EUROPEAN SPACE AGENCY

NAVISP Element 1 Work Plan 2025

List of Proposed Procurements

Item Ref. (Paragraph)	Subject of Procurement	Estimated Price Range (kEUR)	Duration (months)	ITT issue	Opt Out
4.1	EL1-101	800	24	May-25	-
4.2	EL1-102	400	12	Feb-25	-
4.3	EL1-103	800	24	Mar-25	-
4.4	EL1-104	450	12	Jan-25	-
4.5	EL1-105	500	18	Nov-25	-
4.6	EL1-106	800	12	Apr-25	-
4.7	EL1-107	800	12	Jun-25	-
4.8	EL1-108	650	18	May-25	-
4.9	EL1-109	630	18	Jul-25	-
4.10	EL1-110	750	24	Sep-25	-
4.11	EL1-111	950	18	Mar-25	-
4.12	EL1-112	300	18	Jun-25	-
4.13	EL1-113	750	24	Jan-25	-
4.14	EL1-114	200	12	Jan-25	-
4.15	EL1-115	200	9	Feb-25	-

Table 1 – List of Proposed procurements

ANNEX

NAVISP Element 1 Work Plan for 2025

1. INTRODUCTION

Activities under Element 1 of the Navigation Innovation and Support Programme (NAVISP) are defined and implemented according to an annual work plan to be prepared and proposed by the Agency, and to be approved by participating States in Element 1. The annual work plan is prepared in the context of the wider NAVISP innovation process, which takes into account, among the others, the state-of-the-art, the trends and the gaps in the Positioning, Navigation and Timing (PNT) innovation, on the basis of appropriate consultation with the participating States and ex-ante coordination with the European Commission (EC) and the European Union Agency for the Space Programme (EUSPA), with the final goal to develop commercial driven PNT solutions.

This document presents the Element 1 Work Plan for 2025.

2. DESCRIPTION OF PROPOSED ACTIVITIES

The Work Plan 2025 includes thirteen (13) very innovative activities, for a global annual budget of 8.58 M€, and two (2) prospective studies for a global budget of 0.4 M€.
The total budget of 8.98 M€.

2.1. EL1-101: Underwater and underground navigation using Muons

When cosmic rays reach the upper part of the Earth's atmosphere, several particles are created, including muons. Muons, elementary particles with the same charge of the electron but with bigger mass, can travel through any kind of material, including water and rock. A muon detector can be very small and very low cost (~ $100). Muons can be used for navigation using Reference Detectors (to determine the Time-of-Flight). In [Tanaka, 2022, Nature], deep-underground tests were reported, achieving meter-level accuracy. In [Tanaka, 2020, Nature], a Muon Positioning System is proposed to measure deformations of the seafloor. This system requires one User Detector (installed on the seafloor), four Reference Detectors (installed on four buoys), one GPS-RTK system per buoy and a communication cable between User Detector and one of the Reference Detectors. Although Tanaka is proposing the use of bigger detectors, all these components are assumed to be low-cost. Performance and flexibility could be improved for example by changing the cable for a wireless communication system, installing an atomic clock on one or multiple detectors.

Although this concept is of major of interest (as it allows navigation in problematic environments), this concept does have certain challenges (e.g., for an increasing distance between Reference Detector and User detector, the update rate of positions decreases). For reference, EL1- 014 "PNT using Neutrino Particles" attempted to use other particles to navigate. Its results are somewhat relevant and will be made available as part of the solicitation package.

The objective of this activity is to consolidate and demonstrate underwater and underground navigation using Muons, with a target performance better than the performance of Muon Positioning Systems reported in literature.

The tasks to be performed shall include:

- Identification of commercial needs and opportunities (e.g. offshore engineering, mining, …)
- Identification of the challenges for navigation using muons
- Considering the challenges, consolidation of algorithms and hardware (muon detectors, time-synchronisation, communication)
- Design, construction, and verification in the laboratory of a demonstrator
- Underwater and underground demonstrations.

The main outputs of the activity will consist of:

- Technical Notes
- Hardware and Software prototype.

It is noted that no Participating State expressed their opt-out for this activity (EL1-101).

Funding required: 800k€	*Duration: 24 months*	*ITT issue: May-2025*

2.2. EL1-102: Quantum receiver for navigation applications

Recently, a wide range of experimental quantum techniques have been demonstrated in communications and sensing fields. Atom-based quantum techniques are emerging as a completely new and promising tool for advanced communications. Accurate radio-frequency (RF) electromagnetic field sensing in free-space plays a fundamental role in wireless communication, and Rydberg atoms are remarkable quantum sensors for RF electric field measurements.

The working principle of the quantum electric field sensor starts with lasers excited atoms to high-energy Rydberg states, with a large principal quantum number n (where typically $10 \leq n \leq 100$). This high n value means that the electron is in a very high-energy state in which the atoms act as highly sensitive electric dipoles. Incident RF/microwave radiation from near-DC to THz affects the internal state of Rydberg atoms, which in turn imposes modulations on the optical fields passing through the atoms. These modulations are read out as spectral features on the electrical current produced by a photodetector. The coupling of incident RF or microwave radiation to the Rydberg atoms is a coherent process, which does not mandate any net absorption of the incoming radiation. In contrast, traditional antennas operate by absorbing incident radiation, which drives free electrons and produces a current that carries the properties of the incident field.

In recent years, there has been a surge of new research and engineering of these sensors, including the development of a miniaturized sensor head, and the first demonstration of angle-of-arrival measurements (by BT Group for example).

The objective of this activity is to to study, design, and demonstrate the use of quantum receivers for navigation applications. Furthermore, the quantum receiver shall be exploited to provide Angle of Arrival estimates for multiple Signals-of-Opportunity (SoOP) in various frequency bands. To handle appropriately this activity's technology risk, a go/no-go check point will be established, during the execution of the contract, to ensure its ultimate feasibility.

The tasks to be performed shall include:

- Survey of Rydberg receivers state-of-the-art
- Investigate solutions such as Rydberg electromagnetically induced transparency (EIT) in atomic vapours
- Study direction finding applications based on phase difference measurements
- Provide a new receiver architecture for navigation purposes
- Demonstrate the deployment of quantum receiver with GNSS, LEO-PNT, or terrestrial-based positioning.

The main outputs of the activity will consist of:

- Report on state-of-the-art
- Design description and justification report
- Quantum receiver prototype for navigation applications (TRL at least 4).

It is noted that no Participating State expressed their opt-out for this activity (EL1-102).

Funding required: 400k€	*Duration: 12 months*	*ITT issue: Feb-2025*

2.3. EL1-103: Precise and Stable Navigation with Quantum Accelerometer

Navigation systems that rely on Inertial Sensors are prone to drift and inaccuracies over time, affecting their accuracy, reliability, and autonomy, particularly in challenging scenarios where GNSS signals and/or external reference points availability is limited or strongly impacted.

Quantum accelerometers enable high-precision navigation with long autonomy, effective fault detection in case of sensor fusion and/or user navigation independence, with noticeably benefits in constrained environments.

Those characteristics make such a technology a viable solution to reach the stringent user performance requirements of Safety of Life (SoL) PNT applications (e.g. underwater, maritime, rail, aviation, automotive) even in challenging scenario.

For instance, in underwater applications, moving to the surface to navigate results in task interruptions and puts vehicles at increased risks. Furthermore, in case of high depth operations, the cost of repeatedly surfacing can be substantial, both in terms of time and energy.

Similarly, in railway applications, the lack of GNSS visibility for long periods, the significant drift errors of odometer sensors along with the urgency to less rely on the current high expensive infrastructure, impose the need of new innovative technologies to improve the performance of inertial sensors and to overall enhance the Train Localisation System.

Quantum accelerometers offer a promising solution, leveraging principles of quantum mechanics to provide unprecedented accuracy and stability. Integrating quantum accelerometers into navigation systems can significantly improve navigation capabilities, enabling more precise and reliable operations in challenging environments.

This project can be considered a follow-up of the previous two NAVISP activities, NAVISP-EL1-013 and NAVISP-EL1-013bis.
Both were limited to the feasibility analysis and design of first generation of quantum inertial sensors prototypes (gravimeter and accelerometer), but without fully addressing the integration of these sensors in the whole navigation system.

The objective of this activity is to research, develop, and integrate a quantum accelerometer within traditional navigation system for different market segments: e.g. underwater, maritime, rail, aviation, automotive, tailored to meet the stringent user requirements of SoL applications.

The quantum accelerometer uses ultracold atoms to make highly accurate measurements. When cooled to extremely low temperatures the atoms start to display their ‘quantum’ nature, resulting in wave-like properties. As the atoms move through the sensor, an ‘optical ruler’ is formed by using a series of laser pulses. This allows the acceleration of the atoms to be precisely measured and with high stability.

Unlike conventional accelerometers, quantum ones are inherently immune to drift and to external disturbances, making them ideal for applications where precise and stable measurements are critical and the availability of GNSS signals and external reference points is limited or absent.

To demonstrate the quantum accelerometer in an Inertial Navigation System package, an angular velocity sensor needs to be present (MEMS or other mature technology).

The tasks to be performed shall include:

- Survey of state of the art on Quantum Accelerometers
- Quantum Accelerometer Prototyping and/or Procurement
- Analysis and model characterization of non-linear noise errors of the quantum accelerometer
- Integration with an on-board Navigation System (ad-hoc data fusion algorithms: e.g. tuned Extended Kalman Filter (EKF), particle filter, etc.)
- Study to compensate possible environmental constraints, such us effect of vibrational noise, and vehicle dynamics on the sensor/navigation system performance
- Performance Evaluation and Testing in controlled scenario and in different real word operational conditions (e.g. maritime, aviation, road, rail domain)
- Analysis to overcome the HW limitations: e.g. power consumption, size, weight, cost, etc.

The main outputs of the activity will consist of:

- Proof-of-Concept (PoC) of a quantum accelerometer integrated in an on-board navigation system (TRL 5/6). The PoC shall be executed in controlled and relevant environments considering at least two different application areas (e.g., maritime and rail).
- Report on the possibility to exploit the innovation in an Element 2 activity.

It is noted that no Participating State expressed their opt-out for this activity (EL1-103).

Funding required: 800k€	*Duration: 24 months*	*ITT issue: Mar-2025*

2.4. EL1-104: AI for Anomaly Detection in Multi-Sensor PNT

There is currently considerable research effort being devoted to the development of multi-sensor PNT approaches which promise greater resilience and potentially greater accuracy than GNSS alone. New sensors are also being developed which have less well understood characteristics and vulnerabilities. These include quantum inertial sensors and quantum gravimeters and magnetometers. For such complex multi-sensor systems with less well understood sensors, it may not be possible to fully understand the error sources and failure modes a priori.

Traditional methods for sensor fusion rely on pre-defined error models. However, with novel sensors like quantum devices, these models might not exist or be inaccurate. While machine learning excels at learning complex, non-linear relationships from data, it can identify error patterns and dependencies between sensors that traditional methods might miss.

This project will seek to develop machine learning approaches to characterising sensors and detecting anomalies that will impact the contributions of these sensors to the position and time solution. For systems which include the use of external signals such as GNSS and signals of opportunity, the machine learning algorithms can also be used to identify spoofing or changes in the signals structure or orbits from satellites of opportunity. As this is not the first attempt to apply Machine Learning to complex systems, the highest novelty possible in the development will be sought (typically considering the newest quantum sensors models).

The objective of this activity is to develop machine learning algorithms for anomaly detection and characterization in complex multi-sensor PNT systems with novel sensors for robust and adaptable positioning and timing.

The tasks to be performed shall include:

- Sensor Characterization: Machine learning algorithms will be developed to analyse sensor data and identify patterns that correlate with sensor health and performance. These algorithms will be trained on data from various sensors (including novel ones) under different operating conditions
- Multi-Sensor Fusion with Anomaly Detection: The activity will design algorithms that combine data from multiple sensors (including GNSS, Signals of Opportunity (SoOP), and novel sensors) for PNT. These algorithms will integrate anomaly detection models to isolate and attribute suspicious readings to specific sensors or external signal sources (e.g., GNSS spoofing)
- Machine Learning for Signal Integrity Monitoring: Machine learning models will be developed to analyse the characteristics of GNSS and SoOP signals for integrity monitoring. These models will be trained to identify deviations that might indicate spoofing attempts or changes in signal structure.

The main outputs of the activity will consist of:

- A suite of machine learning models for:
    - Characterizing sensor behaviour and identifying anomalies

    - Fusing multi-sensor data for PNT with real-time anomaly detection
    - Monitoring the integrity of GNSS and SoOP signals for spoofing attempts
- A deployable PNT system with anomaly detection capabilities, enabling robust and adaptable positioning and timing
- An adaptable framework that continuously improves anomaly detection through machine learning and integration of new data and threats.

It is noted that no Participating State expressed their opt-out for this activity (EL1-104).

Funding required: 450k€	*Duration: 12 months*	*ITT issue: Jan-2025*

2.5. EL1-105: Hybrid black-white-modelling estimation and machine learning algorithms for PNT engines

The application of machine learning (based on “black-box” modelling) is of interest in problems that are difficult to solve based on traditional (optimal) estimators for simple models (“white-box” modelling). Black-box modelling is difficult to be explained and understood (i.e., difficult to understand what to expect in unknown or new situations), involve high computation complexity, and is not necessarily deriving the optimal solution.

In many problems traditional methods are optimal and require much lower number of operations than machine learning techniques. Moreover, their behaviour can be better understood. In the context of PNT engines, traditional solutions can provide optimal solutions in controlled environments, while require more advanced solutions in difficult environments. A hybrid black-white estimation approach targets to exploit the best of both approaches, enhancing and refining the solution of the traditional solution with machine learning only when needed. One of many other possible examples of hybrid processing is KalmanNet, in this case focusing on the learning of complex dynamics based on EKF (as “white-box” modelling).

The objective of this activity is to study, design, implement and demonstrate the application of hybrid black-white-modelling estimation and machine learning algorithms for PNT engines, exploiting the best of each approach to achieve optimum solutions with minimum resources used.

Note that EL1-087 (verifiable AI) does not cover the achievement of optimum performance with hybrid solutions while minimizing the required resources. Its results will be included in the solicitation package, as far as possible, being relevant for the verification point of view.

The tasks to be performed shall include:

- improve the achieved accuracy in harsh propagations, while being also optimum in mild propagation conditions
- minimize the number of resources required in the receiver
- demonstrate that the hybrid approach works in a controlled and accurate way when operating in new changing environments
- assessment of the derived solutions, to be performed based on field tests, considering code and carrier observables from commercial GNSS receivers, as well as inertial sensors.

The main outputs of the activity will consist of:

- Definition and design of innovative hybrid black-white PNT solutions
- Hybrid black-white PNT engine processing tool and test report

- Roadmap for commercialization, including potential Navisp EL2 activities.

It is noted that no Participating State expressed their opt-out for this activity (EL1-105).

Funding required: 500k€	*Duration: 18 months*	*ITT issue: Nov-2025*

2.6. EL1-106: Beamforming user antenna for wideband radionavigation signals in C-band

The rapid increase in GNSS RFI (e.g., in Baltic and Scandinavian peninsula there were 122 days with GPS jamming in 2022, and 294 days in 2023) is staggering. Accordingly, in recent years, beamforming techniques have been deployed in GNSS receivers (in the L-band) either to provide a spatial filter or to improve the signal-to-noise-power (CN0) level.

Beamforming techniques can achieve a directional pattern performance towards a desired location by varying the phase and amplitude of every individual antenna's weight. Therefore, the main lobe of the array pattern can be steered towards the desired direction without physically moving the antennas. Furthermore, array antennas can be utilized as a spatial filter; i.e. the null regions of the array antenna pattern can be steered towards the undesired directions (e.g. directions where there are jammers/spoofers, interference, noise sources, etc), consequently achieving a high CN0 to the desired signals.

With the introduction of the "new space" paradigm, the C-band for satellite-based PNT systems attracts a significant attention. Companies such as Xona Space and Trustpoint, are deploying it in the new satellites' constellations. Furthermore, some new RF frontend devices have been introduced that are able to provide multiple RF-chains with a wide bandwidth in the C-band, e.g, USRP x410 (30k€ euros) provides 4Rx and 4Tx channels with a bandwidth up to 400 MHz per channel.

Finally, the C-band navigation signals have a great interest for the automotive sector due to the large operational bandwidth and the foreseen high positioning accuracy. Accordingly, providing a beamforming receiver, in the C-band, will increase the positioning accuracy, reliability and resiliency against multipath, jamming and spoofing.

The objective of this activity is to design, develop, and validate a beamforming navigation receiver in C-band RF spectrum. The proposed system should be able to provide the following:

- Beamforming the main lobe towards the LEO satellites, steering it as fast as required by their very high relative velocity
- Providing a spatial filter to mitigate the jamming and spoofing attacks
- Capable of acquiring and decoding live LEO-PNT signals
- Consider the spatial movement of the receiver to represent mobile receivers in vehicles.

The tasks to be performed shall include:

- study, design, and demonstrate the deployment of C-band beamforming antenna

- include the ability to receive a very large bandwidth in the C frequency band (up to 240 MHz, according to potential evolutions in ITU)
- ensure a high phase stability among the RF-chains and the entire bandwidth
- include high gain dual polarization antenna elements that have a stable pattern response over the wide bandwidth
- optimize the antennas' placement to provide accurate beamforming response over the large bandwidth.

The main outputs of the activity will consist of:

- Survey of state of the art on array antennas for the wideband signal processing in the C-band
- beamforming navigation receiver (compact hardware and software) and verification and validation test report

It is noted that no Participating State expressed their opt-out for this activity (EL1-106).

Funding required: 800k€	*Duration: 12 months*	*ITT issue: Apr-2025*

2.7. EL1-107: Ultra high spatial resolution GNSS receiver for automotive industry

The ability of exploiting the spatial dimensions has allowed array antennas to be exploited in various applications. Over the past years, array antennas have been deployed in GNSS receivers either to provide a spatial filter or to improve the signal-to-noise ratio (SNR) using beamforming techniques.

To achieve a high spatial resolution, a large array antenna aperture should be used. The manufacturing process of a large array antenna aperture, with fully synchronized and phase-coherent radio frequency (RF) chains, is very expensive and complex.

Lately, synthetic aperture techniques and the supercorrelator have been proposed in the literature to provide spatial diversity. Those techniques rely on the movement of a single antenna receiver. This single antenna movement in space will create a linear virtual array, and accordingly, a directional ambiguity should be resolved. On the other hand, the supercorrelator technique relies on a long coherent correlation time.

In this activity a moving array antenna instead of a single antenna receiver is proposed. Furthermore, the deployed antenna should support simultaneously Right Hand and Left Hand Circular Polarization to increase the degrees of freedom without increasing the physical array antenna aperture. By exploiting the vehicle movement, the aperture of the array antenna (with a limited number of antennas) can be virtually expanded to provide the virtual effect of hundreds of antennas.

This will enable the following:

- Ultra-high beamforming gain, beyond any current HW
- Unlimited jamming and spoofing cancellations
- Very deep nulls towards interference, spoofing and multipath effect
- Very accurate spoofing and jamming direction finding
- The high spatial resolution array antenna should enable new applications using GNSS signals, e.g., refraction index of the ionosphere layer, dynamic mapping, obstacle detection, etc.

The objective of this activity is to implement a compact system (i.e. a hardware and a software) that is suitable to be embedded in vehicles. The hardware solution should include an array antenna to provide spatial and polarization diversities for GNSS signals. The software solution, on the other hand, should exploit the vehicle movements to increase the spatial resolution of the compact array antenna.

The proposed technique in this activity can be distinguished from the synthetic aperture and supercorrelation techniques as follows:

- The proposed activity aims to deploy a dual polarization array antenna
- In case of static receiver, the array antenna will keep providing beamforming applications, though the resolution is limited to the amount of the deployed physical antennas multiplied by two (for dual polarization)
- In case of mobile receiver, the aperture of the deployed array antenna will be increased due to the movement of the vehicle, i.e. achieving a synthetic aperture that is 2*N times larger than single antenna synthetic aperture techniques (N being the number of physical antennas that will be deployed)

The tasks to be performed shall include:

- Study, design, and demonstrate the use of a compact dual polarization array antennas in vehicles. The spatial movement of the vehicle should be captured by an accurate IMU device and modelled to create a virtual array antenna with an ultra-large aperture.
- Design the system with the following characteristics:
    - Phase coherency among antenna elements
    - Multiple frequency channels and dual polarization antenna elements
    - Accurate measurement of the vehicle movements
- Model the spatial movements to create an ultra large array antenna aperture
- Exploit the ultra large aperture to provide new applications, e.g. refraction index of the ionosphere layer, debris detection, dynamic mapping, obstacle detection, etc.

The main outputs of the activity will consist of:

- a GNSS receiver (hardware and a software)
- a compact moving platform that can resemble the vehicle movement to test, verify and validate the proposed GNSS receiver
- verification report.

It is noted that no Participating State expressed their opt-out for this activity (EL1-107).

Funding required: 800k€	*Duration: 12 months*	*ITT issue: Jun-2025*

2.8. EL1-108: Assessment of Time Transfer Techniques for Resilient Regional (Transnational) UTC Infrastructure

Timing is a highly important use case of GNSS, as many sectors such as telecommunications, emergency services, transport and finance depend on precise time to operate correctly. Therefore, there is a need to provide Critical National Infrastructure (CNI) with accessible, resilient sources of precise reference time using time transfer techniques which are complementary to GNSS. The time reference should always be traceable to UTC (Coordinated Universal Time), the global time standard.

Local realisations of UTC(k) are operated at National Metrology Institutes (NMIs) in many countries, providing a real time UTC traceable reference source. An assessment of the feasibility of time transfer complementary to GNSS for comparison of UTC(k) clocks at geographically separate locations, ideally in different countries, will pave the way for a more resilient, certifiable timing infrastructure to protect CNI on a wider scale.

There are many techniques complementary to GNSS which can transfer precise time, for example using satellites, terrestrial broadcast, optical fibres or line of sight links, all of which are in scope for this activity. This activity may address the use of optical fibre-based time transfer techniques such as White Rabbit and Electronically Stabilised fibre optic system (ELSTAB), over long distance or transnational links, assessing technical and regulatory challenges.

The objective of this activity is to perform a detailed assessment of the use of a time transfer technique, complementary to GNSS, for precise comparison of UTC(k) clocks at geographically separate locations, ideally between different countries. It is envisioned that this Proof-of-Concept (PoC) activity will lay the foundation for a future NAVISP activity to implement this time transfer technique transnationally to support CNI.

The tasks to be performed shall include:

- review state-of-the-art time transfer techniques which are complementary to GNSS. A selected time transfer technique will be assessed, including a PoC, with the aim of increasing the transnational robustness of UTC(k) timing infrastructure for the future benefit of CNI. This time transfer technique will be used to compare two or more clocks at geographically separate locations. The technical and regulatory challenges, achievable stability and accuracy to UTC of the selected technique will be investigated
- define a roadmap towards wider implementation of the selected time transfer technique between countries and the interfaces with CNI.

The main outputs of the activity will consist of:

- Report of state-of-the-art time transfer techniques which are complementary to GNSS
- Feasibility study and PoC of the selected technique, including an assessment of any transnational issues, regulations and standards relating to the use of the selected time transfer technique between two or more UTC(k) realizations in different countries

- Roadmap for future implementation between countries and potential interfaces with CNI, including a cost/benefit analysis per country to inform potential future activities, both in Element 2 and Element 3. To ensure the activity's capability to inform follow up Element 2 and Element 3 activities, it will be conducted in Phases, conditioned by a go/no-go check point.

It is noted that no Participating State expressed their opt-out for this activity (EL1-108).

Funding required: 650k€	*Duration: 18 months*	*ITT issue: May-2025*

2.9. EL1-109: 5G Localisation for Safety of Life Applications in Rail

Safe Localisation of railway vehicles is necessary to allow train control systems to operate. Today this is done within the European Train Control System (ETCS) by using fixed location tags called Eurobalises and odometry sensors.

While Eurobalises typically are safe, fairly accurate and robust, they impose high costs for installation and maintenance on the infrastructure operator and only provide positions at discrete locations. Odometry systems are often inaccurate and not robust enough in challenging environments.

These challenges make it necessary to establish new methods for train localization. In the past the main focus has been on GNSS based solutions, which offer great potential for rail applications. However, these solutions often lack robustness to environmental effects and resilience to jamming, spoofing and cyberattacks to ensure the necessary level of safety to be used in train control applications.

Since the current rail mobile communication network GSM-R nears its end of life, railway operators invest heavily in the 5G based Future Railway Mobile Communication System (FRMCS). This opens the opportunity to use FRMCS, in combination, if required, with other components and features of the 5G signal, as an alternative means for absolute and relative positioning.

The objective of this activity is to analyse if 5G / FRMCS based positioning could be an alternative and complementary source of PNT for safety critical rail applications. To do this positioning solutions using the public 5G networks are to be tested in the rail environment.

The tasks to be performed shall include:

- Critical review of the capabilities of FRMCS and other 5G associated positioning protocols
- Specification of requirements and test cases, based on railway user needs, for a 5G / FRMCS based positioning solution
- Development of a prototype that is able to compute relative and/or absolute range estimates from 'all in view' multi-band 5G/FRMCS network infrastructure
- Testing of the protype in the rail environment, including recording of a high accuracy reference data set for comparison (ground truth)
- Analysis of the positioning performance against the ground truth data set.

The main outputs of the activity will consist of:

- Hardware and Software Design of a 5G localization prototype for train localization
- Test dataset including ground truth data

- Performance and Availability analysis in the rail environment, clustering of results based on environmental conditions.

It is noted that no Participating State expressed their opt-out for this activity (EL1-109).

Funding required: 630k€	*Duration: 18 months*	*ITT issue: Jul-2025*

2.10. EL1-110: User Equipment Platform for Positioning with 5G/6G Non-Terrestrial Networks

The future 5G and 6G non-terrestrial networks (NTN) will offer continuous and ubiquitous coverage, serving predominantly terrestrial users in remote and underserved areas. The latest 3GPP releases imply that the user equipment (UE) must be equipped with the Global Navigation Satellite System (GNSS) receiver determining its position, velocity, and time (PVT) to be able to connect to NTN. To alleviate the dependence of UE on GNSS, the use of 5G NTN signals for positioning is being actively studied. Although various concepts and solutions to provide PVT with NTN have been identified, the development and prototyping of representative user side solutions remain to be addressed in detail. Current NTN system studies would greatly benefit from design, evaluation, and breadboarding of realistic user equipment algorithms and solutions.

The objective of the activity is to design and develop a user equipment (UE) platform to evaluate and trade off user-side processing solutions and algorithms for positioning with 5G/6G Non-Terrestrial Networks (NTN).

The tasks to be performed shall include:

- design and develop a generic user equipment platform in the form of hardware and software to evaluate and trade off user-side processing solutions and algorithms for PVT with NTN
- Validate the positioning performance of the UE using a representative NTN simulator.

The main outputs of the activity will consist of:

- technical notes summarizing the UE solutions and algorithms
- a UE platform capable of implementing and evaluating various user-side processing solutions and algorithms
- a validation report summarizing the achievable positioning performance, and recommendations for future development.

It is noted that no Participating State expressed their opt-out for this activity (EL1-110).

Funding required: 750k€	*Duration: 24 months*	*ITT issue: Sep-2025*

2.11. EL1-111: Managing GNSS Local Effects in the Railway Environment for Advanced Safe Train Positioning

The European Rail Traffic Management System (ERTMS) is a single European signalling and speed control system that ensures interoperability of the national railway systems throughout the single European railway area. ERTMS is comprised of the European Train Control System (ETCS, an in-cab signalling system that includes Automatic Train Protection – ATP) and a track to train radio communication system (GSM-R and the Future Railway Mobile Communication System – FRMCS).

Advanced Safe Train Positioning (ASTP)

The European railway and CCS (Control-Command and Signalling) supply industry are working on the evolution of ERTMS, which includes a new ASTP element that is expected to use GNSS and EGNOS to provide safety-related train position, speed and acceleration to ETCS using multiple sensors in a multi-sensor architecture. GNSS is considered one of several sensors in an ASTP architecture, where other sensors potentially include inertial, rotational, radar-based, and optical sensors. The ASTP is being specified by industry as a black box, allowing manufacturers the flexibility to integrate GNSS/EGNOS in their solutions without a high level of prescription on the ASTP design. It is on this basis that manufacturers compete in their ERTMS product offerings as they have some margin to innovate. Interoperability is a key requirement for the ASTP, where stringent safety and performance requirements need to be met, with a modular approach for the ASTP element in terms of the on-board CCS architecture.

EGNOS for Rail

The EGNOS for Rail workplan was established as a collaboration between the rail sector and the space sector. Participants in the rail sector include: the Europe's Rail Joint Undertaking (ERJU); CCS suppliers, railway infrastructure managers, and railway undertakings involved in Flagship Area 2 of the ERJU; the European Railway Agency (ERA); and the ERTMS Users Group (EUG). Participants from the space sector include ESA and EUSPA.

The objective of the EGNOS for Rail workplan is the development of an EGNOS railway Safety of Life (SoL) service based on pseudorange domain integrity commitments excluding impact from the local environment. ESA activities aligned with this workplan include Horizon Europe HE-024 (EGNOS System Studies on Railway).

Rationale for the Activity

As mentioned above, the ASTP is considered a black box where the management of local effects, including multipath and NLOS, and ensuring resilience against interference and spoofing, is responsibility of the manufacturer and it is a gap that needs to be addressed to meet the stringent application-level performance targets.

This activity aims to support the successful bidder in the development of concepts and techniques suitable for managing local effects of the railway environment in the ASTP with the required performances. This includes assessing novel approaches such as the use of estimators based on robust statistics and associated integrity concepts for harsh environments. The activity intends to develop the fundamental enabling technologies needed for managing local effects, where the TRL would then be increased through a possible follow-up activity in NAVISP Element 2.

This activity is also expected to contribute to the understanding of achievable performances of user barriers (via reporting made publicly available), potentially providing:

- Input to assumptions on user barriers enabling an assessment of end-to-end performances of ASTP and GNSS/EGNOS contribution (relevance to HE-024 EGNOS System Studies for Railway; EGNOS4Rail workplan WP3.4 for assessing performances of EGNOS for Rail SoL Service)
- Input / contribution to future railway user standards for GNSS/SBAS (e.g., Minimum Operational Performance Standard (MOPS) for Railway SoL Service, contributing to future CCS Technical Specification for Interoperability (TSI) for ASTP)

This activity has been coordinated with key stakeholders in the EGNOS for Rail workplan and with EUSPA.

The key objective of the activity is to study, design, implement, and demonstrate solutions for managing GNSS local effects in the railway environment for the ASTP with a level of confidence compatible with target Tolerable Hazard Rates (THRs).

The activity foresees the following tasks:

- Study and identification of candidate PNT integrity algorithms / approaches suitable for managing GNSS local effects in railway (e.g., severe multipath and NLOS, spoofing, interference) as part of an integrity concept using EGNOS (Railway SoL pseudorange domain integrity service) considering assumptions on receiver, target THR, scenarios (e.g., dynamics), etc. The use of estimators based on robust statistics to improve performances in harsh railway environment shall be considered in the possible approaches.
- Definition of candidate multi-sensor architectures to support allocation of requirements including integrity requirements to elements of the architecture (e.g., considering the possible use of multiple GNSS receiver chains and application of concepts of diversity / dissimilarity to relax requirements on a single receiver chain).
- Considering candidate multi-sensor architectures, a trade-off assessment of candidate algorithms / approaches and allocations between selected user barriers and over-bounding models (faulty / nominal) in proposed concepts.
- Design, implementation and demonstration of proposed concepts including methods and user barriers for management of local feared events. This includes design of user barriers / approaches for providing resiliency against spoofing and interference.
- Validation and assessment of performances of proposed concepts (size of ATPL, ATP accuracy, etc.) using real data from test campaigns.

ESA will potentially provide, as an item made available, synthetic fault-injection data and spoofing scenarios from the railway simulation testbed in the TEC navigation laboratory. The activity is also expected to utilise field data from representative railway environments (RF samples, ground truth, etc.) provided from previous industry test campaigns.

The main output of the activity will consist of:

- Documents (review, trade-off analysis, technical specification, test and validation reports)
- Implementation and demonstration of proposed concepts

It is noted that no Participating State expressed their opt-out for this activity (EL1-111).

Funding required: 950k€	*Duration: 18 months*	*ITT issue: Mar-2025*

2.12. EL1-112: Development of a GNSS Receiver Size Weight & Power Model

In recent years, the design of GNSS receivers has become increasingly complex due to ongoing developments in signal structures and the growing variety of carrier frequencies, bandwidths, waveforms, chipping, and data rates. Based on these parameters and on the advancements in the different application domains, no effective, comprehensive tool currently exists to evaluate the best trade-off in terms of size, weight and power, as well as cost, (SWaP-C) for the design of GNSS receivers (including antenna, front-end, digital signal processor, ASIC, FPGA, etc.).

This lack of predictive modelling leaves designers uncertain about the impact of the different signal and system options/choices on receiver architecture and consequently on SWaP-C characteristics, leading to suboptimal solutions that may not fit the main stakeholder needs of the addressed value chain.

The objective of this activity is to create, validate, and deploy a parametric and flexible and expandable model capable of estimating the SWaP-C metrics of GNSS receivers, based on GNSS signals, system characteristics and application domains. The model will assist system designers in optimizing GNSS receiver architecture, providing key insights into implementation complexity and trade-offs associated with various signal structures, processing options and technologies.

The tasks to be performed shall include:

- State of the Art & Requirements Analysis:

  The project will begin with a comprehensive review of current GNSS receiver architectures, including high-volume, commercial products and professional-grade receivers. This review will assess the performance, size, weight, power consumption and costs (SWaP-C) of receivers, including all the components (antenna, front-end, digital stage, etc.). An analysis of the current and future semiconductor roadmaps will be performed to figure out the related computational capacities, power efficiency, available interfaces, and integration capabilities to foster and support the development of new, more-tailored GNSS receivers/products. An analysis of the current and future semiconductor roadmaps will be performed to understand the processing power, efficiency, and integration capabilities available for GNSS receiver development. This step will include trends in ASICs, FPGAs, and general-purpose processors used in signal processing.

- Structural Model Development:

  The second task is to establish a general structural model of GNSS receivers for different application domains. This model will incorporate elements such as the antenna, front-end, and digital signal processor, and will account for the Multi-System Constellation Layers. Parametric models will be developed for each sub-system, including frequency bandwidth, sampling rates, signal structure, and different processing features and functionalities. The model will also consider up-to-date semiconductor technologies and future roadmaps.

- Development of SWaP-C Estimation Models:

  The 3rd task aims at developing the SWaP-C estimation model and engine for the intended GNSS receiver/solution using the state-of-the-art analysis of Task 1 and the structural model implementation of Task 2. The signal design parameters are the key drivers of the SWaP-C budgets and together with the other configuration parameters will feed the prediction algorithms in charge of performing such assessments.

- Tool Integration and Validation:

  The SWaP-C estimation model will be integrated into a user-friendly expert tool. This tool will be validated through comparison with baseline GNSS receivers for specific high-volume, professional, and safety-of-life applications.

The main outputs of the activity will consist of:

- a deliverable SW (a validated expert tool for the SWaP-C characterization of GNSS receivers)
- State-of-the-Art and Requirements Analysis Assessment
- Architectural Model for GNSS Receivers in different application domains
- SWaP-C Estimation Models
- Validation Plan and Testing Results

It is noted that no Participating State expressed their opt-out for this activity (EL1-112).

Funding required: 300k€	*Duration: 18 months*	*ITT issue: Jun-2025*

2.13. EL1-113: Low profile thermal cell optical clock based on acetylene-filled hollow core fibre for future ground & space PNT

GNSSs now provide a ubiquitous dependency for modern technology, critical national infrastructure and business logistics, particularly in the realms of positioning, navigation and timing (PNT). There is a clearly identified need for alternative high-accuracy, resilient holdover clocks techniques to be available, whether ground or space-based, should problems arise with 24/7 delivery of GNSS signals resulting from outages due to intentional jamming, space clock failures or space weather interference. Future resilient PNT systems will need to maintain improved accuracies over longer fly-wheeling intervals than is currently possible with the current deployed clock systems. This can be achieved by use of robust optical clocks offering improved accuracies with lower Size, Weight and Power (SWaP), compared to the conventional microwave clocks such as active hydrogen masers in the ground segment, and passive masers and RAFS used in space.

One example is thermal cell optical clocks based on a single laser wavelength operating at 1542 nm in the optical band. Frequency servocontrol to narrow-linewidth Doppler-free absorptions in molecular acetylene offers the potential for low-profile, robust and resilient compact systems for both space and ground deployment.

Typical components of this clock would be a low pressure acetylene reference enclosed either within a sealed compact cell or within a sealed coiled hollow core fibre (HCF) cell, a narrow linewidth Distributed Feedback laser with its frequency pre-stabilised by means of a ultra-low-expansion cubic cavity, the generation of Doppler-free saturated absorption signals in molecular acetylene to provide the frequency references, and an octave-spanning frequency comb for the optical to microwave down-conversion to provide standard timing outputs.

The objective of this activity is to demonstrate the feasibility and the performance of the reference stage (physics package) of a thermal cell optical clock.

The tasks to be performed shall include:

- Thermal cell acetylene-based optical clocks can be used in ground and space infrastructure when high frequency stability is important and can provide extended fly-wheel holdover periods at a reduced cost and lower SWaP. The main tasks envisaged are:
- Hollow core fibre (HCF) cell filling with low pressure acetylene, pressure optimisation and sealing in robust anti-resonant HCF designs
- HCF cell evacuation and sealing for use as a laser pre-stabiliser
- Evaluation of acetylene Doppler-free signal frequency stability and drift performance within 10cm x 10mm diameter silica cells in comparison to acetylene-filled anti-resonant few-metre HCF cells
- Preliminary system evaluation against conventional standards (e.g. masers, Cs 5071, cold atom optical standards)

- SWaP design optimisation

The main outputs of the activity will consist of:

- Hardware and Software prototype
- Frequency and frequency drift performance evaluation report in silica cells and HCFs
- SWaP design optimisation report

It is noted that no Participating State expressed their opt-out for this activity (EL1-113).

Funding required: 750k€	*Duration: 24 months*	*ITT issue: Jan-2025*

2.14. EL1-114: Geodesy-enabled applications

Positioning and Navigation applications depend very heavily on the definition of a reference frame where the products are defined. In particular, GPS uses WGS-84 and Galileo the Galileo Terrestrial Reference Frame (GTRF), which are both "steered" to the International Terrestrial Reference Frame (ITRF).

The steering is performed by comparing suitable products and making the reference frames overlap as much as possible, in terms of origin and alignment. This is the way GPS and Galileo, and other navigation systems, can be interoperable. The national reference coordinate systems, used for example for cadastral data, are formally different and aligned as well to ITRF in some way.

Other digital models, like Digital Elevation Models and Building Information Systems are defined in, possibly different, arbitrary reference frames.

Despite the alignment of the references is good (cm level), a further improvement would allow to push existing applications (mainly in the scientific domain) to their limits and would enable new applications, for the benefit of the economy, the society and its citizens.

The objective of this activity is to study the benefits for the non-scientific applications originated by improving the ITRF and the accuracy of Precise Orbit Determination (POD), stemming from GENESIS (and other geodetic techniques).

The current reference frames are aligned relatively well, but a further improvement of the alignment would help existing scientific applications and would probably create new applications. Whereas the benefit for the scientific applications has been described in the motivations behind the creation of the ESA Genesis program and other similar initiative, the benefit for industrial, professional and possibly commercial applications is less direct and more subtle. Straightforward benefits (e.g. increase of ultimate product accuracy) are expected directly from better alignment, but other benefits can be more indirect (like increase of accuracy of augmentation products caused by the increase of accuracy of satellites POD). A dedicated study is considered necessary to understand better the impact, with the objective to focus on the most promising applications

The tasks to be performed shall include:

- Review of the state of the art in reference frames used in Positioning and Navigation (definition, mutual relationship and maintenance)
- Analysis of the trends and identification of the gaps that are considered important to fill in the industrial and professional applications
- Identification of the industrial actors and possible activities outlines

The main outputs of the activity will consist of:

- Final report demonstrating and justifying the potential applications benefitting from improvements in reference frames performance, identification of industrial players, and description of potential activities.

It is noted that no Participating State expressed their opt-out for this activity (EL1-114).

Funding required: 200k€	*Duration: 12 months*	*ITT issue: Jan-2025*

2.15. EL1-115: ADAS Technology and PNT

Advanced Driver Assistance Systems (ADAS) are technologies developed targeting a higher level of autonomous driving and security. These include, amongst others, alerting and warning, crash mitigation, driving assistance, visual environment monitoring and hands-free technology. PNT plays an important role in many of these systems.

Positioning plays and will play a key role in the future. Main concerns include high accuracy, fast convergence and integrity, features currently well under study. However, the more we advance in driving automation, the more automated navigation cases become prominent. These include, amongst others, Simultaneous Localisation and Mapping (SLAM), Automated Cruise Control (ACC), Lane Centering Functions (LCF), dynamic route mapping, map-free navigation or vehicle-infrastructure convergence.

ADAS and self-driving technology is an opportunity for European PNT.

The objective of this activity is to get an overview on the latest trends on ADAS technology and understand PNT opportunities within the space.

The tasks to be performed shall include:

- Considering the SAE’s levels of driving automation, from Level 0 (no driving automation) to Level 5 (full driving automation), provide an overview of trends within ADAS technology related to SAE Level 2-5 in the next few years, understand the gap in PNT technologies and identify PNT-development opportunities for the next 2-5 years
- Explore the European landscape to identify actors across the supply chain that could work with NAVISP developing new PNT-related products and services in this area, identifying potential activities.

The main outputs of the activity will consist of:

- ADAS overview and role of PNT
- ADAS trends and PNT gaps / developments
- List of potential activities in the area of ADAS

It is noted that no Participating State expressed their opt-out for this activity (EL1-115).

Funding required: 200k€	*Duration: 9 months*	*ITT issue: Feb-2025*

3. WORK PLAN 2025 SUMMARY

Table 2 summarizes in a synthetic way the Funding Required and the planned Duration, for all the activities.

ID	Name	Duration (months)	Funding Required (k€)
EL1-101	Underwater and underground navigation using Muons	24	800
EL1-102	Quantum receiver for navigation applications	12	400
EL1-103	Precise and Stable Navigation with Quantum Accelerometer	24	800
EL1-104	AI for Anomaly Detection in Multi-Sensor PNT	12	450
EL1-105	Hybrid black-white-modelling estimation and machine learning algorithms for PNT engines	18	500
EL1-106	Beamforming user antenna for wideband radionavigation signals in C-band	12	800
EL1-107	Ultra-high spatial resolution GNSS receiver for automotive industry	12	800
EL1-108	Assessment of Time Transfer Techniques for Resilient Regional (Transnational) UTC Infrastructure	18	650
EL1-109	5G Localisation for Safety of Life Applications in Rail	18	630
EL1-110	User Equipment Platform for Positioning with 5G/6G Non-Terrestrial Networks	24	750
EL1-111	Managing GNSS Local Effects in the Railway Environment for Advanced Safe Train Positioning	18	950
EL1-112	Development of a GNSS Receiver Size Weight & Power Model	18	300
EL1-113	Low profile thermal cell optical clock based on acetylene-filled hollow core fibre for future ground & space PNT	24	750
EL1-114	Geodesy-enabled applications	12	200
EL1-115	ADAS Technology and PNT	9	200
	Total		8980

Table 2 - Activities' funding required and activities' duration

Table 3 summarizes the timeline for all the activities, considering the expected date for the Invitation-To-Tender (ITT) issue, the negotiation process, the Contract award and execution.

The plan is the result of an optimization trying to start as early as possible challenging activities and spreading evenly the effort over the time, to also provide for an affordable commitment profile.

ID	Name	2025												2026												2027											
		J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
EL1-101	Underwater and underground navigation using Muons					ITT																															
EL1-102	Quantum receiver for navigation applications		ITT																																		
EL1-103	Precise and Stable Navigation with Quantum Accelerometer			ITT																																	
EL1-104	AI for Anomaly Detection in Multi-Sensor PNT	ITT																																			
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EL1-106	Beamforming user antenna for wideband radionavigation signals in C-band				ITT																																
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EL1-112	Development of a GNSS Receiver Size Weight & Power Model						ITT																														
EL1-113	Low profile thermal cell optical clock based on acetylene-filled hollow core fibre for future ground & space PNT	ITT																																			
EL1-114	Geodesy-enabled applications	ITT																																			
EL1-115	ADAS Technology and PNT		ITT																																		

Table 3 - Activities' ITT and Contract execution planning