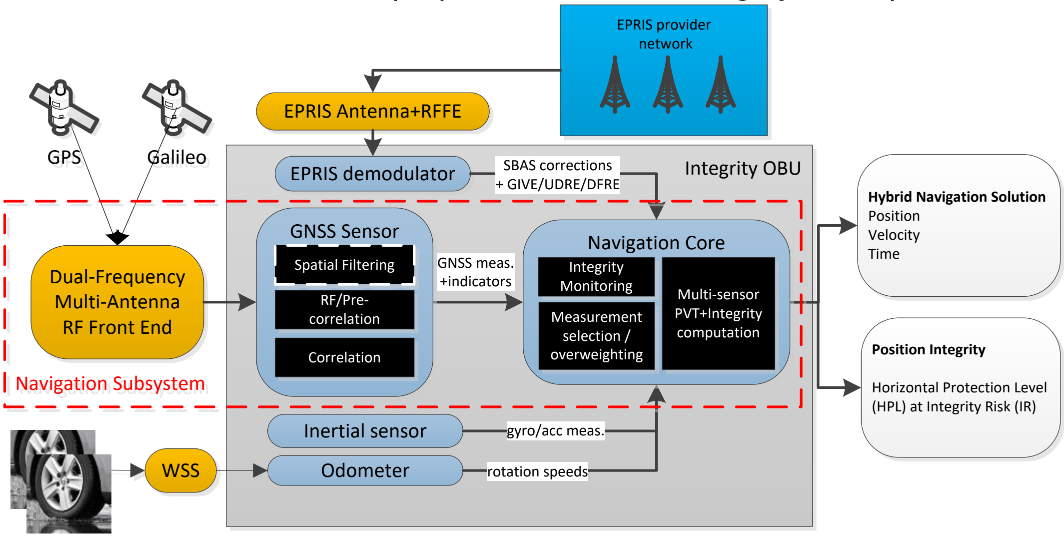


Figure 1 Overview of an integrity OBU model

An experimentation of this concept was performed in representative user conditions.
Some results show that there is still some work to be done to improve hybridization algorithm:

- with better measurement error modelling to improve integrity (e.g. taking into account time-correlated measurement errors)
- with addition of absolute sensors like magnetometers to improve navigation in tunnels.

However, it is considered that the obtained results already allow:

- To show the interests of EPRIS service to improve the accuracy of the user position and provide reliable integrity bounds in the pseudo-range domain
- To confirm that a user integrity concept based on the main principles and algorithms described in §5.1.4 and §5.1.5, with some improvements, would allow to comply with the main requirements expressed by stakeholders of insurance telematics applications (recalled in §5.2)

Finally, this work was also completed by an economic analysis which objective was to conduct a Cost-Benefit Break-Even Analysis of the proposed EPRIS service, focusing on the key conjoint decision-making stakeholders with respect to the adoption of EPRIS (i.e. GNSS Receiver Manufacturers (Rx manufacturers) and Telematics Service Providers (TSPs)). The key analytical objective of this analysis was to **determine the minimum conditions to achieve commercially sustainable adoption by Rx manufacturers & TSPs** for potential niche professional applications (i.e. the volume at which Total Costs = Total Benefits). Two break-even CBAs were conducted: one for Rx manufacturers and one for TSPs. The model was based on assumptions (high-impact and high-uncertainty assumptions adjusted as part of sensitivity analyses) and valuation estimation (of costs and benefits), which were informed by stakeholder consultations.

Under the base case scenario corresponding to the assumptions listed in the paragraph 8.1, the cost-benefit break-even analysis model determined that:

- For **Rx manufacturers**, the **Break-Even Volume is 234,114 Rx units**.
- For **TSPs**, the total aggregate OBU shipments (equal to Rx shipments, by assumption) is 234,114 over the 10 years of the lifecycle (i.e., 2025-2034), requiring a **Break-Even Additional Revenue of €36.41 per OBU/year**.

3. PROJECT SUMMARY AND WORK BREAKDOWN

3.1. PROJECT SUMMARY

EGNOS (European Geostationary Navigation Overlay Service) is Europe's regional satellite-based augmentation system (SBAS) that improves the accuracy of the Global Positioning System (GPS) signals and provides integrity information, making it suitable for applications requiring accurate and reliable positioning. EGNOS currently provides augmentation to the GPS Standard Positioning Service (SPS). EGNOS augments GPS using the L1 (1,575.42 MHz) Coarse/Acquisition (C/A) civilian signal function by broadcasting correction data and integrity information for positioning and navigation applications over Europe and the neighbouring countries around the Mediterranean Sea.
EGNOS delivers three services, free of charge:

- Safety of Life (SoL) Service, able to meet the demands of safety-critical applications in sectors such as civil aviation (e.g. in landing procedures) requiring enhanced and guaranteed performance and an integrity warning system;
- Open Service (OS), EGNOS OS providing positioning, navigation and timing services open to be used by mass-market receivers and common user applications, including automotive, precision farming and surveying.
- EGNOS Data Access Service (EDAS), disseminating EGNOS raw data and corrections and commercial data service via terrestrial networks in real time, within guaranteed maximum delay, security and performance. EDAS is intended for users or for commercial and professional products requiring augmented performances (i.e. further enhancement of GPS position accuracy, improvement of EGNOS OS availability and exploitation of EGNOS integrity data).

EGNOS for transport and mobility applications including road, are available thanks to the effort of European research projects co-funded by the industry.

Past European projects and studies identified the road sector among the most promising for EGNOS, software solutions and technologies using EGNOS are today available giving opportunities for automotive users to have more accurate and reliable positioning for enhancing their applications and/or developing new applications. Generated benefits were extensively proven particularly for the so labelled "liability and payment-critical" applications, for which a charging/payment linked to a service contract depends on the position information, and therefore relevant undetected non-availability or large errors can result into significant legal or economic consequences for the service or application provider. For example, road insurance telematics applications, such as pay-as-you-drive (PAYD) and pay-how-you-drive (PHYD) insurances today widely adopted, are based on the position information measured through a device installed on board of the vehicle (On-Board Unit – OBU). In presently operational insurance telematics solutions, the devices are largely based on the use of satellite navigation (GNSS – Global Navigation Satellite System) technologies integrated with additional sensors such as inertial sensors (gyroscopes and accelerometer) or odometer.

The next generation of EGNOS, EGNOS V3, will augment GPS and Galileo constellations in the L1 and L5 bands and will extend the service area to the entire landmasses of EU member states.

The **European Commission (EC)** is defining the roadmap for the long-term evolution of the EGNOS programme beyond EGNOS V3, including new services or uses/applications of EGNOS. In this framework, **EC and EUSPA** (EU Agency for the Space Programme, https://www.euspa.europa.eu/) have launched a project named EPICURE (EGNOS service for Payment and lIability Critical applications for Users in Road insurancE), and focused on the liability and payment-critical applications and specifically on PAYD and PAHD applications.

Conducted by a team led by **Thales Alenia Space**, with the participation of **FDC**, **Université Gustave Eiffel** and **know.space**, and with a duration of 18 months, the project's main goal was to study and develop the basic principles and concepts for the future EGNOS integrity service, specifically to fit in the road insurance telematics applications. In this framework, the market's stakeholders played an important role in the project, as they were consulted in key points of the project and asked to provide inputs and feedbacks concerning various aspects. To this aim, a Working Group of stakeholders was established, including the main actors of the value chain, i.e. GNSS receiver manufacturers, GNSS OBU suppliers, car manufacturers (and relevant associations), telematics service providers, infrastructure managers (and relevant associations), insurance companies (and relevant associations), standardisation bodies, competent authorities and policy makers.

3.2. WORK BREAKDOWN ORGANIZATION

The project WBS is provided below:

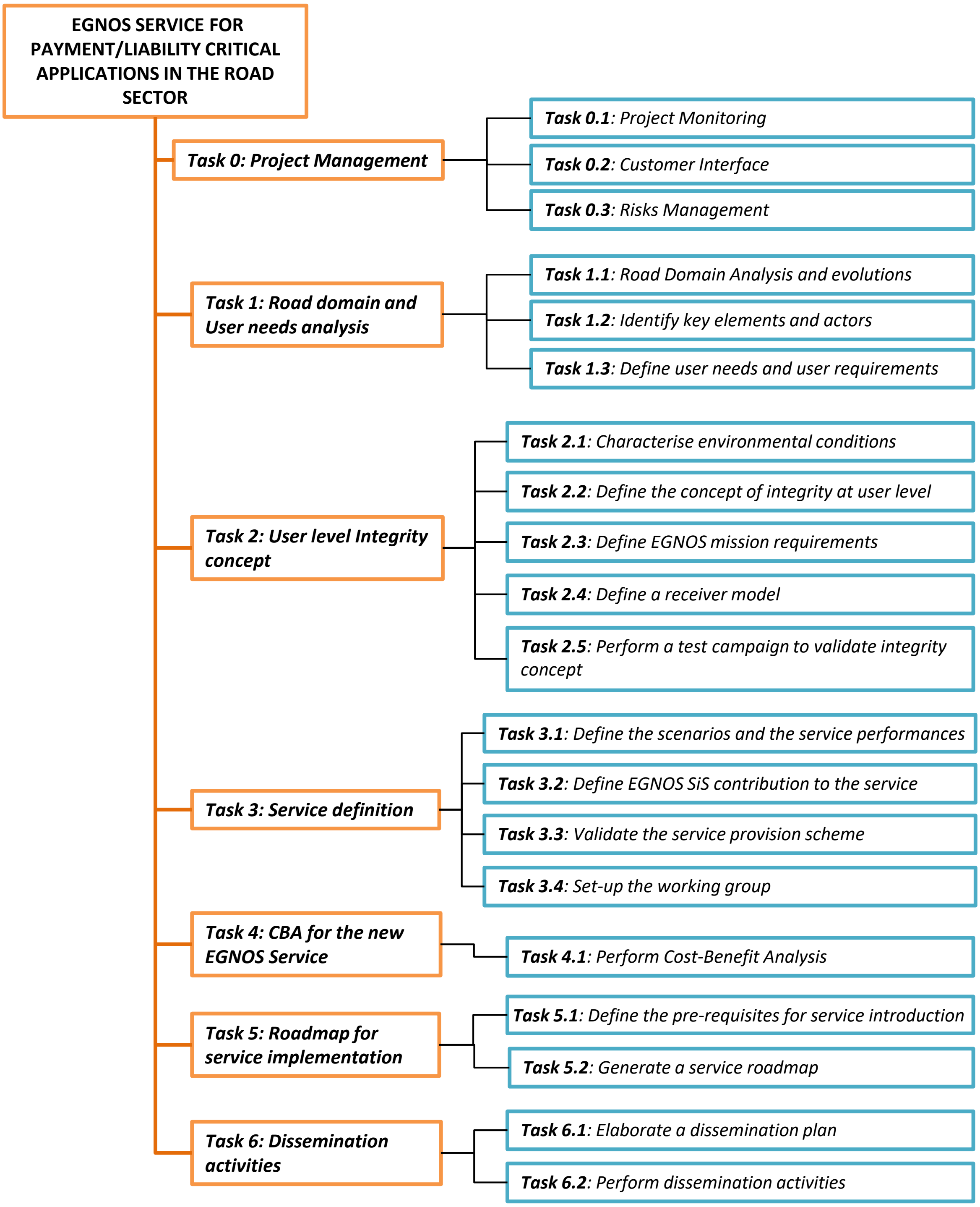


Figure 2 Work Breakdown Organization

3.3. EPICURE PROJECT CONSORTIUM

The project was organized as follows :

- **Thales Alenia Space France**, acting as Prime Contractor;
- **FDC**, acting as sub-contractor;

- **Université Gustave Eiffel**, acting as sub-contractor;
- **know.space**, acting as sub-contractor.

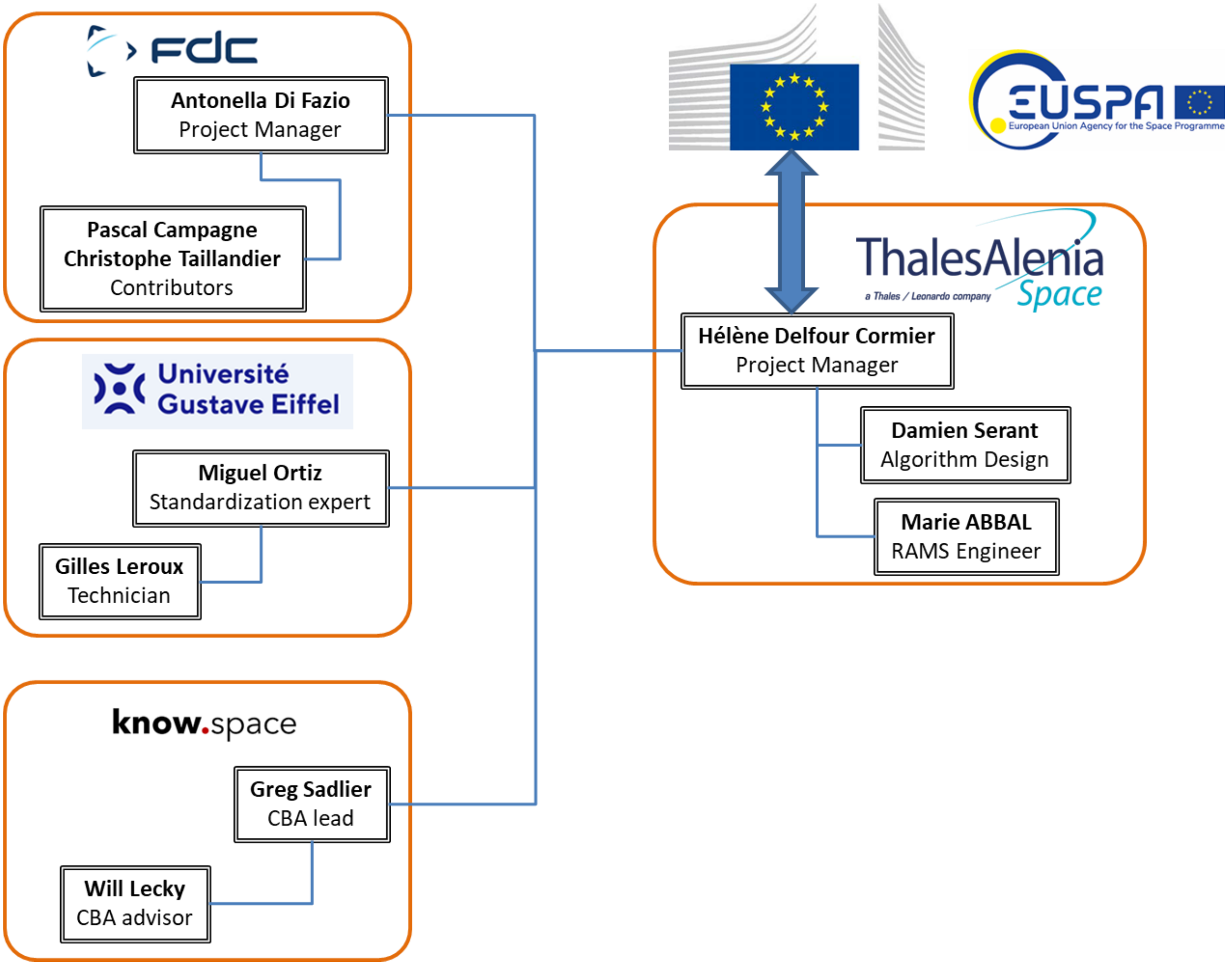


Figure 3: EPICURE project organisation

3.4. STAKEHOLDERS OF THE WORKING GROUP

EPICURE project relied extensively on the opinion of the stakeholders involved in the road insurance telematics applications. For this purpose, EPICURE set-up a Working Group of stakeholders, that was kept alive throughout the project execution and was involved in the relevant main phases as explained below.

The composition of the EPICURE Working Group was conceived to accomplish with its fundamental role, and according to the following rationales:

- The main actors of the value chain were represented, enabling complementary and interdisciplinary viewpoints.

- Some of the stakeholders participating in previous EUSPA initiatives, for leveraging on the related heritage, were considered together with other stakeholders allowing to have a larger and more complete perspective.
- Market champions were included, especially players from the Italian insurance telematics market that, was considered a good and interesting example[4]. Furthermore, the selected market champions were also able to provide an international prospect.
- Although EPICURE's reference market is mainly the road insurance telematics, a few stakeholders from other PCA mainly road user charging[5] were considered, based on the commonalities identified in the previous initiatives mentioned above.
- The chosen representatives from the different entities came from various departments, such as research & development, strategy & operations, sales, business development, engineering, experts on Intelligent Transport Systems[6] for the road sector. This ensured a plurality of visions, considering the timeframe addressed in the project (i.e. 2021-2035).
- Moreover, the selected stakeholders and relevant chosen representatives were based on well-established existing contacts with the EPICURE's team members, and they were willing to actively contribute along the project's execution.

The next figure shows the value chain of the EPICURE's reference market, also comprising:

- Relevant associations (such as the associations of road insurance companies, car manufacturers and road users), having the necessary wide outlooks;
- Competent authorities and policy makers, having the ability to drive the market;
- Standardisation bodies, for getting the corresponding technical views.

In the figure, the first "line" reports the actors of the value chain specifically involved in the PAYD/PHYD service provision. The other two "lines" include the actors not directly involved in the service provision however playing a key role as above-mentioned (competent authorities, policy makers and relevant standardisation bodies who can be decision-makers for the market or technology solutions and relevant evolutions at local, regional, national and international level).

[4] Italy was an early adopter of insurance telematics applications and it still represents a significant share of the Insurance telematics market: https://medium.com/@kapurprayanca140/italy-accounted-for-33-1-of-the-global-usage-based-insurance-market-share-in-2016-a76bd406186a

[5] RUC

[6] ITS

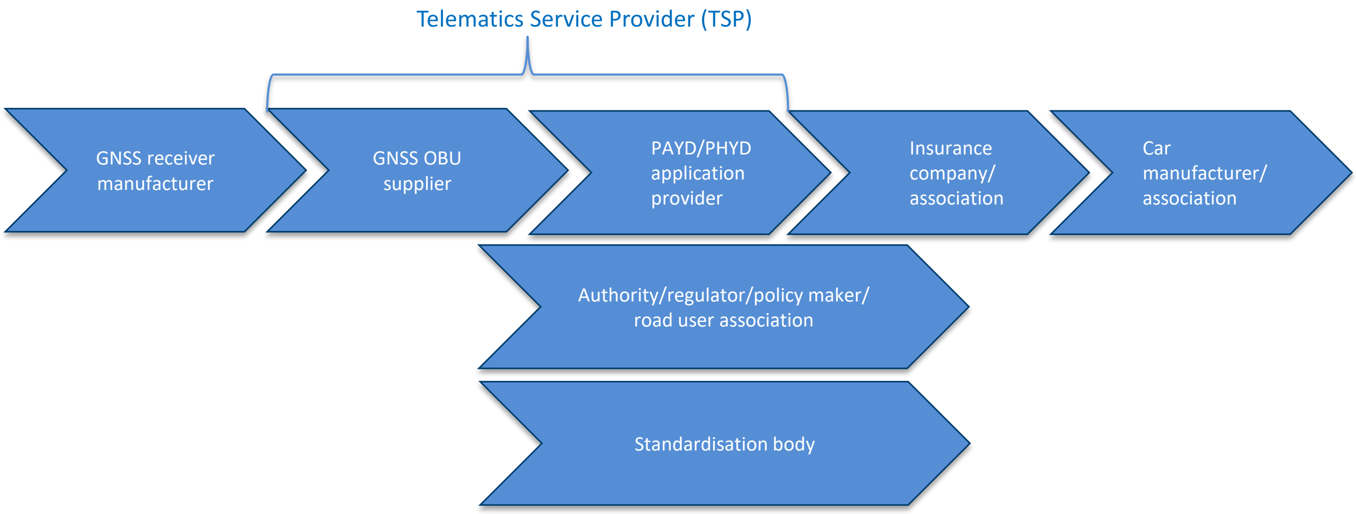


Figure 4 Value chain of the road insurance telematics market

The list of stakeholders involved based on the criteria listed above, is reported in the table below.

Through this final report, we address our special thanks to these stakeholders for their appreciated involvement in the project.

They contributed in particular as follows through three interactions:

- The first interaction for gathering user needs and requirements concerning the GNSS positioning components and functionalities, through dedicated interviews
- The second interaction (still through dedicated interviews) for validating the service definition related to the designed integrity concept and for collecting inputs for the economic analyses and impact assessment;
- The third interaction through a webinar for having feedbacks on the elaborated roadmap, and possibly further recommendations and guidelines to be considered for the refinement of the roadmap.

Profile/competence	Entity (alphabetical order)	Road insurance telematics	ETC (Electronic Toll Collection)	Nationality	Geographical Presence
TSP	ALFAEVOLUTION TECHNOLOGY	✓	✓	Italy	Europe
Insurance company/TSP	Allianz Technology	✓		France	Europe

Profile/competence	Entity (alphabetical order)	Road insurance telematics	ETC (Electronic Toll Collection)	Nationality	Geographical Presence
Infrastructure operator	Autopistas		✓	Spain	Spain
TSP	Autostrade Tech		✓	Italy	Worldwide
Insurance company	AXA	✓		France	Europe
GNSS OBU supplier	Continental		✓	Germany	Worldwide
Pre-normative testing and conformance assessment	EC JRC			Europe	Europe
TSP	GEOTAB	✓		Italy	Worldwide
Policy maker	Roma Servizi per la Mobilità		✓	Italy	Italy
Policy maker	Città Metropolitana di Firenze		✓	Italy	Italy
Policy maker	Municipality of Verona		✓	Italy	Italy
TSP	Octo Telematics	✓		Italy	Worldwide
Standardisation expert	Rapp Trans			Swiss	Worldwide
Insurance company	Sara Assicurazioni	✓		Italy	Italy
GNSS receiver manufacturer	Septentrio			Belgium	Worldwide
Standardisation expert/TSP	Sogei			Italy	Italy

Profile/competence	Entity (alphabetical order)	Road insurance telematics	ETC (Electronic Toll Collection)	Nationality	Geographical Presence
GNSS receiver manufacturer	Syntony			France	Worldwide
TSP	Targa Telematics	✓		Italy	Worldwide
TSP	T-Systems	✓	✓	German	Worldwide
GNSS receiver manufacturer	u-blox	✓	✓	Swiss	Worldwide
Standardisation body	UNI			Italy	Europe
Insurance company/TSP	Vodafone Automotive	✓		Italy	Europe

4. TASK 1 : ROAD DOMAIN AND USER NEED ANALYSIS

This paragraph is related to the "Road Domain Analysis and User Needs for Payment/Liability Critical Applications" and it reports:

- The user needs and requirements for PAYD/PHYD applications, specifically having an impact on GNSS positioning components and functionalities;
- The analysis of the competitive landscape in a time frame 2021-2035, in terms of value chain, stakeholders, key players, technologies, solutions, service offering, legislative framework (national, EU, international), standardisation;

as elaborated on the basis of the contributions of the EPICURE's Working Group of stakeholders.

It provides a picture of the road insurance telematics and the electronic road tolling markets, as it is today, its present trends and future evolutions (in the next 5-10 years and more in the future 2035 perspective). The picture was drawn further to a consultation involving the stakeholders composing the EPICURE's Working Group, well representing a significant sample of the considered markets, and also including key players of the automotive applications although not strictly related to the road insurance telematics and the electronic road tolling applications (see §3.4 above).

Thanks to the constructive and proactive participation of the respondents, the consultation led to important findings, also in the light of the present trends and future evolutions of the addressed markets:

- **Demand does not appear to be strong** for mass road insurance telematics or electronic road tolling
- There is **a potential demand** for commercial niche fleet management applications : A possible opening can come from the road insurance telematics oriented to professional end-users and policy holders, for two reasons:
    - firstly because the relevant dynamics are slower with respect to the consumer sector,
    - and secondly because they offer added value services for commercial fleet managers on top of which tailored innovative services can be added [including road insurance telematics]
- … **if** the maximum overall delta cost is inferior to $50 per unit (i.e., €42 per unit)
- Receiver Manufacturers & Telematics Service Providers are **conjoint decision-makers** for adoption

With the own values and ideas indicated by the respondents, a table of consolidated requirements was compiled for feeding the design of a possible new EGNOS integrity concept (and associated functionalities, features and services). The performance parameters involved in this table (see Table 2 below) are defined in §1.5:

Performance parameters	Targeted value
Availability	99.9 %
Horizontal accuracy	1m – 5m
Vertical accuracy	NA
Time accuracy	10ms - 1s
Integrity	None – 25m[7]
Robustness to spoofing	“Medium”[8]
Robustness to GNSS interferences	“High”[9]

Table 2: Performances requirements (end-to-end solution) after stakeholder’s consultation

[7] The value 25m corresponds to the so-called alarm limit involved in integrity performance (see definition given in §1.5)
[8] According to [17]: *Low* - a spoofing attack would have very little impact (operational, liability or economic) on the application service provision scheme; *Medium* - a spoofing attack would have impact (operational, liability or economic) on the application service provision scheme but may remain marginal; *High* - a spoofing attack would have huge impact (operational, liability or economic) on the application service provision scheme.
[9] According to [17]: Low - the application can endure an interference without being disrupted; Medium - the application can endure an interference during a certain period while providing a sufficient level of service; High - an interference would be critical for the application proper functioning.

5. TASK 2 : USER LEVEL INTEGRITY CONCEPT

This task had an important weight in the EPICURE project, leading mainly to the following outcomes:

- Proposal of foundations of a user level integrity concept with the objective to meet the user needs identified in task 1 (D210, see summary in §5.1)
- Identification of links between this integrity concept and an EGNOS service with commitments introduced at pseudorange level (see §5.1.6 and §6)
- Derivation of receiver model requirements allowing to instantiate this user level integrity concept at receiver, antenna and OBU levels (D220, see summary in §5.2)
- Experimentation of the proposed system and user level integrity concept on the basis of a real data collection performed in representative road environments (D230, see summary in §7)

5.1. SUMMARY OF USER INTEGRITY CONCEPT ANALYSIS (D210)

5.1.1. Definitions of integrity in non-aviation domains

After Task 1, it appeared that the concept of Integrity Risk has been totally wiped out from the performance requirements, although Protection Levels still remain. Clearly, this observation raises the problem of understanding what integrity represents. Although a clear definition is available to aviation users, the term "integrity" itself suffers from miscellaneous definitions and anyone could interpret it unequally. Table 3 below shows different definitions of “integrity” as stated by different international standardisation entities/bodies.

Standardisation body	Definition of integrity
3GPP[10]	The Integrity of a Positioning System is a **measure** of the **trust** that can be placed in the correctness of the Positioning State supplied by the Positioning System, including the ability to provide timely and valid Alerts to the UE and/or the user when the Positioning State does not fulfil the condition for intended operation
ETSI SES-SCN[11]	**Measure** of the **trust** in the accuracy of the location-related data provided by the location system
ISO TC204[12]	**Measure** of the **trust** that can be placed in the correctness of the information supplied by a navigation system and that includes the ability of the system to provide timely warnings to users when the system should not be used for navigation. **Integrity risk** is the probability that, for positioning terminals providing a **protection level** (3.13) as integrity-related quantity, the actual error on a given output component exceeds its associated protection level. Confidence level is also defined in TS21176, based on the definition of Integrity Risk provided by EN16803.
CEN-TC5-WG1[13]	General performance feature referring to the **trust** a user can have in the delivered value of a given Position or Velocity component. Note 1 to entry: This feature is expressed by 2 quantities: the **Protection level** and the **associated Integrity risk**. Note 2 to entry: In this document, the definition of integrity is inspired by, but significantly simpler than, the definition of the same concept for the civil aviation community

Table 3 Integrity in non-aviation standards

From that table, it is clear that “integrity” is seen as “a measure of trust” of the “positioning state”, or “navigation system information”, “position or velocity component”, which is a good starting point. However, there are some dissimilarities and a strong need for harmonisation.

For the activities of this project, we considered the definition of Integrity as proposed by the CEN-TC5-WG1 and thus we kept the computation of the Protection Level (limited to the horizontal plane of the Position) corresponding to a pre-determined Integrity Risk.

Because road insurance applications rely on post-processing, EPICURE also did not consider the Time-To-Alert (TTA) concept.

[10] Refers to [RD12]
[11] Refers to [RD13]
[12] Refers to [RD14] and [RD15]
[13] Refers to [RD16]

5.1.2. Specificities of road applications and main features of EPICURE integrity concept

As described above, civil aviation has been an important actor for the development of an integrity concept and the concept has been validated for aeronautical applications. However, the direct application of the aviation integrity concept to road usage is not possible due to the different environment. Indeed, the integrity computation used in SBAS system relies on assumptions and models which are reasonable for an avionics GNSS receiver, in terms of almost constant environment and dynamics which can be exploited for the bounding of local errors (in addition to system errors):

- Local errors are (nearly) normally distributed
- System errors are predominant with respect to the local errors in terms of integrity tree.

For road usage, these assumptions are not valid anymore and moreover, the GNSS receiver is under harsh environment, as depicted on the following figure:

- Local errors are predominant (due to multipath more particularly)
- Direct path may be less numerous than indirect paths, and their distribution is not well known
- Environment is changing, with frequent signal outage, signal reflection

Figure 5: Typical road environments (Open Sky -> Semi-urban -> Canopy -> Tunnel -> Urban Canyon)

Moreover, instead of 3D positioning of the aircraft as in the civil aviation, a position on a 2D map is generally considered as sufficient for the road applications.
For all these reasons, it is proposed to foster new types of integrity concept and algorithms which are mostly based on the measurements that the receiver itself can produce. This concept is usually known as RAIM (Receiver Autonomous Integrity Monitoring).

However, basic PVT and RAIM algorithms, generally based on the available raw pseudorange measurements, have relatively poor performance. Hence it becomes necessary to exploit as much other information as possible when combining the measurements for the PVT computation. This additional information could be provided internally (by specific signal processing) or externally (exploiting the messages of the different navigation and augmentation systems) or also via other non GNSS sensors (such as Inertial Navigation System or odometers).

Based on the specificities of road applications highlighted above, the EPICURE integrity concept has been developed relying on three main pillars:

- Advanced GNSS antenna and receiver technologies: these technologies are exploited to increase robustness to threats encountered in terrestrial environment (see next paragraph).
- Multi-sensor on-board unit: GNSS is coupled with other sensor(s) within the on-board unit to cope with frequent GNSS signal blockage in terrestrial environment (at least Inertial Navigation System – INS, with expected performances as described in [D220])
- Application context: The application context can be used to compute a protection level associated to any metric involved in the billing process (e.g. bound of distance error). Indeed, better knowing the uncertainty on the parameters involved in the billing process (such as the distance in PAYD applications) would allow decreasing the probability of "missed" billing. It would thus increase the financial efficiency.

5.1.3. Road environment threats identification

Such threats have been classified by various working group such as CEN-CENELEC [3]. According to this working group, this classification reported considers that threats are either "unintentional" or "intentional". Note that the term "attack" is used by this working group even for unintentional threats such as interference.

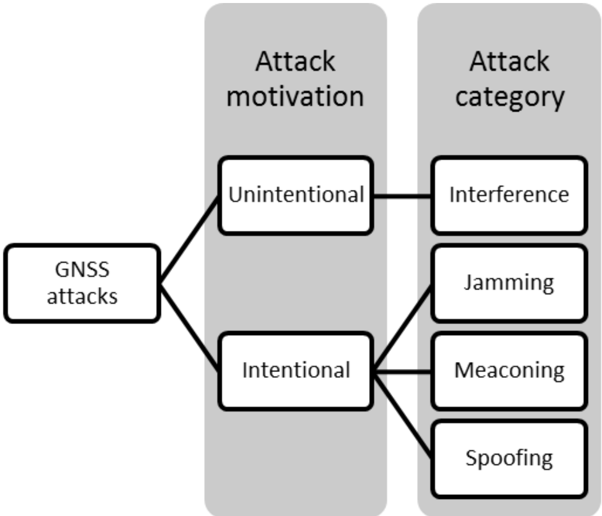


Figure 6: GNSS Attack taxonomy (source CEN-CENELEC)

On the first case the threat is provoked by natural effects due to physical property of the signal propagation (e.g. atmosphere) or the physical environment (e.g. multipath). It includes also sharing of the GNSS frequency band with other systems (e.g. L5 band used by Telecom). This "unintentional" is considered by CEN-CENELEC as an "interference" (wording that is sometimes mixed with jamming) in the sense where it interferes with the nominal working of the receiver, by modifying the signal broadcast by the GNSS satellite, or increases the apparent noise so as to reduce the C/N0. This class of threats is more detailed in §5.1.3.1 below.
The second case deals with attacks that aim at inhibiting the receiver capability to process the useful GNSS signal and then to estimate an accurate and reliable position & timing solution.

Such threats are generated by more and more sophisticated devices, and thus it is important to consider them as an increasing risk to be detected and mitigated. This class of threats is more detailed in §5.1.3.2 below.

5.1.3.1. UNINTENTIONAL THREATS

The propagation threat deals with the signal crossing of the atmosphere, and in particular the troposphere and the ionosphere. Both of these layers impact differently the signal.
The **troposphere** generates an overall delay on the signal for which models exist and are quite accurate.
The **ionosphere** generates also a delay on the code (pseudo-range) however “stimulate” the carrier phase. As the phenomenon depends on the solar activity over the day and over a solar cycle (about 11 years), it is not predictable. Even if some models exist they are not accurate enough for some applications.
The GNSS **multipath** is a particular interference (unintentional attack) characterized by the same GNSS signal reaching the receiver several times from different directions with different levels of attenuation and delay.
GNSS multipath is due to the GNSS signal reflection on surrounding environment (ground, buildings, trees …). The reflection can be specular or diffuse depending on the reflecting surface characteristics (smooth, irregular …).
The **signal outage** threat deals with unexpected interruptions of signal reception whereas the GNSS satellite is correctly transmitting it. It is typically due to masking, because of the environment (building …) that obscures the line of sight of the satellite.
By extension, it deals also with the attenuation of the signal without total disappearance, for example when a vehicle is under trees. This threat will decrease the C/N0 that, if too low, will stop the tracking of the SV.
Interferences are provoked by systems which share the frequency band of the GNSS ones, and transmit signals which disturb the useful GNSS signal.
Most of them are coming from radar or telecom transmitters. These signals are well known. However they can be provoked also by classified sources that are secret. Finally they can be transmitted accidentally by radio amateur, uncontrolled laboratory tests, and also HW malfunctions.

5.1.3.2. INTENTIONAL THREATS

A GNSS **jamming** attack is a deliberate emission of radiofrequency interference aiming at degrading the performances or to disrupt the PVT functionality of a GNSS receiver.
It is characterized by the power ratio between the interference and the GNSS signal (J/S), and the interference waveform (Continuous Wave, Chirp, Narrow-band noise, broadband noise …) and frequency. Jamming GNSS-based vehicle tracking devices may be performed to prevent a supervisor’s knowledge of a driver’s movements, or avoiding road user charging.
The GNSS **spoofing** attack is a deliberate transmission of counterfeit GNSS-like signals aiming at making a GNSS receiver producing false PVT data without disruption in the delivery of the PVT solution.
The spoofing attack can play at different levels: at data level by changing part of the navigation message, at channel level by replacing one or several GNSS channels with a counterfeit signal.

The GNSS **meaconing** attack is a particular spoofing attack consisting in rebroadcasting delayed real GNSS signals.
It is characterized by the rebroadcasting delay (time offset), and the difference between the recording position and the rebroadcasting position (position offset). The position computed by the targeted receiver will be the recording position.

5.1.4. Threats management in EPICURE integrity concept

The threats presented in the previous sections can have an impact on the performances of the receiver, in terms of position availability, accuracy, or integrity. It is thus important to take them into consideration and implement countermeasures to detect the presence of threats as much as possible, and when possible, mitigate their effects.
The next table summarizes the technics (also called countermeasures) proposed in the frame of EPICURE to detect and mitigate each threat identified above.
This table describes what is the effect of each used technic on the measurements, between the following three types of effects:

- Overweighting (ie the measurement is still considered in the PVT but with a weight commensurate to its quality),
- Exclusion (ie the measurement is discarded from the PVT if its quality is below a threshold)
- Redundancy increase (ie the technic allows to increase the redundancy in measurements used for the PVT)

The table below also classifies each used technic between the following three types of detection and mitigation:

- “Local”, when detection and mitigation is based on GNSS antenna and receiver technologies (local to the On-board Unit)
- “SBAS”, when detection and mitigation is allocated to the SBAS system (e.g. EGNOS)
- “A priori”, when there is no need of smart detection and mitigation algorithms and the corresponding effect can be reliably modelled a priori

<table>
<tr><th colspan="2">Type of threats</th><th>Countermeasure</th><th>Countermeasure effect</th><th>Countermeasure type</th></tr>
<tr><td rowspan="5">Atmospheric propagation</td><td>Troposphere delay</td><td>Accurate existing delay model</td><td>overweighting</td><td>A priori</td></tr>
<tr><td rowspan="4">Ionosphere delay</td><td>Coarse delay model (single-frequency)</td><td rowspan="2">overweighting</td><td rowspan="2">Local</td></tr>
<tr><td>Multi-frequency processing</td></tr>
<tr><td>Ionospheric correction by SBAS</td><td rowspan="2">overweighting</td><td rowspan="2">SBAS</td></tr>
<tr><td>Residual delay error bound by SBAS</td></tr>
<tr><td rowspan="4">Local environment</td><td rowspan="3">Multipath</td><td>Multicorrelator discriminator</td><td>overweighting</td><td>Local</td></tr>
<tr><td>Multi-antenna techniques</td><td>overweighting exclusion</td><td>Local</td></tr>
<tr><td rowspan="2">Hybridization with sensors</td><td rowspan="2">Redundancy increase</td><td rowspan="2">Local</td></tr>
<tr><td>Signal outage</td></tr>
</table>

<table>
<tr><th colspan="2">Type of threats</th><th>Countermeasure</th><th>Countermeasure effect</th><th>Countermeasure type</th></tr>
<tr><td></td><td></td><td>Multi-constellation feature</td><td>Redundancy increase</td><td>Local & SBAS</td></tr>
<tr><td rowspan="6">Interference (unintentional) / Jamming (intentional)</td><td>Wideband</td><td rowspan="2">AGC[14] analysis
Spectral analysis</td><td rowspan="2">overweighting</td><td rowspan="4">Local</td></tr>
<tr><td rowspan="2">Narrowband</td></tr>
<tr><td rowspan="2">Spectral analysis
Spectral blanking</td><td rowspan="2">overweighting</td></tr>
<tr><td rowspan="2">Continuous</td></tr>
<tr><td>Multi-antenna techniques (spatial blanking)</td><td>overweighting exclusion</td><td>Local</td></tr>
<tr><td>Pulsed</td><td>Temporal blanking</td><td>overweighting exclusion</td><td>Local</td></tr>
<tr><td rowspan="2">GNSS Spoofing</td><td rowspan="2">Spoofing / Meaconing</td><td>Code-carrier coherency</td><td>overweighting exclusion</td><td>Local</td></tr>
<tr><td>Multi-antenna techniques</td><td>overweighting exclusion</td><td>Local</td></tr>
<tr><td rowspan="3">System errors</td><td rowspan="2">Satellite inaccurate clock/ephemeris</td><td>Satellite error correction by SBAS</td><td rowspan="2">overweighting exclusion</td><td rowspan="2">SBAS</td></tr>
<tr><td>Residual satellite error bound by SBAS</td></tr>
<tr><td>Receiver noise</td><td>Tracking loop noise estimation</td><td>overweighting</td><td>Local</td></tr>
</table>

Table 4 List of threats and countermeasures

5.1.5. Integrity concept selection

The EPICURE project performed a critical analysis of techniques providing a quality indicator of the navigation solution, in terms of performance, complexity and latency. Some methods can provide an instantaneous confidence level, while others require several consecutive observations of the GNSS constellation signals. The capability of these techniques to take into account additional information, with the aim to increase the overall integrity receiver performance, was also considered.

After a complete trade-off of the state-of-the-art algorithms, the EPICURE project recommended the use of **KFMI (Kalman Filter Measurement Innovation)** as the best candidate for integrity algorithm:

- It presents a relatively simple but efficient Fault Detection and Exclusion capability. The exclusion of bad measurements allows reaching a good accuracy, which limits the integrity risk.
- It has a low computation load.
- It provides immediate detection capability, on the contrary to Relative RAIM methods which require several temporal measurement sets, thus showing lower reactivity.
- The protection level computation is usual but efficient.

[14] AGC: Automatic Gain Control

- The unlimited number of instantaneous measurement exclusion is an important characteristic, since urban environment can raise multiple faults. The resulting increase in Dilution-of-Precision is mitigated by the use of multiple constellations.

Moreover, the KFMI algorithm can easily adapt to the **hybridization of GNSS measurements with movement sensors (IMU, odometers)**, allowing an improvement in the exclusion process by exploiting additional data that will not suffer propagation issues. The KFMI algorithm is preferably used in a tight-coupling scheme: this avoids computing one PVT per constellation, and on top of this, it allows the inclusion of sensor data at the same stage, taking benefit of both multi-constellation and multi-sensor approach at the same time with relatively simple complexity.

As a difference to civil aviation integrity concept, the proposal here is to account for the local environment without arbitrary information (e.g. as for multipath). As a basic assumption, we consider that the probability of occurrence of local errors is not determined a priori, nor is the distribution of those errors. Indeed, considering through a priori error budgets that Non-Line-of-Sight and multipath events are always present on the GNSS signals would lead to very high (of several km) – thus impractical – Protection Levels. We thus considered that all measurements are characterised dynamically, by implementing **signal quality indicators** issued by several GNSS signal processing stages. The GNSS signal processing has also the primary goal to detect and mitigate threats as introduced above.

These indicators can be further exploited to either exclude or overweight faulty measurements. In case of overweighting, the coefficient will be chosen such that the resulting error envelope encapsulates the error by setting adequate probability. As a consequence, the overweighed measurement remains fault-free and overweighting is taken into consideration when **computing the PVT and the associated Horizontal Protection Level**.

Finally, the KFMI integrity algorithm has also the capability to **integrate additional external information**. The most convenient and efficient way is to include information relative to the pseudo-range measurements used by the KFMI coupling and hybridization scheme. The local errors are already addressed by the GNSS processing stages, but it can be beneficial to include bounds of the remaining system errors impacting the pseudo-range. Some GNSS system errors are classically monitored by SBAS such as EGNOS, and it concerns the characterization of the residual ionospheric delay errors and of the residual satellite clock and ephemeris error.

5.1.6. Integration of the new EGNOS service

EGNOS has been originally developed with the primary objective to augment the positioning estimation of a GNSS user by sending corrections.

EGNOS also provides bounds of remaining errors after application of these corrections:

- UDRE (or DFRE for dual frequency users) represents the bound of remaining orbit and clock errors after application of the corresponding EGNOS corrections

- GIVE (for mono-frequency users) represents the bound of remaining ionosphere error after application of the EGNOS ionosphere corrections

The physical architecture relies on ground based infrastructures and a space segment.

The space segment (SBAS satellites) is responsible for broadcasting the corrections to the GNSS/EGNOS users in terms clock, orbit and ionospheric corrections and also associated bounds of remaining errors (UDRE/DFRE and GIVE)

The ground segment is responsible for the measurements of the GNSS signals in several locations of the ECAC zone and includes the algorithms to determine the EGNOS corrections that will be uplinked to the SBAS satellites for broadcast to the users.

Especially, the Central Processing Facility, which is in charge of collecting raw measurements and implementing estimation algorithms (Orbit, Clock, Ionospheric delay), determines the so-called Satellite Residual Error.

This error represents the estimated residue of the remaining contributions in terms of clock, orbit after application of the corrections. These residual errors are computed in the pseudorange domain, and that is why they are particularly interesting in the frame of EPICURE. They are specifically estimated considering the worst user location (SREW) in order to bound it with UDRE (or DFRE for dual frequency users), and thus to ensure integrity with a certain probability.

The integrity concept in EPICURE considers that the error distribution and bounds is useful information because they can be fed into the user-level integration algorithm.

The pseudorange error model considered at user level is:

$$\sigma_k^2 = \sigma_{clk/ephem,k}^2 + \sigma_{tropo,k}^2 + \sigma_{Iono,k}^2 + \sigma_{noise,k}^2 + \sigma_{multipath,k}^2$$

where:

- $\sigma_{clk/ephem,k}$ is the standard deviation for the k^th satellite orbit/clock error. This term can be provided by EGNOS/EPRIS (EGNOS Pseudo-range Integrity Service, as further defined in §6), based on UDRE/DFRE

- $\sigma_{tropo,k}$ is the standard deviation of the residual troposphere error. It writes, as per the MOPS model [2] :

  $$\sigma_{Tropo,k} = 0.12 \times \frac{1.001}{\sqrt{0.002001 + \sin^2(El_k)}}$$

- $\sigma_{i,noise,k}$ is the standard deviation deduced from the measurement noise estimator. If multi-frequency is used this term includes the effect of multi-frequency combination

- $\sigma_{i,multipath,k}$ is the effect of multipath. In practice quick measurement variations due to multipath are included in $\sigma_{i,noise,k}$. This term contains the maximum residual bias after compensation and estimation of multipath by SAGE processing

- $\sigma_{Iono,k}$ is the standard deviation of residual ionosphere correction given by EGNOS/EPRIS (if in mono-frequency configuration), based on the GIVE

In the case of Dual Frequency corrections, the Grid Ionospheric Vertical Error (GIVE) is considered a near-zero residual error and is not transmitted/used.

5.1.7. RAMS methodology and assessment regarding availability and integrity performances

Two main groups of equipment are contributing to availability and integrity performances in the proposed integrity concept:

- EGNOS system and GNSS/EGNOS receiver,

And

- Additional sensors (Inertial Measurement Unit (IMU), and Wheel Speed Sensors (WSS))

An apportionment model allocation for these liability critical performances (for integrity and availability) could be done through allocation tree. As the need of integrity was not fully confirmed by the stakeholders in task 1, this allocation task has not been fully developed in the frame of EPICURE project, since the need to perform a top-down allocation from not consolidated requirements could be questioned.

However, the following tasks were initiated:

- to define feasible performances for EGNOS service in terms of integrity and availability (bottom-up approach, see §Table 6)
- to represent the different contributors on preliminary integrity / availability trees

It has to be noted that this apportionment for the multi sensor OBU was initiated only regarding quantitative performances. Indeed, as stated before, the applications considered in this study are not SoL critical applications then no “qualitative” apportionment or safety considerations are made on the OBU (such as DAL allocation usually done for aviation context according to aeronautical standards, in particular DO 178B [RD3] / 278A [RD4]).

Obviously, the OBU concept may be very interesting and useful for other applications such as, in particular, the autonomous vehicle. In such a case, Safety standards and methodologies would apply (e.g. ISO 26262 Road vehicle – functional safety and ISO 21448 – SOTIF Road Vehicle – Safety Of the Intended Functionality).

The following figure presents the preliminary allocation tree for Integrity risk:

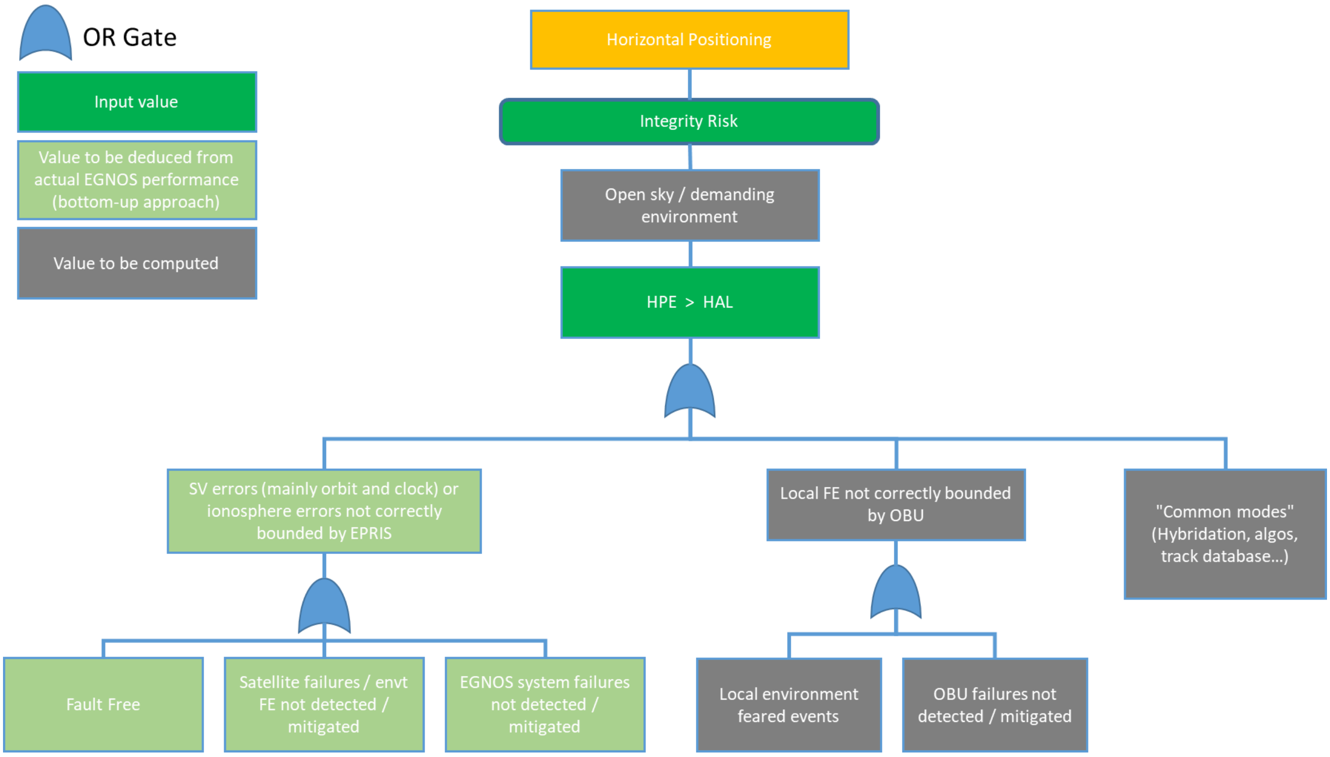


Figure 7: Integrity Risk allocation Tree

Integrity Risk can arise when the Horizontal Position Error becomes larger than the Horizontal Protection Level (HPL), and larger than the Horizontal Alarm Limit (HAL), due to the following causes:

- SV errors or ionosphere errors not correctly bounded by EPRIS (EGNOS Pseudo-range Integrity Service, as further defined in §6).
- Local Feared Events are not correctly bounded by the OBU
- Common modes due to hybridisation, algorithms…

SV errors or ionosphere errors not correctly bounded by EPRIS should in theory be mitigated by the hybridisation with position information provided by the OBU, and vice versa. However, it is difficult to know in what extent such mitigation would be efficient at preliminary stage. It was therefore conservatively considered that each of these causes could directly generate an integrity risk. The Integrity Risk allocation tree should be refined later on.

The following figure presents the preliminary allocation tree for availability:

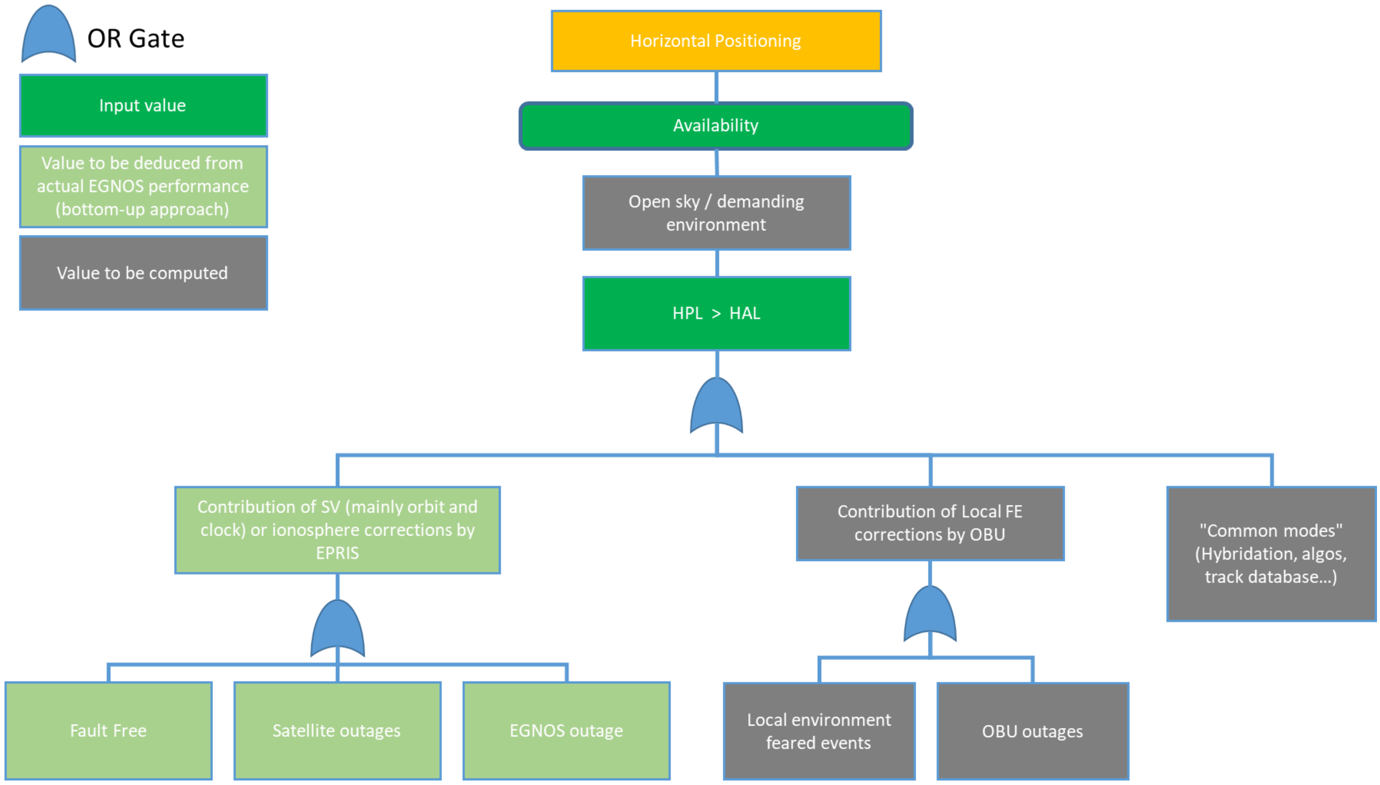


Figure 8: Unavailability allocation Tree

This preliminary Unavailability allocation Tree is conservative, as it considers that the following causes can directly lead to the unavailability of the horizontal positioning at user level:

- Contribution of SV (mainly orbit and clock) or ionosphere corrections by EPRIS
- Contribution of Local FE corrections by OBU
- Common modes due to hybridisation, algorithms…

In theory, the impact of EPRIS outages on the unavailability of the horizontal positioning at user level should be mitigated by the hybridization with position information provided by the OBU for some time. The unavailability allocation tree should be therefore refined later on. Whereas the Integrity Risk allocation tree from Figure 7 and the Unavailability allocation tree from Figure 8 look very similar at a preliminary stage, they may differ significantly once refined.

5.2. RECEIVER MODEL REQUIREMENTS (D220)

The objective of the requirements is to be exhaustive, and as precise as possible in order to facilitate the design and development step of a product that will entirely fulfil the actual needs. It shall be concise and understandable.

These needs have been deeply analysed firstly in the past ([17]) and more recently in the frame of Task 1. It has been identified that the needs are not equivalent according to the application field (insurance telematics, electronic toll, zone billing, taxi meter, car sharing …) or the stakeholder visions (insurance company, TSP, policy maker …). Either the interest of accuracy, integrity and robustness against feared event is completely divergent, or the level of them can differ by an order of magnitude.

Nevertheless, whatever the level of interest is, the specification of the Navigation Subsystem of the OBU has to cover a maximum of items of interest; oppositely, care shall be put to avoid over specification, since it shall reflect the primary objective of road insurance market requirements.

Typically it is considered that the GNSS shall be the corner stone of the Navigation Subsystem to initialize the algorithms, then to contribute basically to the positioning process. Also some sensors have to complement or to substitute GNSS due to the particular case of the urban environment where the GNSS availability is not always granted. Furthermore regarding the spoofing and jamming threats, the level of impact, and thus the level of the robustness expected at receiver level, is classified in [17] as “Low”, “Medium” or “High”. No precise need is quantified behind the request. However it is considered that detection functions have to be specified on that purpose, based on the quantified performance targets given in the last two lines of Table 5. Note that the performance parameters involved in this table are defined in §1.5.

Performance parameters	Targeted value	Comment
Integrity Availability (monthly)	99.9 %	Hourly, in experimentation
Horizontal Position Accuracy (95%)	1m (open, semi-urban, canopy) 5m (tunnels, urban canyon)	[open, semi-urban, canopy] [tunnels, urban canyon]
Horizontal Velocity Accuracy (95%)	1 km/h (PHYD specific)	PHYD specific
Vertical accuracy	Not applicable	No need identified
Time accuracy (95%)	<1s	Aligned with EUSPA reports
Time-To-First-Fix	30s	Mentioned in EUSPA reports
Integrity	HPL<25m HVPL<10km/h With IR = 10^{-5}/h	The IR value comes from RTCM SC134 while previous EUSPA reports mentioned 10^{-4}
Time-To-Alert	Not applicable	No safety-critical application Post-processing billing
Robustness to GNSS interference/jamming	47 < J/S < 59 dB	Variable jammer-to-receiver distance
Robustness to Spoofing	P_{fa} < 1% P_D > 75%	when spoofing signal power ≥ authentic signal power

Table 5 Consolidated performances requirements baseline for the integrity concept

Finally the provision of the SBAS service is a major requirement to be defined in the frame of the project.

All these concerns were considered to define the **functional requirements** and **performance requirements.** Functional requirements specify behaviours of the Rx whereas performance requirements specify quantitatively the performances that shall be achieved by the Rx

Regarding the **performance requirements**, some figures of merit can be specified when the need has been clearly expressed. This is the case of the accuracy (horizontal and vertical). For the protection level (PL) and the integrity risk (IR) it was proposed to keep the initial figure of merit of HPL<25m as no more stringent need has been identified, but to consider an IR of 10^{-5}/h.

In addition to technical requirements (functional and performance), some operational requirements were proposed in order to specify the way the Navigation Subsystem will be used, and the impact on the accommodation of hardware on the vehicle, or software in the OBU.

All detailed proposed requirements can be found in [D220]. As a summary, the following figure gives an overview of the functional architecture considered for the OBU.

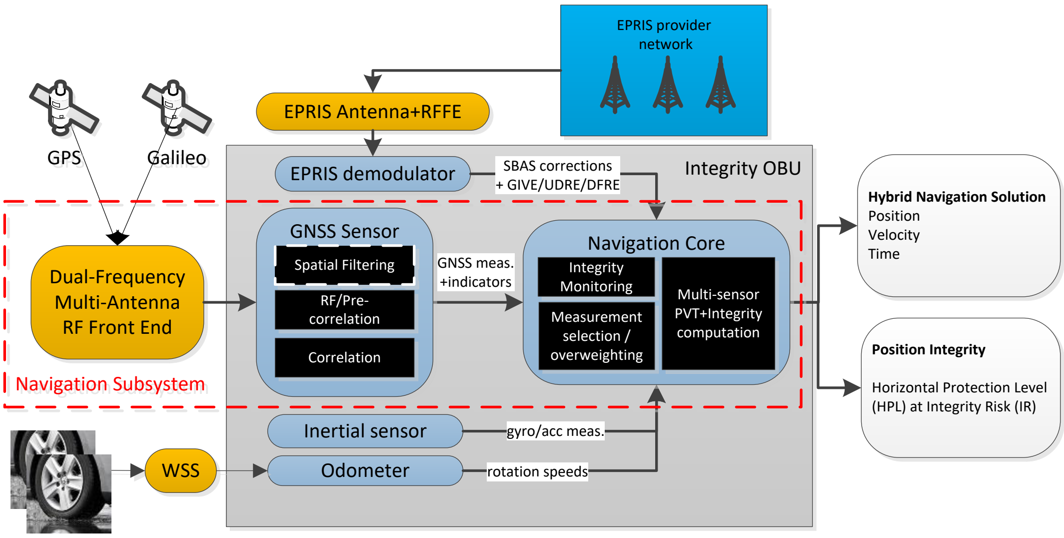


Figure 9 Overview of an integrity OBU model

6. TASK 3 : SERVICE DEFINITION & TASK 5 : ROADMAP FOR SERVICE IMPLEMENTATION

As pointed out above, SBAS systems and in particular EGNOS could efficiently support the EPICURE proposed integrity concept by providing:

- Satellite corrections (orbit and clock)
- a bound of residual satellite orbit / clock errors after these corrections are applied
- ionospheric corrections (for use by single-frequency users only)
- a bound of residual ionospheric errors after these corrections are applied (for use by single-frequency users only)

EGNOS currently provides augmentation to the GPS Standard Positioning Service (SPS). EGNOS augments GPS using the L1 (1,575.42 MHz) Coarse/Acquisition (C/A) civilian signal function by broadcasting correction data and integrity information for positioning and navigation applications over Europe and the neighbouring countries around the Mediterranean Sea. EGNOS delivers three services, free of charge:

- Safety of Life (SoL) Service, able to meet the demands of safety-critical applications in sectors such as civil aviation (e.g. in landing procedures) requiring enhanced and guaranteed performance and an integrity warning system;
- Open Service (OS), EGNOS OS providing positioning, navigation and timing services open to be used by mass-market receivers and common user applications, including automotive, precision farming and surveying.
- EGNOS Data Access Service (EDAS), disseminating EGNOS raw data and corrections and commercial data service via terrestrial networks in real time, within guaranteed maximum delay, security and performance. EDAS is intended for users or for commercial and professional products requiring augmented performances (i.e. further enhancement of GPS position accuracy, improvement of EGNOS OS availability and exploitation of EGNOS integrity data).

In this context, the existing solutions in road domain applications, already benefiting from EGNOS Open Service (OS) and EGNOS Data Access Service (EDAS), cannot fully exploit the level of confidence of the EGNOS corrections provided by the EGNOS Safety Of Life (SoL) service. In fact, the commitment offered by EGNOS service provider for the use of EGNOS Safety Of Life (SoL) messages is tailored to the aviation environment, which is less constrained than the road case.

Moreover, this commitment is valid in the user domain as described in the EGNOS Safety Of Life Service Definition document [4], which is tightly linked to the assumption that the user receiver is compliant to MOPS [2], and is not valid for road users. No commitment is defined so far in [4] related to pseudo-range level performances.

6.1. INTEGRITY COMMITMENT IN THE PSEUDO-RANGE DOMAIN

In sectors other than aviation, various methods can be used to compute a position and a protection level in the position domain. These methods include the mitigation of the local threats that degrade the GNSS signal and the hybridization of the GNSS measurements with other sources. The conversion of the augmentation provided by EGNOS into VPL/HPL depends on the selected method, and it would be complex to add each method in a standard equivalent to the MOPS for civil aviation.
This consideration led to define a new service that is characterized and specified in the pseudo-range domain, then not depending on the user algorithms. In the frame of EPICURE, this service was called EPRIS (EGNOS Pseudo-Range Integrity Service).

The new EGNOS service EPRIS is proposed to be defined through the following key performance indicators:

- the **service area** which defines the Geographical zone where EPRIS service is provided, basically landmasses of the European Union Member States and EGNOS contributing countries;
- the **EPRIS availability** that is the percentage of time when the EPRIS service is available, meaning that the EPRIS message is available at its access point that could be either Signal in Space or EDAS, that is the data access service through the internet and the bounds of residual errors, that is to say orbit and clock residual errors and ionosphere are below their respective thresholds
- the **ranging accuracy at 95%**, which correspond to Satellite residual error and error in Grid ionospheric vertical delay
- the **timing accuracy** that is related to the maximum offset between EGNOS Network Time and GNSS times
- And finally, the **Pseudo-range integrity** that corresponds to the probability over one hour that real pseudo-range errors are not overbounded by their respective estimated bounds (UDRE and GIVE)

EPRIS is proposed to be introduced through consecutive implementation steps to support an early adoption and incremental service introduction. The following sections describe the content of the service solutions proposed by EPICURE on the basis of EGNOS versions. Each version upgrade leads to improve the service availability. The versions are indifferently named “Step x” or “Vx” (abbreviation used in some views to shorten the name of the step).

In these paragraphs, the EPRIS service is also represented in the overall context of Road Insurance Telematics Service provision (RITS). Evolutions of each step are highlighted wrt the current architecture associated to these services, depicted on the following figure:

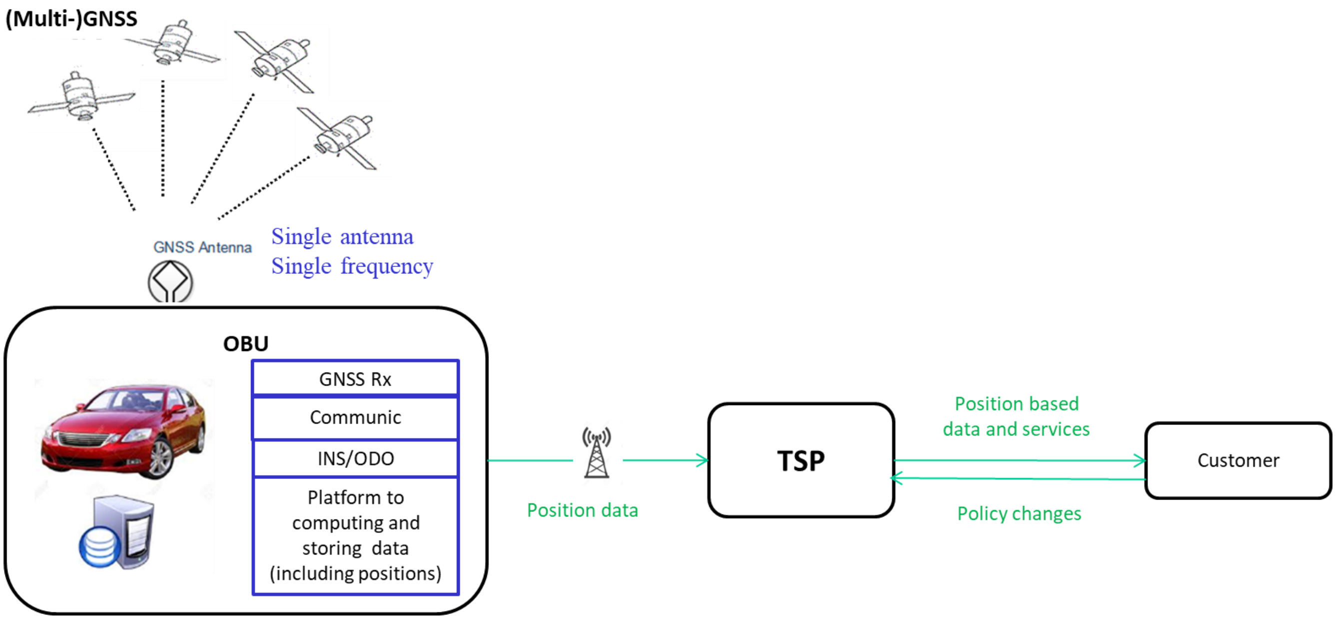


Figure 10: Current architecture associated to RITS services

6.1.1. Step 1: Single frequency Single Constellation Service

The main feature in V1 consists in adding on top of the SiS links used to transmit navigation data (CSP SiS) and augmentation data (GEO SiS) a transmission by a cellular network link.

The EPRIS service contains:

- The dissemination of the augmentation messages through SiS
- The monitoring of the system that could be retrieved by the TSP from the EDAS
- The dissemination of the augmentation messages through EDAS (terrestrial means)
- The dissemination of the GPS navigation data (for A-GNSS) through EDAS

The only evolution of EGNOS system to provide EPRIS V1 is the authentication of the messages at EDAS[15] output.
A qualification of EPRIS requirements (at the level of pseudo-ranges) is needed including the authentication function.

In the global context of RITS service, the changes introduced in the step 1 global RITS architecture (wrt Figure 10) are highlighted in light blue in the following figure:

[15] EDAS should evolve to offer this authentication capability. Other notable requirement applicable to EDAS in step V1 is related to availability :the EGNOS V2 EDAS shall have an availability of 98%

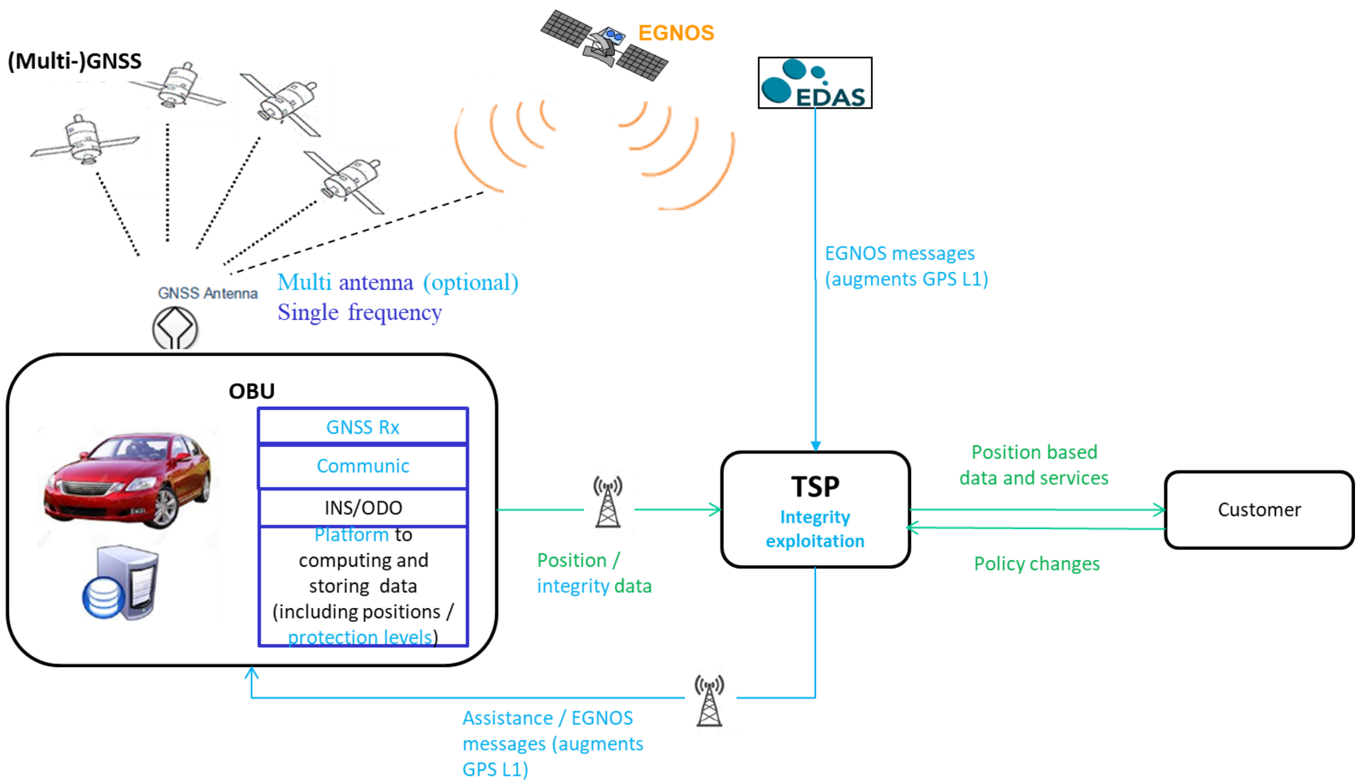


Figure 11: Global architecture associated to RITS services corresponding to EPRIS V1

6.1.2. Step 2: Introduction of Dual frequency Dual Constellation Service

The main evolution in V2 is the introduction of Galileo CSP that enables the DFMC. The backward compatibility of the OBU is ensured to:

- Maintain the service for OBU of previous generations
- Ensure robustness to the loss of the GPS L5 channel when on an OBU of new generation

The EPRIS service contains:

- The dissemination of the augmentation messages through SiS and EDAS[16]
  - Orbit, clock and ionosphere corrections for GPS satellites as in step 1
  - Bound on ionosphere residual errors as in step 1
  - Bound on GPS orbit and clock residual errors as in step 1

[16] EDAS associated to EGNOS V3.2 is assumed to cover already the dissemination of these data, with authentication mechanism. Other notable requirement applicable to EDAS in step V2 is related to availability :the EGNOS V3.2 EDAS shall have an availability of 99.975%

- Orbit and clock corrections for GPS and Galileo satellites (with messages as per EGNOS V3.2 for DFMC users)
- Bound on the GPS and Galileo orbit and clock residual errors (with messages as per EGNOS V3.2)

- The dissemination of the GPS and Galileo navigation data (for A-GNSS) through EDAS associated to EGNOS V3.2
- The monitoring of the system that could be retrieved by the TSP from the EDAS associated to EGNOS V2 and EGNOS V3.2

Step 2 is compatible with GPS single frequency users and DFMC users.

In the global context of RITS service, the changes introduced in the step 2 global RITS architecture (wrt Figure 11) are highlighted in light blue in the following figure:

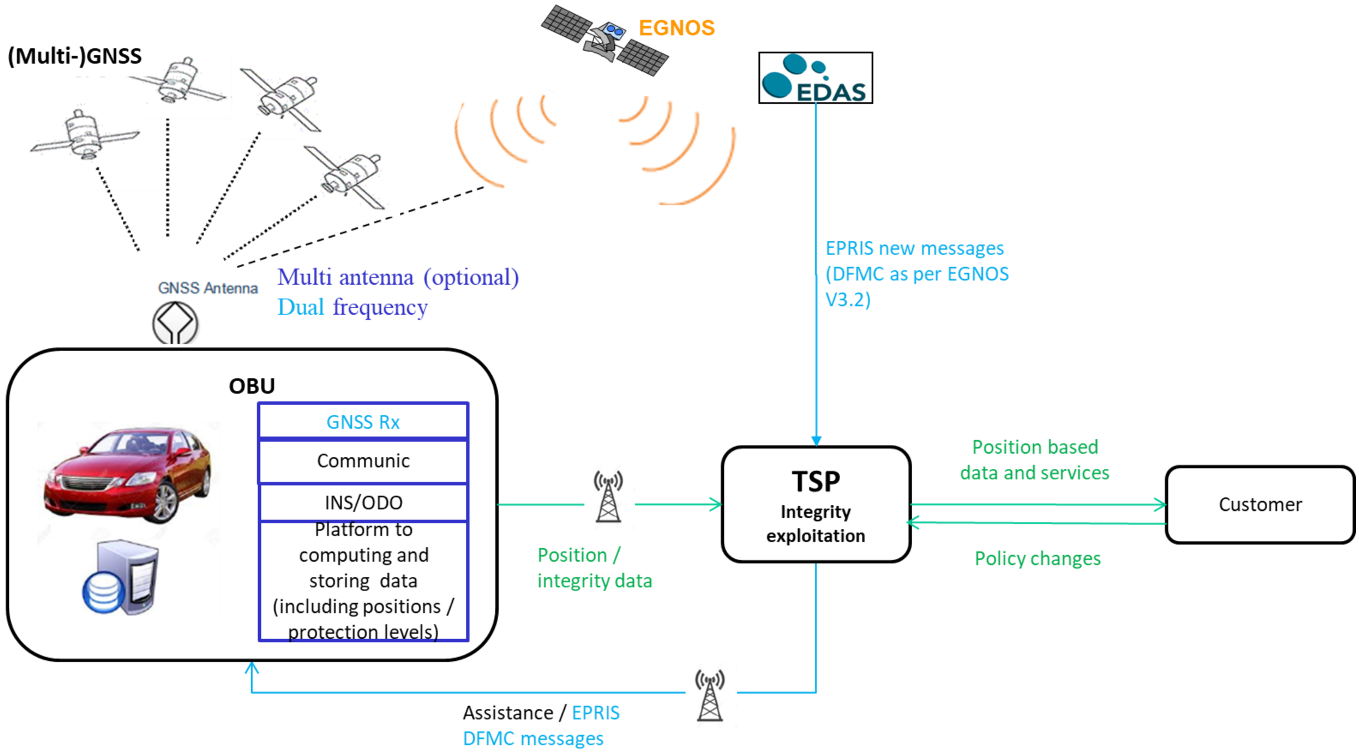


Figure 12: Global architecture associated to RITS services corresponding to EPRIS V2[17]

[17] Note that the diagram focuses on the deltas wrt step 1 but step 2 ensures a backward compatibility wrt step 1

6.2. SYNTHESIS OF THE EPRIS SERVICE LEVEL REQUIREMENTS FOR EACH STEP

The EPRIS service level requirements analysed in [D310] are synthetized in the following table. For the steps 1, the consolidation of the values needs further analyses and experimentations. The presented figures are preliminary and their consolidation is expected in the WP EGNOS V2.4.3 for the maritime applications.

These requirements represent an initial target. They have been derived from the system and service requirements through a paper analysis. In particular, it has been ensured that in fault-free conditions, the $\sigma_{UIREmax}$ and the ranging accuracy are consistent considering the confidence levels (respectively 99.999% for integrity and 95% for accuracy). Through experimentations done in the frame of the study H2020-ESA-035 for evolution of EGNOS missions for aeronautical users, the performances in step 2 (EGNOS V3 in DFMC) presented in this table are anticipated to be compatible with EGNOS V3.

The performance indicators used in the following table are defined hereafter:

- SREW (Signal Ranging Error Worst user location): The Satellite Residual Error for the Worst user location (SREW) is defined as the pseudo-range error due to the remaining satellite ephemeris and clock errors, after corrections, for the worst user location of the service area.
- GIVD (Grid of Ionosphere Vertical Delay) error: The Grid Ionospheric Vertical Delay Error (GIVD Error) is defined as the vertical pseudo-range error at the considered ionospheric Grid Point (IGP) location due to the remaining ionospheric delay after applying the GIVD corrections.
- Protection levels (σ_{flt}, σ_{UIRE} *and* σ_{DFRE}): the range domain protection levels are the upper reliability limits for the GNSS range error. This is illustrated in the figure below for the case of UDRE:

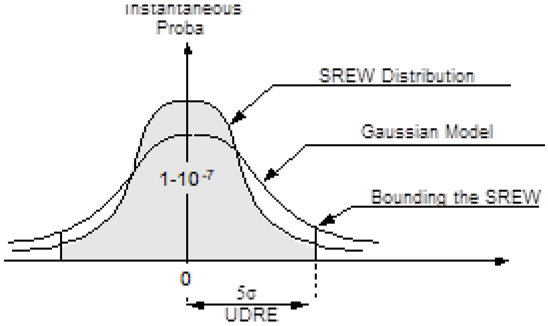


Figure 13: SREW bounding process

The bounds are computed using:

- The standard deviations of a Normal distribution associated with the user differential range error for a satellite after application of satellite / clock corrections (σ_{UDRE} / σ_{DFRE})
- The standard deviation of a Normal distribution associated with the residual ionospheric vertical error at an ionospheric grid point for an L1 signal (σ_{GIVE})

σ_{UDRE} / σ_{DFRE} and σ_{GIVE} are broadcasted by the system. σ_{flt}, σ_{UIRE} *and* σ_{DFRE} are the instantiations of the standard deviation for a line of sight respectively for orbits and clock in SF, ionosphere in SF and orbits and clocks in DF.

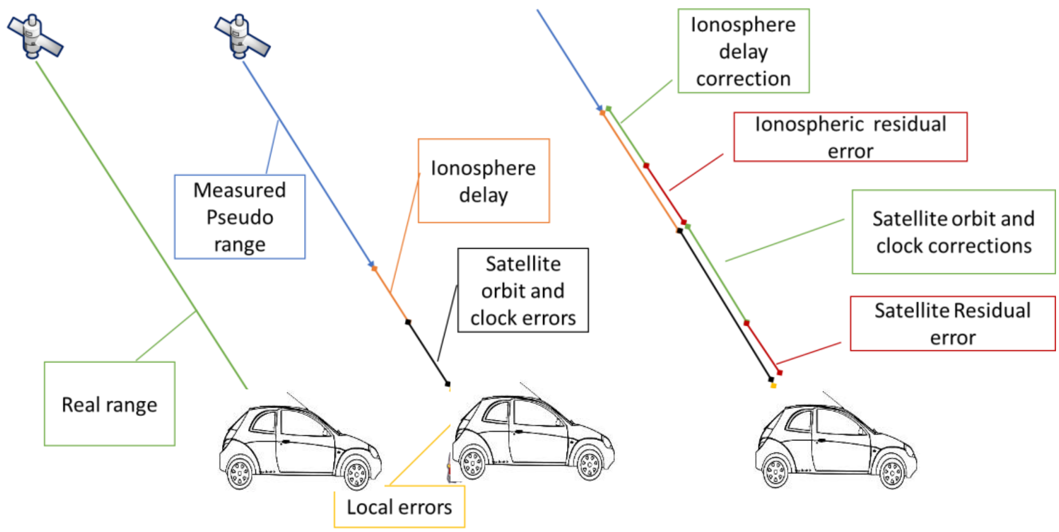


Figure 14: Definition of GIVD error and SREW

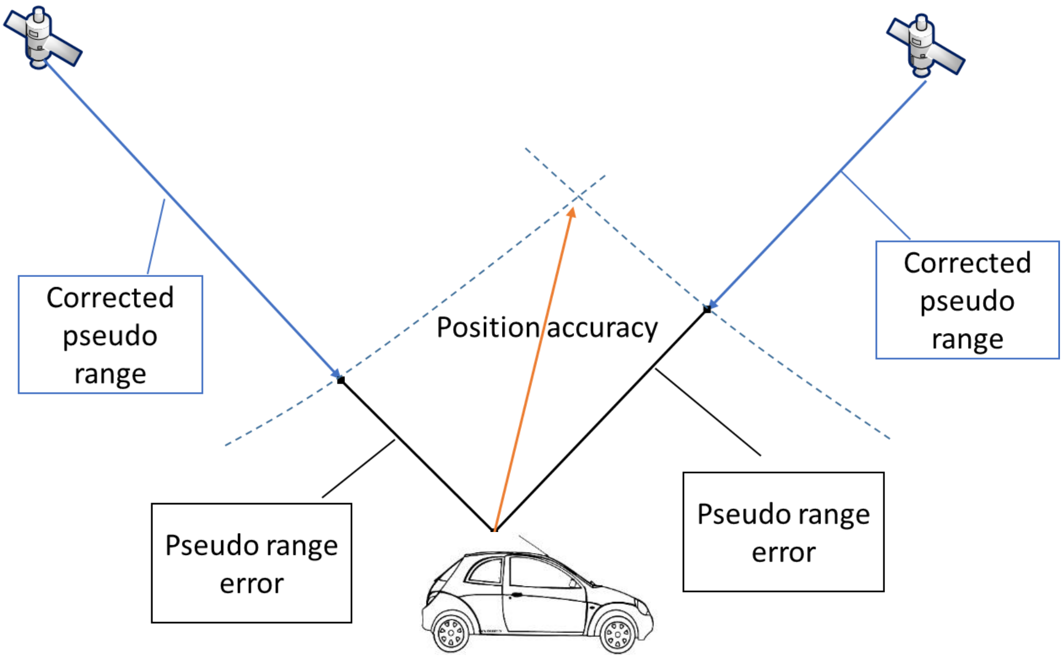


Figure 15: Relation between pseudo-range error and position error

For step V1, one maximum sigma is defined for satellite σ_{flt_max}, which is the maximum allowed value for σ_{flt} (equation A-50 of MOPS [2]) and for ionosphere grid point σ_{UIRE_max} which is the maximum of σ_{UIRE} (equation A-58 of MOPS [2]).

For step V2, there is only one value σ_{DFRE_max} which is the maximum of σ_{DFRE}.

Performance parameter	Target performance Step 1	Target performance Step 2[18]	Comment/Detail
Service Area	European Union Member States + EGNOS contributing countries landmasses	European Union Member States + EGNOS contributing countries landmasses	
EPRIS availability	99% via SIS [19] 97% at EDAS access point [20]	99.95% at EDAS access point	Via SIS: bottom-up approach Via EDAS: bottom-up approach in step 1 and top-down approach in step 2, assumed to be met by an updated EDAS (overcoming the fact that SIS is not enough available in road environments)
Ranging Accuracy (95%)	Satellite ($SREW_{95\%}$) 1.5 m Iono (GIVD $error_{95\%}$) 2.2 m	Satellite ($SREW_{95\%}$) 0.7 m	
Max offset ENT GNSS time	10 µs	10 µs	

[18] Step 2 is backward compatible with step 1. However, for the sake of clarity, performances offered in step 1 are not repeated in this column

[19] In open sky environment, accounts for EGNOS availability, message availability and performance $\sigma_{flt} < \sigma_{flt\_max}$ and $\sigma_{UIRE} < \sigma_{UIRE\_max}$

[20] Accounts for EGNOS availability, message availability and performance $\sigma_{flt} < \sigma_{flt\_MAX}$ and $\sigma_{UIRE} < \sigma_{UIRE\_max}$

Performance parameter	Target performance Step 1	Target performance Step 2[18]	Comment/Detail
Pseudo-Range Integrity	σ_{flt_max}[21] =1.6 m σ_{UIRE_max}[21] =15 m IR=10^{-5} /h	σ_{DFRE_max}[21] = 3.6m IR = 10^{-5} /h	3.6 m is obtained from a top down approach described in [D310]. With a bottom-up approach, in step 2 the bound on SREW σflt_max is inflated by the L1-L5 iono-free factor. A very pessimistic assumption that the iono-free amplification (2.6) applies to the whole part provides a bound on the reachable performance (2.6*1.6 m=4.16 m). Step 2 is nevertheless an improvement with respect to step 1 since σDFRE_max in step 2 is lower than the combination (in root square sum) of σflt_max and σUIRE_max from step 1 (15 m).
Continuity	None	10^{-2} /10 min	

Table 6: EPRIS Performance Requirements

[21] Max values are defined for KPIs directly entering into protection levels computations (because protection levels max values have to be compared to alarm limits to derive availability)

6.3. HIGH LEVEL ROADMAP

The roadmap of EPRIS service introduction is described at very high level in the following figure below:

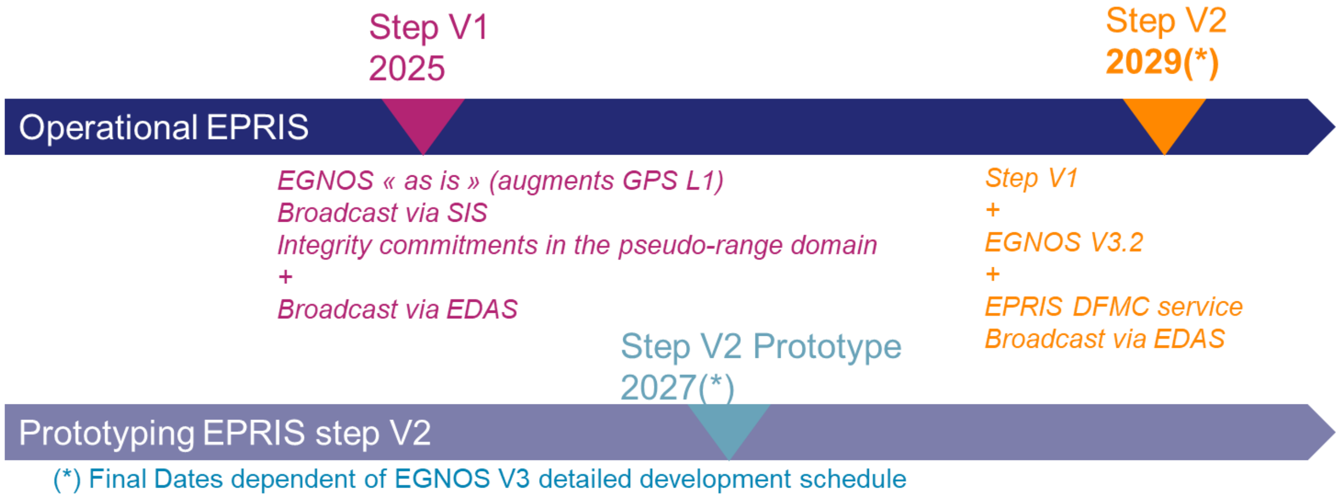


Figure 16: Steps of the EPRIS deployment

More details on steps 1 and 2 schedules can be found in [D510].

The main activities on the critical path of step 1 service declaration are the following ones:

- Activity leading to the consolidation of service level performances (contribution expected from the EGNOS V243 WP on maritime service)
- Tender process to officially launch the development and qualification of step 1
- Standardisation linked to GPS single frequency service, starting from existing 3GPP standards
- GNSS receiver development according to these new standards
- EPRIS V1 service validation

In the frame of step 2 service declaration, the critical path is tighly linked to EGNOS V3.2 development and qualification, followed by the delta-qualification needed for EPRIS V2 specific performance targets (in the pseudo-range domain).

6.4. Proposed Road Insurance Telematics Service provision scheme

The preliminary service provision scheme is depicted in the following figure.
A Service Access Point (SAP) appears in this figure. Even though the SAP is not an essential stakeholder, for some EGNOS based road services (e.g. insurance telematics), it could have an interesting role for the provision of EGNOS operation information. In the long term, it is foreseen that the National Access Points (NAP) will increase its relevance because other road apps will require such information.

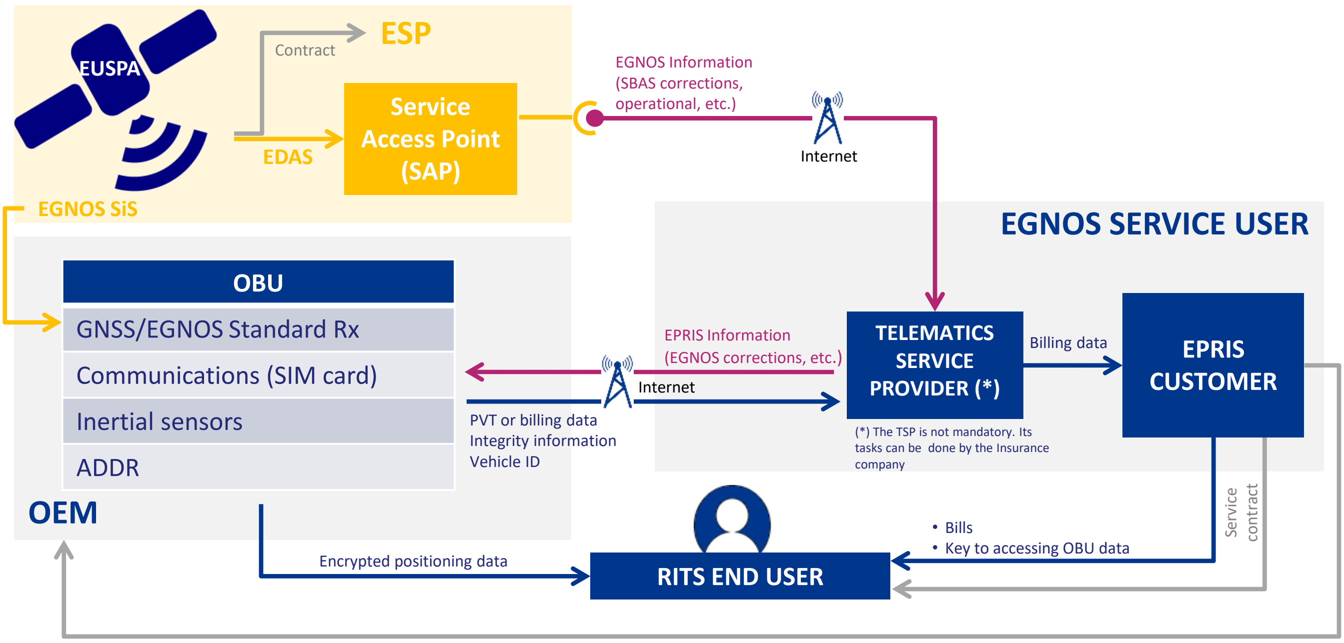


Figure 17: Proposed road telematics Service Provision Scheme

7. TASK 2: EXPERIMENTATION OF THE PROPOSED SYSTEM AND USER LEVEL INTEGRITY CONCEPT (D230)

7.1. ENVIRONMENTAL SCENARIOS

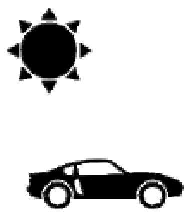
This section shortly describes the environmental scenarios of particular relevance for the collection of real data in order to assess the integrity concept.

There are several past and current works targeting a standardised classification of the road environments for satellite users (including GNSS users), especially in urban areas. One possible approach is the quantitative characterisation of the architectural elements (buildings) and natural elements (trees) surrounding the GNSS user: determination of the portion of the sky being obstructed, height of the building, type of surfaces, height of trees and foliage density…

However, in the frame of this contract, a conservative and simpler approach has been considered. The reference trajectories have been chosen as homogenous as possible and as typical as possible when collecting real data. This participated to a simpler analysis of the results.

In case the chosen itineraries concern different types of road environments, a pre-analysis of the trajectory has been done to extract periods of time that best match a given environment type, according to the use case under analysis.

7.1.1. Open sky



Typically rural areas, where all GNSS satellites are visible (Elevation > 5°)

Building are isolated

It is the reference environmental scenario for the GNSS receiver performances.

Low Horizontal Protection Levels are expected

Very high availability of the GNSS-only PVT solution

7.1.2. Semi-urban

Small (<10m) to medium(15m) height residential buildings

GNSS satellites with very-low elevation are not visible

In the vicinity of buildings

- *multipath is detected in case a satellite with the appropriate* *elevation is visible on the opposite side.*

- *The protection level arises*

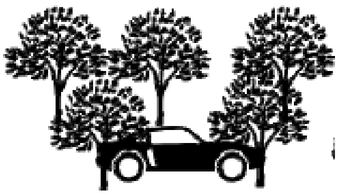
Availability is not deeply affected as a high number of satellites remains

- *Additional sensor can bring information to keep PVT on the correct lane of the street*

7.1.3. Canopy

Tree foliage is dense and a few meters above the GNSS antenna,

The propagation channel suffers from fading, entailing a diminution of C/N0 ratios. GNSS tracking loops errors increase, as well as estimations.



The GNSS PVT availability remains high when trees are isolated.

In case of contiguous tree foliage, coupling with INS improves the accuracy and ensures continuity of the navigation solution

7.1.4. Tunnel

No GNSS satellite is visible

The addition of inertial sensors is key to maintain the navigation solution on track

The GNSS/INS tight coupling is used nominally before the signal outage occurs and during the tunnel, INS measurements are integrated using the initial position at the tunnel entry. Velocity information given from the odometers is also used as input to the hybridisation integration filter.

The PVT accuracy is linked to the IMU short-term to mid-term performances and is likely to increase until the end of the tunnel is reached

7.1.5. Urban canyon

Streets are narrower and the height of buildings is over ~15m.

Only a few satellites are visible:

- *Very high elevation*
- *Available satellites azimuths are close*

Hence, the DOP is degraded (high), the positioning accuracy is affected.

PVT Integrity is affected by Multipath

GNSS-only availability may not reach the requirement, even with multiconstellation

Other sensors are necessary to maintain the positioning accuracy (tight-coupling with a few satellites)

7.2. EXPERIMENTATION SET-UP OVERVIEW

The real data collect was performed using the experimental vehicle VERT[22] belonging to University Gustave Eiffel with the following objectives:

- Provide reference trajectories with a very high accuracy of every point of interest (POI).
- Record raw GNSS signal data (In-phase and Quadrature binary files), that will be processed with an integrity receiver prototype tuned with integrity algorithms as described above.
- Record Commercial-Off-The-Shelf (COTS) receivers' data in order to benchmark algorithms and receiver developed in EPICURE
- Record sensor data such as Inertial Measurement Unit, Wheel speed sensor data, synchronized with raw GNSS signal data (and reference trajectories) for later replaying.

The VERT was designed as a mobile laboratory dedicated to very precise estimation of car trajectory. This design eases installation of new sensors to be tested while providing an accurate reference trajectory for comparison purposes. The figure below shows the system components classified into four categories while the table below provides additional descriptions of these items.

[22] Vehicle for Experimental Research on Trajectories

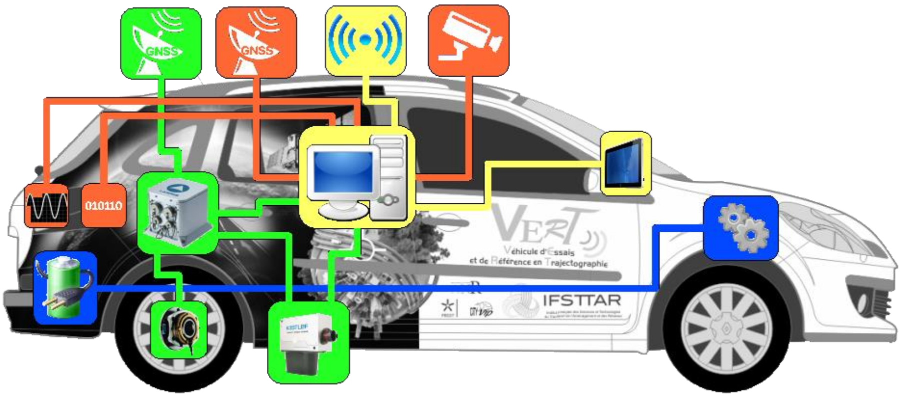
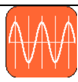


Figure 18 The architecture of the VERT: power supply group highlighted in blue; sensors to be tested, in red; acquisition and visualization group, in yellow; Reference Trajectory Measurement System (RTMeS), in green.

System	Icon	Description
Power supply		A hardware load balancer regulates the battery load of the vehicle between the primary and secondary battery.
		System including a 12VDC-95Ah battery, a 220VAC-2000VA sine-wave inverter and two 12VDC/12VDC current converters.
Sensors		Analogic sensors comprising, for example, gyroscope, accelerometer, electronic clutch pedal position sensor, etc. Data acquisition board with 16 analogic inputs, 24 digital inputs/outputs, 2 readers
		Numeric sensors, i.e., any sensor delivering data via USB, RS232, RS485, bus CAN, bus IEEE, IP Ethernet
		GNSS receivers : dual- or single-frequency, multiple GNSS constellation (GPS/GLONASS/GALILEO)
		Video camera
Acquisition system and Human interface		A two computer system: one for reference trajectory estimation and the other for acquiring additional sensor data; a unique monitoring system (keyboard/mouse/screen) via a switch.
		Front seat screen for duplicating the rear one
		Wireless communication: currently WiFi, future 3G modem
Mobile Reference Trajectory Measurement System (RTMeS)		GPS and GLONASS dual-frequency receiver
		Navigation grade INS inertial unit (tri-axis accelerometer and fiber optic gyroscope)
		Electronic Stability Program using optocouplers-based Hall effect sensors with 48 pulses per wheel rotation
		Optical encoder with up to 1000 pulses per meter.

This vehicle was used to acquire data from the 1st of June 2021 to the 3rd of June 2021, in the various typical environments described before (Open Sky, Semi-urban, Canopy, Tunnel and Urban Canyon), found around Thales Alenia Space in Toulouse, France. This led to data collected over a cumulated trajectory of 226km, representing more than 10 hours of data, with both mono-antenna and multi-antenna configurations.
The figure below shows the recorded trajectory and some photos of the vehicle.

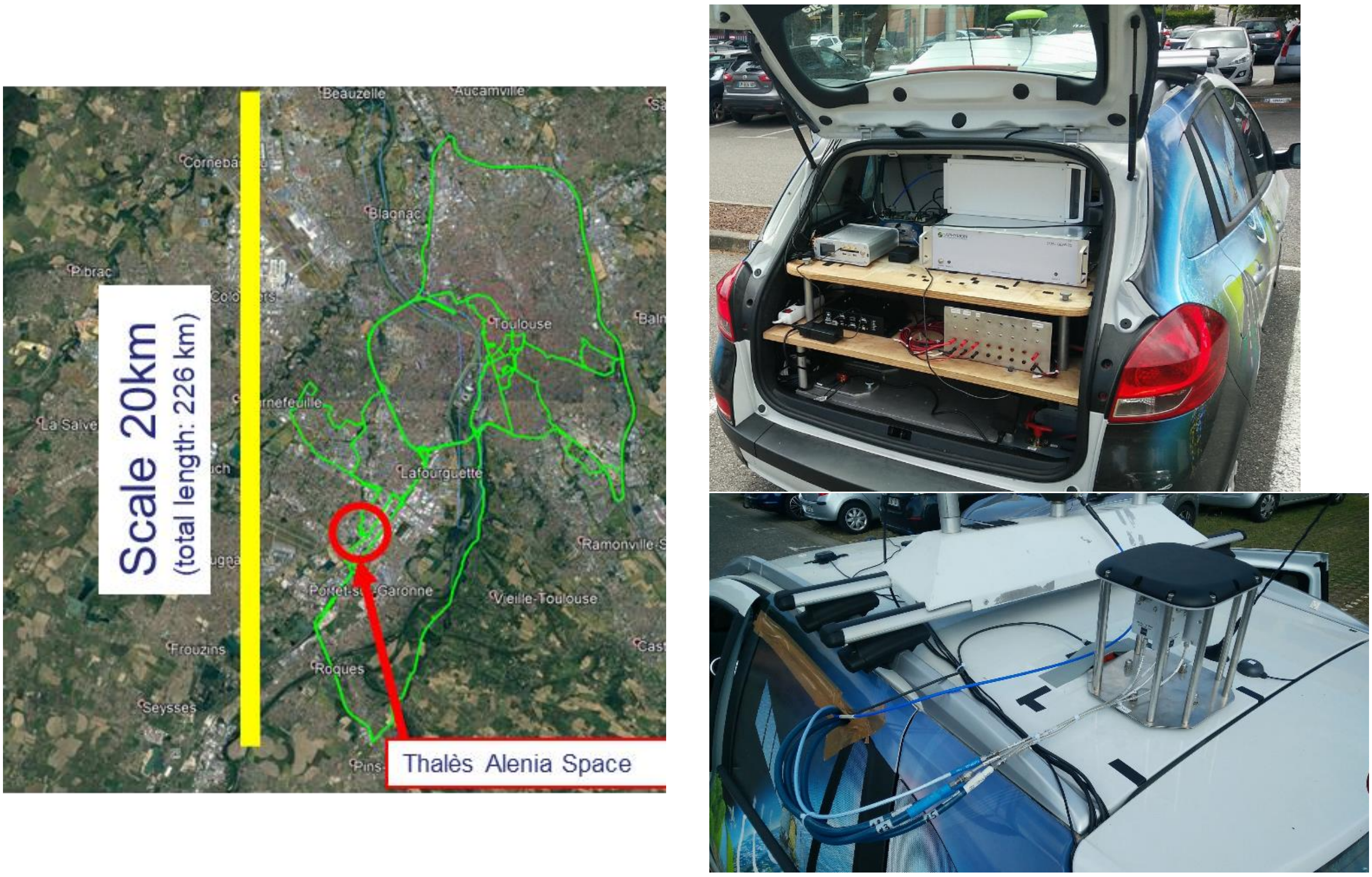
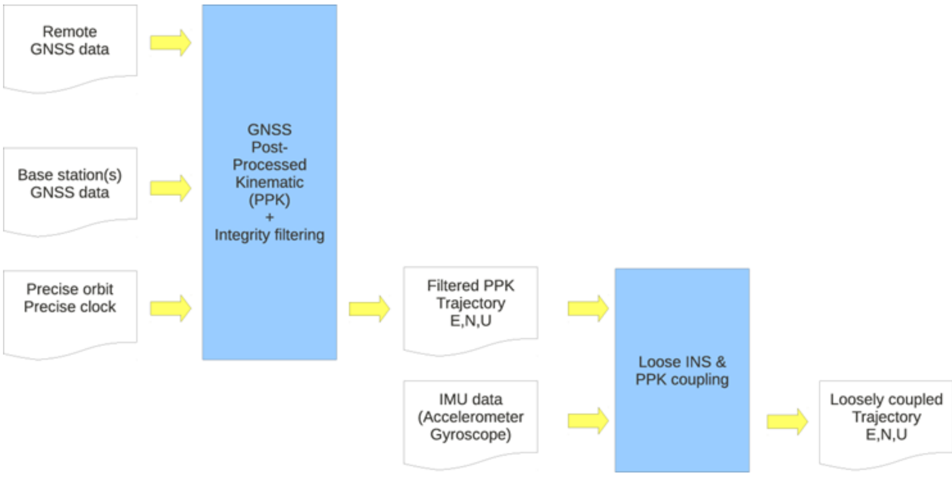


Figure 19: EPICURE data collection recorded trajectory and photos of the used vehicle

7.3. SPECIFIC SET-UP OF THE EXPERIMENTATION

7.3.1. Final ground truth architecture retained

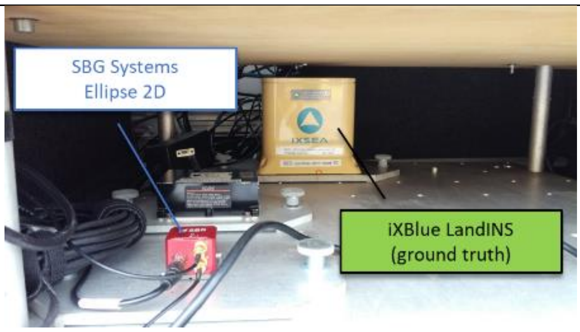
The final ground truth post-processing retained for EPICURE was the loosely coupled: INS/GNSS-PPK/ with Precise orbit and clock:

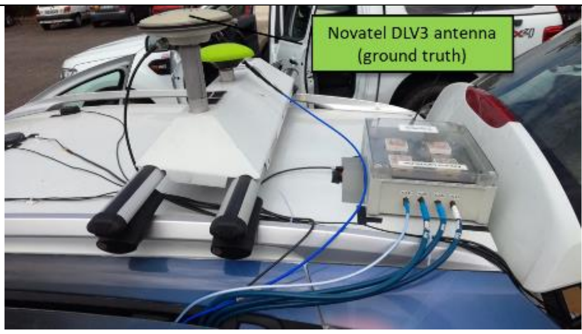


As a reminder, ground truth is composed of a high-end GNSS equipment (Novatel DLV3 GNSS receiver) coupled with a high-end Inertial Navigation System (iXBlue LandINS), coupled to odometer sensor. Even if the INS can deliver real-time output, best results are obtained in post-processing mode. In our case, we:

- first post-processed GNSS data from Novatel DLV3 using a base station to produce PPK solution (equivalent to RTK for off line mode), and precise orbit and clock (final ones, 18 days old). Then we filtered out GNSS PPK to only keep point with fixed (ambiguity solved) with a standard deviation less than 1 m. This correspond to points of quality Q1, Q2 and Q3 on Grafnav software (Novatel suite).

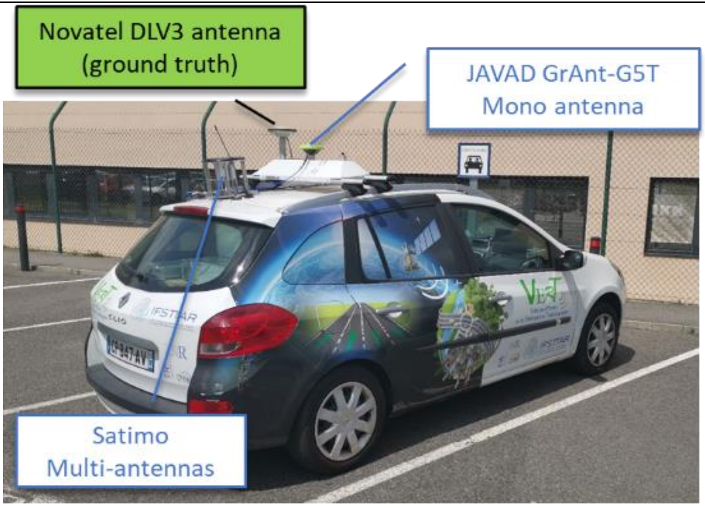
- secondly, once PPK is produced and filtered, we fused it (loose coupling) with inertial data (accelerometer and gyrometer @100Hz) recorded by iXBlue LandINS, in order to produced what we call ground truth or reference trajectory.





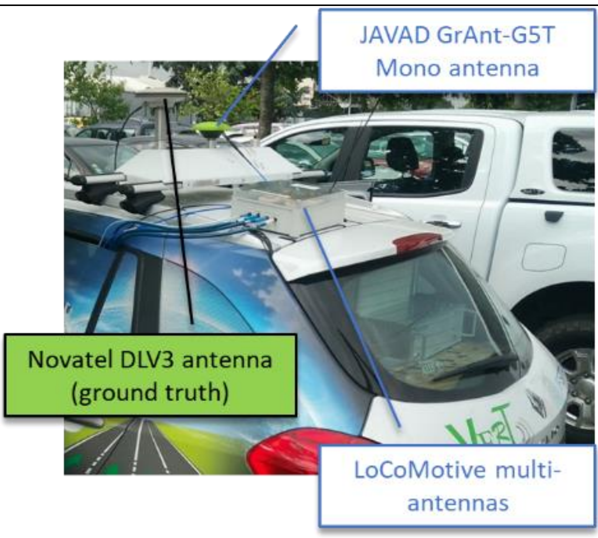
7.3.2. Other equipment set-up

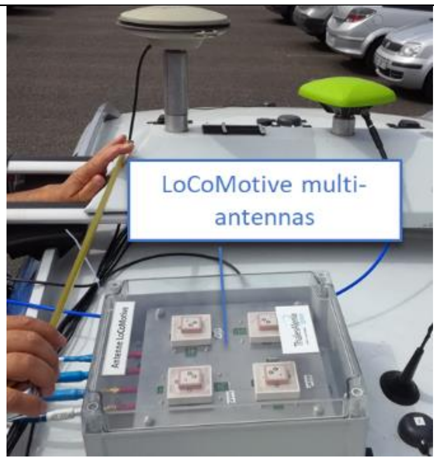
On the figures below, other test equipment installation are shown.



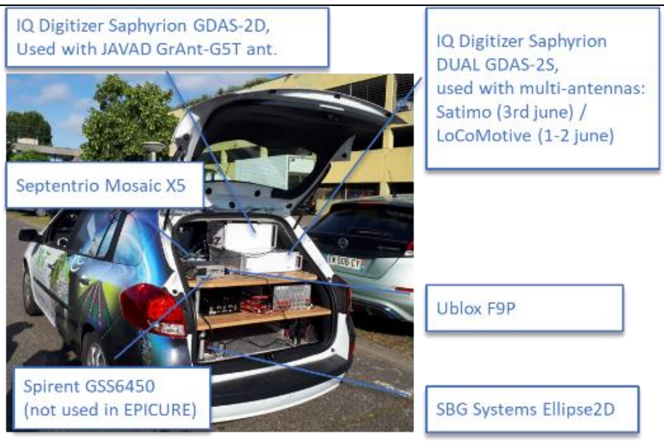
External point of view

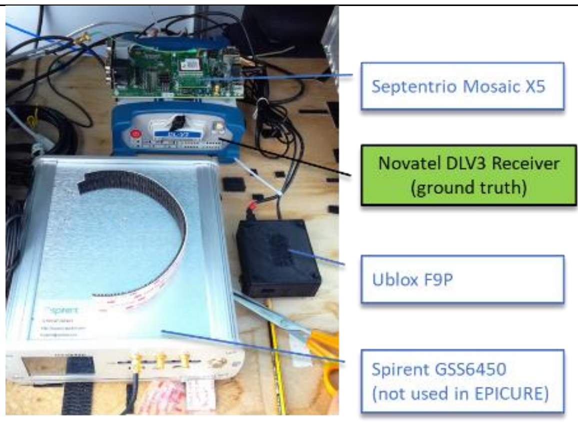
Zoom on Satimo multi-antennas
(used the 3rd of june)





Zoom on LoCoMotive multi-antennas
(used the 1st & 2nd of june)





7.4. RESULTS WITH RESPECT TO EPRIS PERFORMANCES

The above described experimentation set-up allowed to collect data in order to experiment user level integrity concept and algorithms.
As this user level integrity concept relies on EPRIS service to cope with the ionosphere and satellite orbit and clock threats, it is also necessary to analyse in parallel the performances achieved by EGNOS in the pseudo-range domain.

The experimentation allowed to assess the following KPIs linked to EPRIS step 1 service definition with the current EGNOS available Signal In Space.

Performance parameter	Target performance Step 1	Assessed KPI as part of the experimentation
Service Area	European Union Member States + Norway + Switzerland landmasses	This is not a KPI, but rather an assumption For the experimentation, EGNOS V2 service area was considered as an assumption to compute the SREW and to select the IGP grid displayed on the GIVDerror maps
EPRIS availability	99% via SIS 97% at EDAS access point	Could not be assessed during the experimentation due to tools limitations

Performance parameter	Target performance Step 1	Assessed KPI as part of the experimentation
Ranging Accuracy (95%)	Satellite ($SREW_{95\%}$) 1.5 m Iono (GIVD $error_{95\%}$) 2.2 m	Satellite ($SREW_{95\%}$) assessed for the three days of the experimentation Iono (GIVD $error_{95\%}$) assessed for the three days of the experimentation
Max offset ENT GNSS time	10 µs	Could not be assessed during the experimentation due to tools limitations
Pseudo-Range Integrity	σ_{flt_max} =1.6 m σ_{UIRE_max} =15 m IR=10^{-5} /h	σ_{flt_max} assessed for the three days of the experimentation σ_{UIRE_max} assessed for the three days of the experimentation IR at a level of 10^{-5}/h cannot be assessed with three days of experimentation. Assessment of safety indexes (SFI) allows to contribute to this verification

The following figures represent for each day of the data collection, and for each satellite in the PRN mask of EGNOS, the 95 percentile of the satellite residual error for the worst location in the service area.
The observed values range from about 0.6m to about 2.1m.

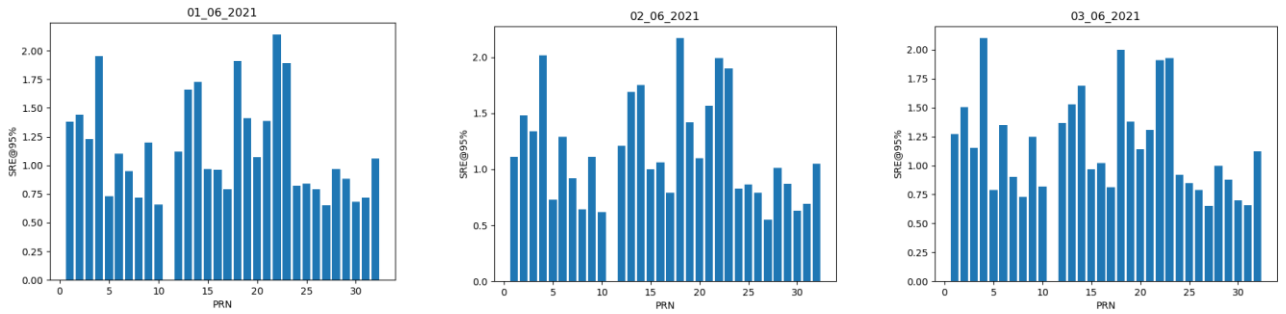


Figure 20 : 95 percentile of the satellite residual error for the worst location in the service area - meters

Now, the following graphs allow to assess another Key Performance indicator targeted for the future EPRIS service, which is related to the **Pseudo-range integrity**.
It relies on the Safety Index (SFI), which gives the ratio between the Satellite Residual Error for the Worst user location in the service area and the sigma UDRE defined as per MOPS standard

(as the standard deviation of a Normal distribution associated with the user differential range error for a satellite after application of satellite and clock corrections).
The following figures represent for each day of the data collection, and for each satellite in the PRN mask of EGNOS, the maximal values of safety indexes.
The obtained results are compatible with non-integrity risks ranging from 10^{-4} to 10^{-7} (because SFI < 5.33 and 3.89).[23]

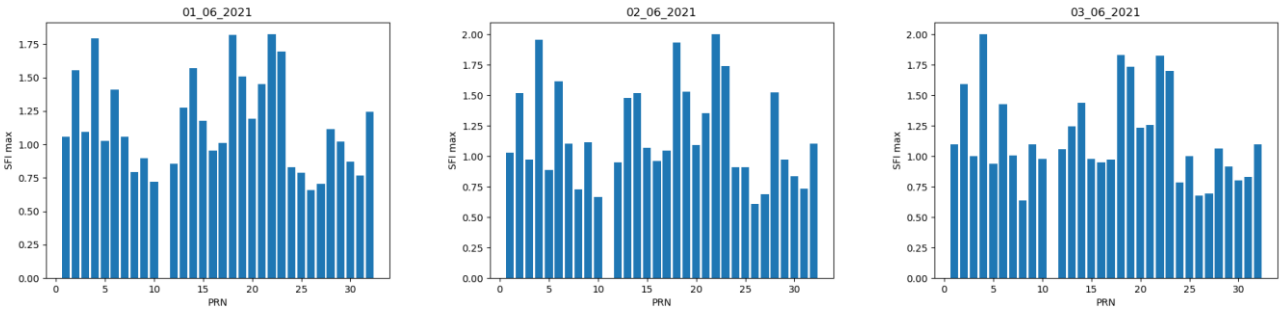


Figure 21: Maximal values of satellite safety indexes

The third type of performed analysis, assesses the Grid Ionospheric Vertical Delay Error which contribute to the **ranging accuracy** performance. The following figures represent for each day of the data collection, and for the ionospheric grid points defined in the EGNOS mask, the 95 percentile of the error in Grid Ionospheric Vertical Delay.
The observed values are for the majority below 2m, with some exceptions at the edge of the service area.

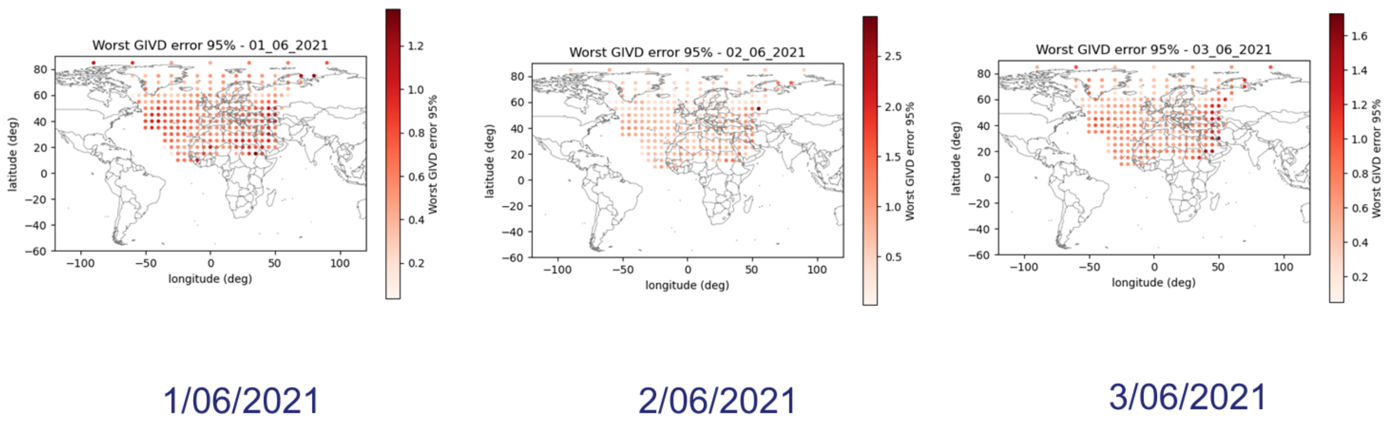


Figure 22: 95 percentile of the error in Grid Ionospheric Vertical Delay – meters

[23] For a level of 10^{-7}, SFI would be expected to be less than 5.33.
For a level of 10^{-4}, SFI would be expected to be less than 3.89.

Finally, the same way as we have previously analysed the satellite related safety indexes, we have also assessed the ionosphere related integrity, which is also related to the **Pseudo-range integrity**.
In this case, the safety Index is the ratio between Grid Ionospheric Vertical Delay error and the sigma GIVE defined as per MOPS standard (as the standard deviation of a Normal distribution associated with the residual ionospheric vertical error at an ionospheric grid point for an L1 signal).
These graphs represent for each day of the data collection, and for the ionospheric grid points in the mask, the maximal values of safety indexes.
Here again, the obtained results are compatible with non-integrity risks ranging from 10^{-4} to 10^{-7} (because SFI < 5.33 and 3.89).

Note that the SFI being the ratio between GIVDerror and sigma_GIVE, low SFI can result from big sigma_GIVE.

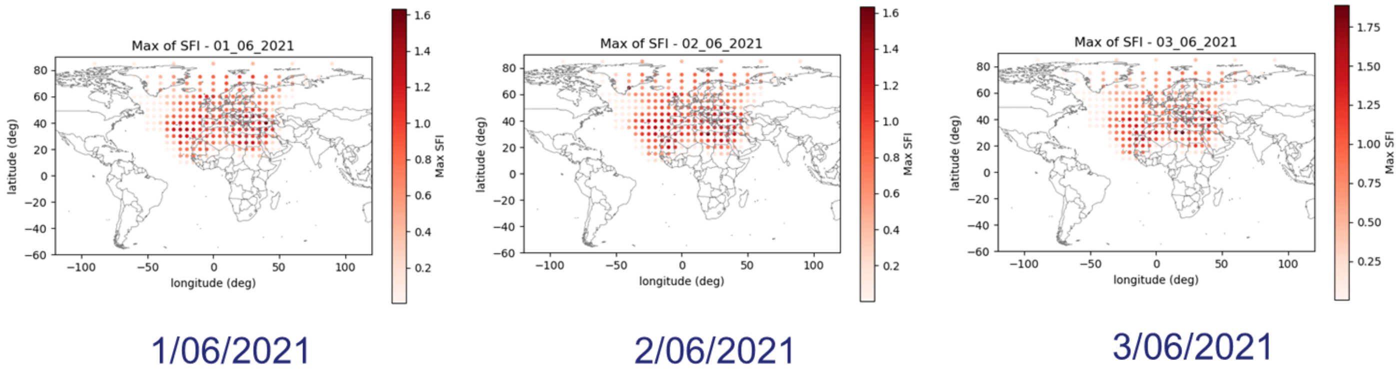


Figure 23: Maximal values of ionosphere safety indexes

7.5. RESULTS WITH RESPECT TO USER LEVEL INTEGRITY PERFORMANCES

Different areas-of-interest were explored during the three days of real data collect. The whole description, including every areas-of-interest for the whole real data collect, is available in [D230]. In the following paragraphs we detail the environments corresponding to the results presented below in §7.5.4, 7.5.5 and 7.5.6,

7.5.1. Urban canyon environment

The afternoon of June 1st and the morning of June 3rd explored urban canyon environments:

- The first section called Urban Canyon #1, is represented in Figure 24 :

Figure 24 – Urban canyon #1 explored on June 1st PM

- The second section called Urban Canyon #2, is represented in Figure 25 :

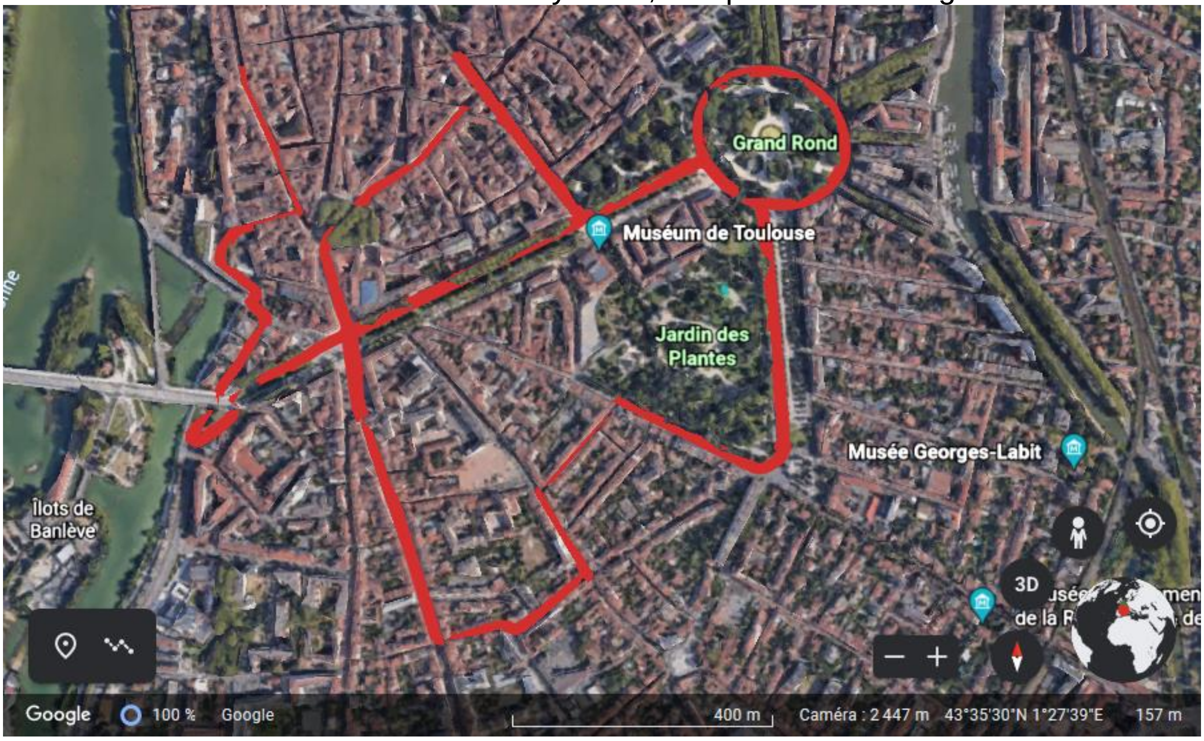


Figure 25 – Urban Canyon #2 explored on June 1st PM

7.5.2. Tunnel environment

A tunnel was explored on June 3rd AM at the parking of the Carme, in Toulouse city-centre. This tunnel is represented in Figure 26:

Figure 26 – Tunnel #2 (climb) and Tunnel #3 (go down) explored on June 3rd AM

7.5.3. Main outcomes

To reach the expected service requirement a combination of technological solutions has been proposed and evaluated on real signal collected in various environements representative of road users. The most interesting solutions are :

- EGNOS EDAS use to
  - reduce uncertainty of orbito and synchro and ionosphere errors and thus improve positioning accuracy
  - get reliable integrity bounds of remaining errors after corrections (HPL reduction)
  - without the drawback of unavalability of the EGNOS GEO SiS signal
- Multi-antenna to improve multipath detection and reduce the MI rate.
- Hybridization to improve accuracy, reduce HPL, improve fault detection and allow navigation when no GNSS signal is available (tunnels)

Dual constellation has been discarded from the final performance test because EGNOS corrections are only available for GPS L1 so far. But of course the final solution will beneficiate from the addition of another constellation as soon as EGNOS DFMC service is available.

DFMC performance has been also discarded from the final performance for the same reason but also because the low number of dual frequency GPS satellites (L1/L5) and degradation of receiver noise with iono-free combination imply that improvement on accuracy and protection level has not been observed. Other type of multi-frequency combination (e.g. estimation of ionospere delay as part of Kalman filter - independent or PVT –) may change this conclusion, as well as the introduction of EGNOS DFMC service and the GPS L5 Full Operational Capability.

The most promising Thales prototype configuration has also been benchmarked with respect to three COTS receivers embarked during the same data collection[24], which results are presented in the following paragraphs for the most stringent scenarios (so-called Urban#1, Urban#2 and Tunnel#2 scenarios). More details can be found in [D230].

The benchmark comparison is performed on the 5 different metrics:

- Horizontal Position Accuracy (HPE or HPA): percentiles (50-75-95)[25] of HPE values
- Horizontal Position Protection Level (HPL): percentiles (50-75-95) of HPL values
- Misleading Information Rate (MIR): percentage of time where HPE > HPL
- Horizontal Position Availability: percentage of time where Position is available
- Horizontal Protection Level Service Availability: percentage of time where HPL<=25m

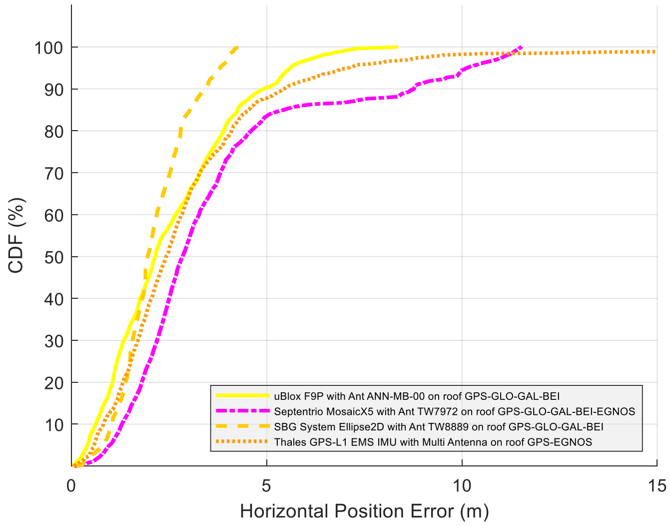
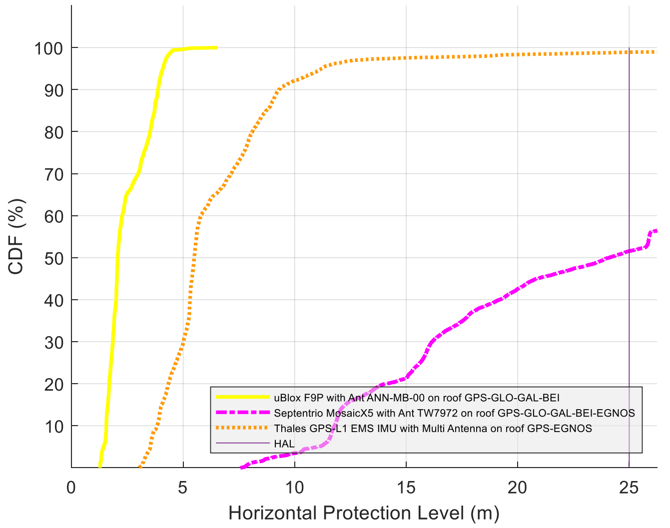
Note on Protection Level: not all COTS have the ability to output protection level values. Among the 3 COTS, only Septentrio MOSAIC-X5 has such a feature. Ellipse 2D has not such feature; and for ublox F9P, a similar feature was used for Protection Level feature: accuracy estimation. Empirical tests lead authors to use 3 times this value as a Protection Level value[26]. Recently, ublox has made available Protection Level on its F9P with the last firmware update (December 2021); but unfortunately, this was not available in June when the data was recorded.

[24] Initial purpose of the benchmarking was to be able to compare outcome of EPICURE algorithm with up-to-date commercial devices. Thus, 3 GNSS based positioning systems representative of automotive domain, i.e. “low cost”, and in the current trend for future automotive applications, has been selected
The following 3 devices have been identified and used for benchmarking purpose:
- GNSS Rx Mosaic X5 from Septentrio : multi-frequencies / multi-constellations
- GNSS Rx F9P from Ublox : dual-frequencies / multi-constellations
- INS Ellipse 2D from SBG System : INS – dual RxGNSS (2xF9P inside)

[25] These percentiles values (50-75-95%) are the ones recommended by EN16803. Usage of 68-95-99.7% is NOT recommended because referring to Gaussian law (1-2-3 sigma). In GNSS road domain, errors and residuals don't follow such a law ; that is why EN16803 chose these percentiles.

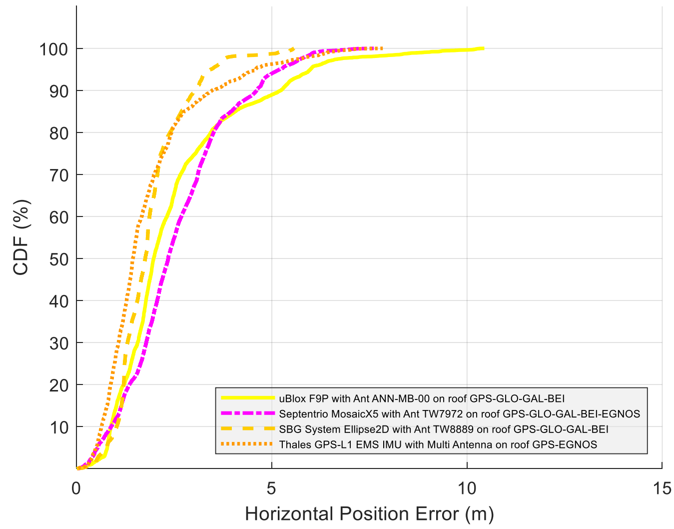
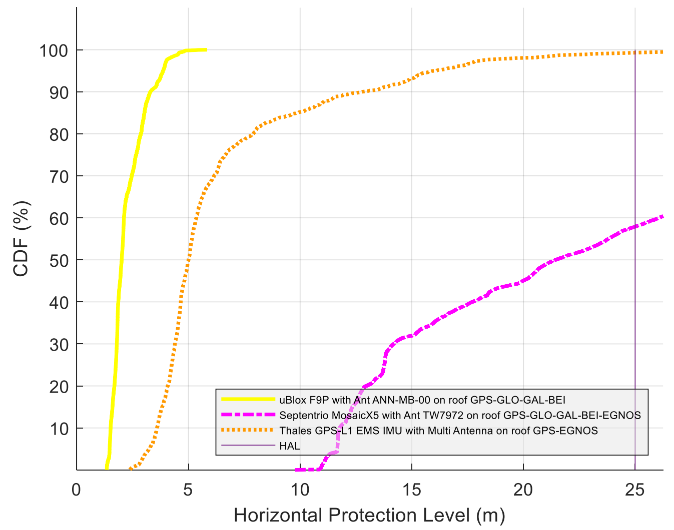
[26] Rationales for the use of 3 times accuracy value as a protection level: on 3 different scenarios (Semiurban Canopy and Clear sky), F9P appears able to deliver accuracy values that multiplied by 3 just bound the real error almost without any misleading information (MI)

7.5.4. Urban #1

<table>
<tr><td colspan="2">Scenario, Date
UTC Time ToD: Begin, End</td><td colspan="3">URBAN #1, 20210601_PM
49168 s, 51032 s</td></tr>
<tr><td rowspan="6">SUMMARY</td><td>HPE comparison</td><td colspan="3">
</td></tr>
<tr><td>HPL comparison</td><td colspan="3">
</td></tr>
<tr><td>Other metrics comparison</td><td>PVT Availability (%)</td><td>Integrity Availability (%)
HPL<= 25m</td><td>MIR (%)
HPE > HPL</td></tr>
<tr><td>MOSAIC X5</td><td>100.0</td><td>51.56</td><td>0.00</td></tr>
<tr><td>F9P</td><td>100.0</td><td>100.00</td><td>47.91</td></tr>
<tr><td>Ellipse 2D</td><td>100.0</td><td>N/A</td><td>N/A</td></tr>
</table>

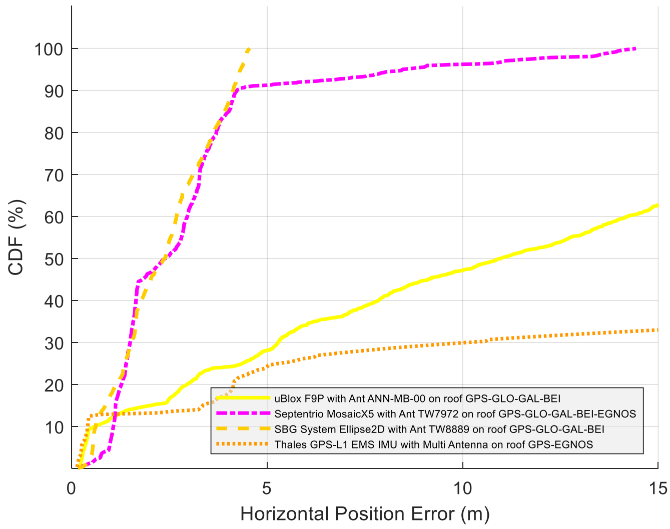
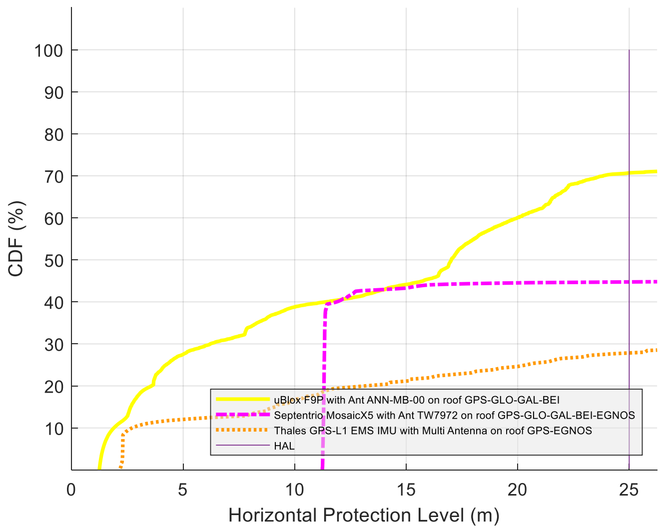
	EPICURE algorithm	100.0	98.87	3.76
	Comments	With regard to HPE, Ellipse 2D provides the best accuracy. With regard to HPL, F9P gives the lower HPL but with the highest MIR. On the other hand, MOSAIC X5 gives the best MIR (0%), but with the highest HPL values. EPICURE algorithm seems to be the best compromise between both, giving well balanced performances between Integrity Availability and MIR.		

7.5.5. Urban #2

<table>
<tr><td colspan="2">Scenario, Date
UTC Time ToD: Begin, End</td><td colspan="3">URBAN #2, 20210601_PM
51032 s, 52434 s</td></tr>
<tr><td rowspan="6">SUMMARY</td><td>HPE comparison</td><td colspan="3">
</td></tr>
<tr><td>HPL comparison</td><td colspan="3">
</td></tr>
<tr><td>Other metrics comparison</td><td>PVT Availability (%)</td><td>Integrity Availability (%)
HPL<= 25m</td><td>MIR (%)
HPE > HPL</td></tr>
<tr><td>MOSAIC X5</td><td>99.8</td><td>57.88</td><td>0.00</td></tr>
<tr><td>F9P</td><td>100.0</td><td>100.00</td><td>59.25</td></tr>
<tr><td>Ellipse 2D</td><td>100.0</td><td>N/A</td><td>N/A</td></tr>
<tr><td></td><td>EPICURE algorithm</td><td>100.0</td><td>99.29</td><td>0.00</td></tr>
</table>

	Comments	With regard to HPE, Ellipse 2D and EPICURE algorithm have both the best performances. MOSAIC X5 and F9P from their side are also very close, and not so far away behind the former ones. With regard to HPL, F9P gives the lower HPL but with a very high MIR (~59%). On the other hand, MOSAIC X5 produces no MI, but with the highest HPL values and thus the lowest availability. In this scenario, EPICURE algorithm clearly offers the best compromise between both: no MI with an almost perfect integrity avalability (~99%).

7.5.6. Tunnel #2

<table>
<tr><th colspan="2">Scenario, Date
UTC Time ToD: Begin, End</th><td colspan="3">TUNNEL #2, 20210603_AM
32442 s, 32707 s</td></tr>
<tr><td rowspan="7">SUMMARY</td><td>HPE comparison</td><td colspan="3">
</td></tr>
<tr><td>HPL comparison</td><td colspan="3">
</td></tr>
<tr><td>Other metrics comparison</td><td>PVT Availability (%)</td><td>Integrity Availability (%)
HPL<= 25m</td><td>MIR (%)
HPE > HPL</td></tr>
<tr><td>MOSAIC X5</td><td>29.6</td><td>44.70</td><td>0.00</td></tr>
<tr><td>F9P</td><td>100.0</td><td>70.69</td><td>21.68</td></tr>
<tr><td>Ellipse 2D</td><td>100.0</td><td>N/A</td><td>N/A</td></tr>
<tr><td>EPICURE algorithm</td><td>100.0</td><td>27.65</td><td>0.00</td></tr>
</table>

	Comments	With regard to HPE, Ellipse 2D give the best performances. Apparently good results of MOSAIC X5 have to be moderated, because they correspond to the very beginning and very end of this scenario (outdoor) ; no data during the real tunnel effect. With regard to HPL, F9P seems to give the best compromise between Integrity Availability and MIR. EPICURE algorithm gives the best MIR (0%).

7.5.7. Synthesis vs requirements

Performance of EPICURE prototype algorithms are compared to requirements in Table 8. Verifiable requirements, selected from Table 5 are listed in Table 7.
The ambitious targeted 95% accuracy of 1 meter for open sky, semi-urban and canopy environments is only reached in open sky and semi-urban. Canopy, with multiple masking and attenuation of signal seems to represent an unexpected challenge. In urban environment, accuracy is reached in one of the two tested sections.
Integrity requirement can only be checked on a limited number of points thus not allowing to assess a target of 10-5/h (from 200 to about 1500 seconds depending on the environment). However, 0 integrity event is reached in open sky, semi-urban and canopy.
Possible improvements explained in as an introduction of §7.5.8 such as use of DFMC (GPSL5 FOC + SBAS DFMC), use of better or additional sensors, improvement of error modelling should allow to reach requirements in all the environments.

Performance parameters	Targeted value	Comment
Integrity Availability (monthly)	99.9 %	Hourly, in experimentation
Horizontal Position Accuracy (95%)	1m 5m	[open, semi-urban, canopy] [tunnels, urban canyon]

Table 7: Verifiable requirement extracted from Table 5

Scenario	HPE 95%	Service Availability (HPL<=25m)	Requirement Pass/Fail
Urban #1	7.09	98.87	HPE : Fail Availability: Fail
Urban #2	4.59	99.29	HPE : Pass Availability: Fail
Tunnel #2	229.32	27.65	HPE : Fail Availability: Fail
Tunnel #3	162.56	31.28	HPE : Fail Availability: Fail
Semi-urban #1	0.78	100.00	HPE : Pass Availability: Pass

Scenario	HPE 95%	Service Availability (HPL<=25m)	Requirement Pass/Fail
Canopy #1	2.88	100.00	HPE : Fail Availability: Pass
Canopy #2	1.61	100.00	HPE : Fail Availability: Pass
Canopy #3	5.54	100.00	HPE : Fail Availability: Pass
Clear Sky #1	0.61	100.00	HPE : Pass Availability: Pass

Table 8: Performance vs Requirement status – EPICURE Algorithm

7.5.8. Conclusions and way forward

Some results show that there is still some work to be done to improve hybridization algorithm:

- with better measurement error modelling to improve integrity (e.g. taking into account time-correlated measurement errors)
- with addition of absolute sensors like magnetometers to improve navigation in tunnels.

These possible ways of improving the existing solutions are described in the D210 update, considering the experimentation results (see [D210]).

However, it is considered that the obtained results already allow:

- To show the interests of EPRIS service to improve the accuracy of the user position and provide reliable integrity bounds in the pseudo-range domain
- To confirm that a user integrity concept based on the main principles and algorithms described in §5.1.4 and §5.1.5, with some improvements, would allow to comply with the main requirements expressed by stakeholders of insurance telematics applications (recalled in §5.2)

8. TASK 4 : ECONOMIC ANALYSIS FOR THE NEW EGNOS SERVICE

In the EPICURE project, an integrity concept customised to road insurance applications was proposed and associated to a new EGNOS service definition for road users (i.e. EGNOS Pseudo-Range Integrity Service (EPRIS)). This Task 4 aimed to conduct a **Cost-Benefit Break-Even Analysis** of the proposed EPRIS service, focusing on the key conjoint decision-making stakeholders with respect to the adoption of EPRIS (i.e. GNSS Receiver Manufacturers (Rx manufacturers) and Telematics Service Providers (TSPs)).

This task was undertaken based on the **"Initial Roadmap"**, originally formulated by the consortium and shared with the stakeholders during the various primary research interactions conducted in the project (interviews, survey, webinar, as discussed in §3.4), with EPRIS rolled out in three phases[27]. Consistent with the planned EPICURE project methodology, the outcomes of the Break-Even-Analysis were, in turn, used to provide inputs for the **"Finalised Roadmap"** (which can be seen in §6 above) elaborated at the end of the project.

The key analytical objective of this analysis was to **determine the minimum conditions to achieve commercially sustainable adoption by Rx manufacturers & TSPs** for potential niche professional applications (i.e. the volume at which Total Costs = Total Benefits). Two break-even CBAs were conducted: one for Rx manufacturers and one for TSPs. The model was based on assumptions (high-impact and high-uncertainty assumptions adjusted as part of sensitivity analyses) and valuation estimation (of costs and benefits), which were informed by stakeholder consultations.

8.1. ASSUMPTIONS

The **Base Case** break-even CBA is grounded on a set of assumptions, which are set out below (key assumptions are adjusted as part of sensitivity analyses – see details in [D410]).

Key assumptions for the break-even CBA:

1. The **time-to-market** is set for a **2025 initial service commencement** Stakeholder input in the survey and consultation (round 1 and 2 of interactions) is consistent with this timeframe;
2. We adopt estimates for Rx manufacturer costs (*Additional* Fixed Cost and *Additional* Variable Cost) and TSP costs (*Additional* Average Cost and *Additional* Communication Cost) based on stakeholder inputs in the second interaction;
3. We adopt estimates for Rx manufacturer benefit (*Additional* Revenue (uplift) per Rx) and TSP benefit (*Additional* Revenue (uplift) per OBU) based on stakeholder inputs in the second interaction;

[27] Initial roadmap : step 1 (Short-term: Broadcast of EGNOS corrections / bounds on mobile networks using EGNOs V2), step 2 (Mid-term: Added Central Processing Facility for Road using EGNOS V2), step 3 (Long-term: Dual Frequency and Multi-Constellation Road service using EGNOS V3)

4. The Rx model sales life cycle and the OBU lifetime follow a **standard 10-year timeframe** (sales of the updated Rx and OBU models will continue for a period of 10 years, such that the Additional Fixed Costs can be amortised across all units sold over this period);
5. The **discount rate** is 4% per year (as per EC guidance[28]);
6. **The ratio of Rx sales per OBU sales is 1** (i.e., Rx manufacturers do not sell Rx into other Rx markets), which is a conservative approach given the likelihood that the updated Rx could be used to provide additional applications and services; and
7. Uncertainties are addressed through a **sensitivity analysis** (i.e., parameters such as the delta cost, delta revenue, and communication costs).

General assumptions important to consider in the break-even CBA:

1. The break-even CBA model is based on the traditional value chain (see Figure 4);
2. EPRIS will only impact the Rx (e.g. chipset, multi-antennae, dual frequency) and the TSP (OBU, remote platform, application(s));
3. Rx manufacturers only **update existing Rx** (i.e. does not require development of a new module);
4. Additional antennae are considered in every step, but are not considered mandatory for the adoption of EPRIS;
5. A **prototype Rx is available** for application development **2 years before EPRIS FOC**;
6. From the TSP's perspective, to be supported by the market the **delta cost for using EPRIS shall not exceed €42/$50**[29] (this includes the adaptations required on the RX/OBU and for the service per OBU (e.g. communication costs));
7. **EPRIS service fee is nil** (€0, or included in the €42/$50);
8. **No certification** of the Rx or OBU is required for EPRIS (as is required for use in aviation, e.g. FAA, EASA certification);
9. There is no external (e.g. European Commission) funding to offset non-recurring expenses; and
10. Following the agreed methodology for the break-even cost benefit analysis[30], the analytical objective is to calculate the **minimum conditions for the commercial sustainability** of adoption (i.e. Benefits = Costs (Break-Even CBA)).

8.2. MAIN OUTCOMES

Under the base case scenario corresponding to the assumptions listed in the paragraph above[31], the cost-benefit break-even analysis model determined that:

- For **Rx manufacturers**, the **Break-Even Volume is 234,114 Rx units**.

[28] European Commission, 'Better Regulation Toolbox'; VIII. Methods, models and costs and benefits; Tool 61: The Use of Discount Rates
[29] €42 corresponds to the $50 delta cost figure provided during the stakeholder consultation.
[30] The methodological approach and implementation agreed by EUSPA are outlined in *Section 1.3 and 1.4* of the present report.
[31] In [D410], the base case scenario study was completed by sensitivity analysis, in particular for a worst case scenario (higher costs, lower revenues) and a best case scenario (lower costs, higher revenues)

- For **TSPs**, the total aggregate OBU shipments (equal to Rx shipments, by assumption) is 234,114 over the 10 years of the lifecycle (i.e., 2025-2034), requiring a **Break-Even Additional Revenue of €36.41 per OBU/year**.

Overall, this break-even CBA enables us to quantify some of the stakeholder decision criteria highlighted during the consultations:

- For Rx manufacturers, the **market size needs to be sufficient to ensure that the 234,114 Rx break-even volume is reached** in the assumed 10-year timeframe; and
- TSPs must retain existing customers and or secure new customers and or increase sales to existing customers, as they need to **generate an additional €36.41 per OBU per year** in order to break-even.

This complements **other decision criteria**, which include the ability to update existing Rx technology to support EPRIS (rather than developing new Rx), the availability of Rx as off-the-shelf technology, the ability to modify OBUs to add new function and services not possible with today's technology, bundled with existing functions and services, and the ability to broadcast EPRIS data through mobile networks across Europe to avoid additional communication costs for TSPs.

The analysis clearly shows that the **Fixed Costs (NRE) for the Rx development is a key driver** of the minimum break-even market size required for Rx manufacturers to decide whether to adopt EPRIS. It also has a secondary effect in that it influences the volume and costs of the TSPs, which drives the minimum break-even revenue required for TSPs to decide to adopt EPRIS. **NRE may be targeted by external stimuli** such as R&D grants to reduce the burden of this initial cost to the Rx manufacturers. They could also stimulate other application markets to use the adapted Rx.

Communication costs for the EPRIS data throughput are the key driver of the minimum break-even revenue required for TSPs to support EPRIS. If EPRIS data were to be broadcasted through mobile networks across Europe as part of ESP's responsibilities, it would mean no additional communication costs would be incurred by TSPs.

Furthermore, **the adoption of EPRIS will also be influenced by various enablers** (e.g. time-to-market c. 2025, delta cost below €42/$50, availability of a prototype Rx 2 years before EPRIS FOC to facilitate application development by TSPs, retention of EPRIS' unique value proposition, ability for Rx manufacturers to sell EPRIS-ready Rx to other markets).

The outcomes of the analysis, as above synthesised, were validated by the stakeholders involved in the consultations. Specifically in relation to the time-to-market, it was noted that any delay in the three phases rollout could penalise EPRIS because of competing technologies especially the emerging ones (e.g., 5G) difficult to predict in 5-7, maximum 10 years.

The **Finalised Roadmap** presented in §6 considers the results of the Break-Even Analysis presented above by simplifying the overall service introduction (two steps instead of three). This indeed goes in the direction of reducing the costs, by reducing the complexity of the technology adaptation/enhancement, and in particular the deployment of new versions (no more retrofit costs between former step 1 and step 2[32], since these two steps are now merged). However, the associated cost reduction cannot be quantified in detail, given the rough cost estimations available from the stakeholders (former steps 1 and 2 of the Roadmap, already considered together as a single step in the CBA, as highlighted in [D410]).

[32] According to the **Initial Roadmap**, which was revised into the **Finalised Roadmap.**

9. TASK 6 : DISSEMINATION ACTIVITIES

In order to promote operational concepts and new EGNOS service definition developed in EPICURE towards the main automotive and GNSS actors, it was mandatory to be presented at the major events attended by them.

Dissemination activities were therefore developed to ensure:

- Large participation of key actors to the project via workshops and consultation on operational and technical matters as part of the Working Group;
- Presentations at GNSS & automotive events: ION ITM, ENC

Although the dissemination activities were disturbed due to Covid-19 sanitary crisis, the following communications were made:

Event Name	Date	Location
European Navigation Conference (ENC)	15/11/2021 to 18/11/2021	Virtual
ION ITM 2022	January 24- 27, 2022	Long Beach And virtual

Another submission was targeted to ITS European congress (draft paper sent for review end of January 2022) but was finally rejected for publication by the organising committee.

10. CONCLUSIONS AND WAY FORWARD

The EPICURE project has studied the basic principles and concepts for a future EGNOS integrity service, EPRIS, specifically to fit in the road insurance telematics applications. In this framework, the market's stakeholders played an important role in the project, as they were consulted in key points of the project and were asked to provide inputs and feedbacks concerning various aspects.

Preliminary service definition was proposed, with preliminary performance targets recommended to be further consolidated in particular in the WP EGNOS V2.4.3 for the maritime applications.

A roadmap for EPRIS service introduction was also proposed with progressive service introduction in two steps:

- Step V1 (2025) : Single Frequency Single Constellation (GPS) service
- Step V2 (2029) : Dual Frequency Dual Constellation (GPS / Galileo) service

Associated to this EPRIS service an overall integrity concept was proposed and experimentation of this concept was performed in representative user conditions.
Some results show that there is still some work to be done to improve hybridization algorithm:

- with better measurement error modelling to improve integrity (e.g. taking into account time-correlated measurement errors)
- with addition of absolute sensors like magnetometers to improve navigation in tunnels.

These possible ways of improving the existing solutions are described in the D210.
However, it is considered that the obtained results already allow:

- To show the interests of EPRIS service to improve the accuracy of the user position and provide reliable integrity bounds in the pseudo-range domain
- To confirm that a user integrity concept based on the main principles and algorithms described in §5.1.4 and §5.1.5, with some improvements, would allow to comply with the main requirements expressed by stakeholders of insurance telematics applications (recalled in §5.2)

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