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Att.: Annex
Paris, 12 January 2024
(English Only)

EUROPEAN SPACE AGENCY

INDUSTRIAL POLICY COMMITTEE

NAVISP Element 1 Work Plan 2024

IPC is invited to approve this Work Plan by simple majority
of the Participating States in Navigation Innovation
and Support Programme (NAVISP) Element 1 Phase 2/3:
AT+BE+CH+DE+DK+ES+FI+FR+GR+HU+IT+NL+NO+PL+PT+RO+SE+UK

SUBJECT

This document provides the Procurement Proposals for the activities contained in the NAVISP Element 1 Work Plan for 2024, which was approved by the Participating States in NAVISP Element 1 at the PB-NAV meeting 128th on the 15th of November 2023.

REQUIRED ACTION

The Industrial Policy Committee is invited to approve the Procurement Proposals of the NAVISP Element 1 Work Plan for 2024.

All proposed procurements are above the threshold requiring Industrial Policy Committee approval, except activities NAVISP EL1-087, -089, -090, -093, -096, -098 and -099.

In case Participating States have expressed their intention not to support any specific procurement (“Opt-out”), this is clearly indicated in the "List of Proposed Procurements" (Table 1) and in the activity’s text.

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List of Proposed Procurements

Open Competitive Tender (Article 13.1 ESA Procurement Regulations)

Reason for Submission Article 21 of Procurement Regulations (ESA/REG/001,rev.5)
Initiating Service Dir.: Navigation
Dept.: Future Navigation Department/NAVISP Element 1 Office (NAV-FNI)

Budgetary Output FUNDS: E/0365-40 (1100467); E/0365-70 (1100470)
COST ELEMENT: 6171000 (studies and technology development)
Price Type Firm Fixed Price
Weighting Factor 1

Approval Level	Item Ref. (Paragraph)	Subject of Procurement	Estimated Price Range (k€)	Duration (months)	ITT issue	Proc. Approach	Opt Out
IPC	4.3.1	EL1-086	600	18	Apr-24	C	-
INFO	4.3.2	EL1-087	400	18	Jan-24	C	-
IPC	4.3.3	EL1-088	600	18	Apr-24	C	-
INFO	4.3.4	EL1-089	400	18	Feb-24	C	-
INFO	4.3.5	EL1-090	500	18	Jun-24	C	-
IPC	4.3.6	EL1-091	800	24	Mar-24	C	-
IPC	4.3.7	EL1-092	750	24	Sep-24	C	-
INFO	4.3.8	EL1-093	500	18	Feb-24	C	-
IPC	4.3.9	EL1-094	600	24	Jul-24	C	-
IPC	4.3.10	EL1-095	600	24	May-24	C	-
INFO	4.3.11	EL1-096	450	15	Nov-24	C	-
IPC	4.3.12	EL1-097	800	24	Sep-24	C	-
INFO	4.3.13	EL1-098	400	18	Oct-24	C	-
INFO	4.3.14	EL1-099	500	18	Oct-24	C	-

Table 1 – List of Proposed procurements

KEY TO TABLES

Estimated Price Range planned per activity: Total Contract Authorisation (CA) values, given in k€, at m.e.c. economic conditions.

C: Open Competitive Tender; (Ref. Article 13.1 ESA Procurement Regulations).

C(1)* : Activities in open competition limited to the non-Large-System Integrators.
Note: In these activities, LSIs are not allowed to submit prime proposals to ESA. LSIs can participate as subcontractors. In this case, the proposal must demonstrate that:

- *The tasks assigned to the LSI do not constitute the core activities of the proposed development;*
- *The technical expertise provided by the LSI is essential to the activity;*
- *The non-LSI in the team retains the key capabilities to develop and exploit the results of the technology activity;*
- *The presence of the LSI in the proposal does not undetermined or limit the leading role of the non-LSI in the team. (Otherwise, the bid will not be considered for further evaluation).*

C(2)* : Activities in open competition, where a significant participation of non-Large-System Integrators is requested.
Note: These activities are open to all potential bidders, LSIs and non-LSIs. However, LSIs that submit bids are requested to include in those bids a relevant participation of non-LSIs, in quality and quantity, in accordance with the ITT guidelines - in the form of a percentage range of expected participation of non-LSIs – on which the C(2) measure is applied. (Otherwise, the bid will not be considered for further evaluation).

C(3)* : Activity restricted to SMEs & R&D organisations, preferably in cooperation.
Note: The measure is proposed when the technology activity relates to early phases of the technology development (TRL<3) with strong expectations on innovation contents, or to technology spin-in, and when SMEs & R&D organisations have recognised expertise and capabilities in the technology domain. (Otherwise, the bid will not be considered for further evaluation).

C(4)* : Activities in open competition, subject to the SME subcontracting clause.
Note: Bidders are required to do their utmost to include in their bid an adequate participation of SMEs as subcontractor(s) (judged in terms of quantity indicated as guidelines of the ITT on which the C(4) measure is applied). Offers shall provide an analysis of the potential advantages of the proposed participation (e.g. long-term prospects for future work). If no such participation is offered, the bid shall contain evidence of the effort made to meet these requirements and the reasons for the lack of success. (Otherwise, the bid will not be considered for further evaluation.)

C(R): Competition is restricted to a few companies, indicated in the "Remarks" column; (Ref. Article 13.2 ESA Procurement Regulations).

*See ESA/IPC(2005)87, rev.4. Industry has been informed, through the esastar "News", of the content of that document.

DN/S: Direct Negotiation/Specialisation; the contract will be awarded by direct negotiation in implementation of a defined industrial policy or resulting from a sole supplier situation (Ref. Articles 14.1.a), d), and e) ESA Procurement Regulations).

DN/C: Direct Negotiation/Continuation; the contract will be awarded in direct negotiation being the immediate continuation of a previous activity with the same contractor (Ref. Article 14.1.c) ESA Procurement Regulations).

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ANNEX

NAVISP Element 1 Work Plan for 2024

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).

This document presents the Element 1 Work Plan for 2024.

2. PREPARATION OF NAVISP ELEMENT 1 WORKPLAN FOR 2024

The NAVISP Element 1 Work Plan prepares the foundations for future innovative PNT developments, the aim being to attract industry interest in the wider PNT domain and offer the possibility to develop new solutions by accessing and combining relevant space and non-space know-how, techniques and technologies.

Element 1 is the exploratory component of NAVISP, and the innovative and disruptive nature of the idea is what matters. New solutions (concepts, systems, equipment, products, algorithms, techniques, technologies) are generated and their feasibility is assessed, tested and demonstrated, with recommendations for follow-on activities.

The Executive has applied the well proven ‘funnel scheme’ to collect the most promising proposals for the Element 1 Work Plan for 2024. The Executive has collected firstly inputs through a focused ESA-wide consultation and a solicitation via the NAVISP website. Secondly, the Executive has collected inputs from other external stakeholders, in particular Participating States and the NAVISP Advisory Committee (NAVAC). Then, the Executive has refined the inputs with the ultimate purpose to populate the work plan according to well-established guidelines and adhering to the prioritization suggested by NAVAC.

3. STATUS OF COORDINATION

The Element 1 Work Plan for 2024 has been shared with the EC and EUSPA through two rounds of formal consultations on both its draft and final versions. This process has been carried out strictly in line with “Coordination between the EC-GSA and ESA on NAVISP Programme Activities” (ESA/PB-NAV(2016)34). Comments received by the EC and EUSPA have been taken into account, and text describing the proposed activities has been updated for the sake of clarity.

4. RATIONALE AND DESCRIPTION OF PROPOSED ACTIVITIES

4.1. Rationale for Work Plan definition

The definition of the Element 1 Work Plan 2024 was carried out in the context of the wider NAVISP innovation process, an extensive process for the innovation of PNT which takes into account the PNT state-of-the-art, the trends and the gaps of the PNT domain technologies, applications and services, the indications of the Participant States, who might relay the European Economic Operators' aspirations, the independent advice by NAVAC, the New Space context and the ESA Agenda 2025.

Following the initial phases of the Programme (with Phase 1 corresponding to the "birth", and Phase 2 representing a "consolidation"), Phase 3 objective is to foster the creation of *"European PNT champions".* Element 1 is key to the achievement of this objective by preparing the grounds for Element 2 (commercial) and Element 3 (institutional) activities.

Consequently, the focus of the Element 1 workplan was on advanced prototyping and larger scale demonstrations, and potential areas of interest were:

- Autonomous Transport and Green Mobility, i.e. PNT for Connected and Cooperative Automated Mobility (with preference to ubiquitous PNT for urban environment, Perception 360 and PNT Monitoring)
- Alternate PNT
- PNT in Rail for control operations

Following the 'funnel scheme', the inputs requested, a described in Section 2, had to meet the NAVISP Element 1 eligibility criteria:

- Addressing innovative PNT concepts, techniques and technologies
- Avoiding overlap with other on-going or planned activities and not addressing EGNSS evolutions

Many proposals were received from the internal advisory committee (mainly from the TEC directorate), few from external organisations via the website, several from the Participating States and few from NAVAC directly. All in all, the amount of candidate proposals received, more than 50, reflected the enthusiasm of the stakeholders in contributing to shape innovative PNT concepts, techniques and technologies for the Element 1, and provided an excellent basis to proceed, through prioritization, to the definition of the activities in this Work Plan.

The criteria used for the prioritization under the lead of NAVAC were:

- Element 1 Innovation trends
- NAVAC recommendations
- New Space Context
- ESA accelerators

The criteria are described briefly in the following paragraphs.

Element 1 Innovation trends: the Element 1 Innovation Process provided a first criterion, considering that it consists of the following high-level steps:

- review of the State of the Art in PNT system/technology
- analysis of the most important trends in PNT system/technology
- identification of PNT system/technology gaps that needs to be filled
- establishing a coherent plan of activities to develop the PNT system/technology identified.

Notwithstanding the observation that trends can change considerably every year, among the many technologies, the following were considered relevant for Element 1 Work Plan 2024, along with the special focus given at the time of requesting the inputs (Autonomous Transport and Green Mobility, Alternate PNT, PNT in Rail):

- Quantum technologies (Photonics optical gyro, inertial [accel/ang vel] and magnetic sensors, optical clocks)
- Precise positioning (PPP-AR, PPP-RTK)
- Sensor fusion (GNSS/ INS/ Visual/ LiDAR/ Bluetooth/ 5G/ UWB/ Magnetic/ Vibration) and its integrity - Role of maps
- Autonomy
- Artificial Intelligence (Machine Learning)
- Indoor navigation
- Meta-signals, Direct Positioning Estimation, Vector Tracking Loop, Factor Graphs, Particle filters, super-resolution/ synthetic aperture receiver
- LEO satcom/5G Signals of Opportunity - 5G/6G Positioning Reference Signal (PRS) (NTN), Doppler processing
- RFI Detection/Characterisation/Mitigation/Monitoring for GNSSs (e.g. for antenna arrays in US for GPS and RFI monitoring for PRS in EU)
- Pulsars

NAVAC recommendations: NAVAC advises the Executive expertly and constantly on the focus to be given to the technical scope of the activities.
NAVAC also provided the following recommendations for Element 1 Phase 3:

- maintain the non-GNSS-centric view with the objective to enhance the robustness of the user's PNT
- include more activities to reduce regulatory risk related with the introduction of existing PNT technologies in new markets (e.g. Proof-of-Concept or demonstration activities)
- support key PNT technology developments (e.g. GNSS chips design capability should be strengthened)
- implement a higher research culture by stretching the scope of activities, including high risk activities

New Space Context: the specific characteristics of the New Space was taken into account as contextual element, in broad sense. They were:

- rapidly advancing commercialisation, significant private capital investment, the diffusion of new technologies and design approaches
- constellations of small satellites
- Internet of Things
- new launchers with more favourably priced access to space
- digital transformation, data driven and cloud based services
- new commercial fields in space (Debris mitigation and removal, On orbit servicing, microgravity manufacturing, energy from space, space mining,

space tourism, space habitat, humans to Mars)

ESA accelerators: the ESA's view on the future of space, elaborated in the ESA's Agenda 2025 and related accelerators and inspirators, was considered. The accelerators are defined as follows:

- Accelerator 1 - Space for a Green Future, using advanced space data, science & technology for sustainable life on Earth, including the development of digital twins of our planet to support society and decision makers to reach carbon neutrality by 2050;
- Accelerator 2 - Rapid and Resilient Crisis Response, for enabling security stakeholders to ensure rapid provision of information, hence allowing quick response to climate-induced and other crises facing Europe;
- Accelerator 3 - Protection of Space Assets, to ensure resilient availability and functioning of space infrastructure on which Europe's economy and society relies for day-to-day life.

4.2. Work Plan activities prioritization justification

The "funnel scheme" was very successful because it allowed to collect many proposals for interesting activities, including several from the Participating States, but of course there was not enough budget to go ahead with their unrestrained implementation. A "sieve" was then necessary to filter out some of the proposals which were considered less urgent from a certain point of view (in line with the criteria for the prioritization mentioned in Section 4.1).

The resulting Work Plan 2024 includes fourteen (14) very innovative activities, for a total annual budget of 7.9 M€, in line with the contributions for industrial activities of the Element 1 for the Phase 3 (24.9 M€ over three years).

The activities were prioritized in accordance with the justifications provided in this section. Table 1 gives an overview of the prioritisation justification elements.

Activities following a relevant Innovation Trend

- **EL1-086** Instantaneous High-Accuracy Positioning based on Hybrid-Meta-Signal Solutions
  It is linked to the trend of High Accuracy and Meta-Signal (the technique by which, by merging in a suitable synthetic way the processing of samples taken on two or more separate frequency bandwidths, one can achieve performance superior to processing the two or more inputs separately. The most trivial example is when, lacking the capability to process the Galileo AltBOC high bandwidth complex signal as a whole, one tries to perform the combined processing of the separate E5a and E5b signals).

- **EL1-088** Proof-of-concept of advanced navigation algorithms based on factor graph optimization
  Factor graphs are a trendy methodology which are employed often in PNT studies and technology development especially in US, but not sufficiently addressed in Europe. By addressing a complex problem as the product of simpler problems, it

can exploit the local properties of the simpler problems to find more efficient solutions.

- **EL1-090** Robust Navigation for Autonomous Driving with Low-Cost/SWaP Arrays of Antennas
  PNT for Connected and Cooperative Automated Mobility is one of the special focus items given to the internal advisors in requesting the proposals, and this proposal integrating more antennas in a single system to exploit spatial correlation, follows a trend that deserves more validation in the field.

- **EL1-093** Enabling PPP ambiguity resolution in satellite and terrestrial frequency-varying carrier-phase signals
  As the quest for High Accuracy goes through the usage of carrier phases measurements, ambiguity resolution is a fundamental processing need. The parallel trend of using terrestrial and LEO systems is injecting in the picture the need to apply the concept when signals having different carrier frequencies are involved.

- **EL1-096** Advanced visual INS for high-end handheld devices
  Visual sensors, at various frequencies, can provide important information for navigation purposes. This trend for autonomous robots and vehicles is already established, and this activity aims at bringing the technology already available in that sector to the handheld devices domain, to support applications like allowing first responders to navigate in difficult environmental conditions.

Activities following a relevant Innovation Trend and a NAVAC recommendation

- **EL1-087** Verifiable AI/ML techniques for PNT applications.
  It comes from the trends but also from the NAVAC recommendation to support key PNT technology developments, in this particular case with a view to safety critical applications.

- **EL1-089** Modelling Quantum Sensors in a realistic navigation system context
  Quantum technologies, in line with the trends in PNT, are high in the agenda of many organisations and governments, for their disruptive potential only developed in certain contexts (lasers, atomic clocks and photonics). They are well addressed also in the PNT domain in US (e.g. the DARPA Precision Inertial Navigation System effort for the High Dynamic Range Atom Sensors (HiDRA) program), but not sufficiently in Europe. Moreover, studying models for Quantum sensors and their impact to PNT systems go in the direction of the NAVAC recommendation to support key PNT technology developments.

- **EL1-091** Proof-of-concept of SOOP with broadband satcom signals in Ku/Ka-band
  Taking inspiration from the pre-GNSS TRANSIT system, providing positioning for nuclear submarines at periscope height in the ’60 with few LEO satellites, in the US there has been an important trend to try to exploit opportunistically the thousands of telecom satellites already flying or in preparation (Starlink, Kuiper, Kepler). However, there has been insufficient motivation in Europe to do the same. Complementarily and in preparation of the activities developed in the ESA LEO-PNT program, this activity is also responding to the NAVAC recommendation to

maintain the NAVISP non-GNSS-centric view to enhance the robustness of the user's PNT.

- **EL1-092** Integrity in 5G Private Networks for Industry 4.0
  In line with the trends, in a world witnessing ever more convergence between telecom and navigation missions, 5G features like the Positioning Reference Signals and Non-Terrestrial-Networks make 5G an ideal candidate to increase the performance, the resilience, the integrity and the ubiquity of PNT solutions in environments ranging from smart cities to industry 4.0 setting. This activity, in particular, looks at the failure modes and rates of the 5G infrastructure in industrial environment where safety of the assets and workers is important. Not being focused on GNSS, this activity is also responding to the NAVAC recommendation to maintain the NAVISP non-GNSS-centric view to enhance the robustness of the user's PNT.

- **EL1-095** Exploitation of Geo-spatial Data for Automated Vehicles
  GNSSs and their dedicated high accuracy and augmentation systems (e.g. WAAS, EGNOS, Galileo HAS) are providing excellent performance in general, under many viewpoints. However, the trend in many experts' opinion is that the solution to the truly fully automated mobility for the future can come only from the fusion of several sensors and systems with very different and independent failure modes, so that the integrity of the final solution will be maximised. Visual sensors can allow Simultaneous Localisation and Mapping (SLAM) in relative sense, and digital twins of our world (like elevation models, roads, terrain feature and building maps) can help navigate in absolute sense, with a suitable match mapping algorithm. With its focus on alternative sensors and digital twins, this activity is also responding to the NAVAC recommendation to maintain the NAVISP non-GNSS-centric view to enhance the robustness of the user's PNT.

- **EL1-097** Use of Machine Learning techniques to optimize the adaptive beam-steering capabilities of CRPAs for GNSS user receivers
  Machine Learning usage and antenna arrays promotion are two significant trends in the PNT products and services, on one side to solve complex problems for which models are not readily available (and for which there is hope to capture the dynamic features directly from the data) and on the other side to combat RF interference at the antenna itself, guaranteeing its stipulated performance, being aware that all signal processing techniques can only be effective up to a certain extent, because they are operating on sampled data captured after the antenna. This activity merging the two key topics is considered to cover also the NAVAC recommendation to support key PNT technology developments, as promoted by the US PNT advisory board.

Activities following a relevant Innovation Trend and resulting from the New Space context

- **EL1-094** High-accuracy formation flying technologies for future distributed space instruments
  It is motivated by the New Space context, which, with many small satellites affordable by several organisations, makes it more probable to pursue the concept of distributed processing, based on interferometric techniques, which require very high relative positioning accuracy to work properly. It is also expected that an extension to UAVs might be a spin-off of this activity.

Activities following a relevant Innovation Trend and an ESA Accelerator

- **EL1-098** Metrics to Assess the Performance of GNSS Authentication Schemes
  The comparison of various authentication mechanisms (taking Galileo OS Navigation Message Authentication as a reference), is covering at the same time the criterion of the trend on the RFI Detection/Mitigation and, in a wide sense, the criterion of the Accelerator 3 (Protection of Space Assets).

Activities following an ESA Accelerator and a NAVAC recommendation

- **EL1-099** Location, Tracking and Salvage support of lost shipping containers at sea
  This activity proposes to mitigate an economic as well as an environmental problem with the use of PNT technology, therefore it covers partially the Accelerator 1 (Space for a Green Future) and partially, by proposing to employ SAR and IoT technology, it covers the NAVAC recommendation to maintain the non-GNSS-centric view to enhance the robustness of the user's PNT.

ID	Name	Innovation trend	NAVAC	New Space	ESA Accelerator
EL1-086	Instantaneous High-Accuracy Positioning based on Hybrid-Meta-Signal Solutions	■			
EL1-087	Verifiable AI/ML techniques for PNT applications	■	■		
EL1-088	Proof-of-concept of advanced navigation algorithms based on factor graph optimization	■			
EL1-089	Modelling Quantum Sensors in a realistic navigation system context	■	■		
EL1-090	Robust Navigation for Autonomous Driving with Low-Cost/SWaP Arrays of Antennas	■			
EL1-091	Proof-of-concept of SOOP with broadband satcom signals in Ku/Ka-band	■	■		
EL1-092	Integrity in 5G Private Networks for Industry 4.0	■	■		
EL1-093	Enabling PPP ambiguity resolution in satellite and terrestrial frequency-varying carrier-phase signals	■			
EL1-094	High-accuracy formation flying technologies for future distributed space instruments	■		■	
EL1-095	Exploitation of Geo-spatial Data for Automated Vehicles	■	■		
EL1-096	Advanced visual INS for high-end handheld devices	■			
EL1-097	Use of ML techniques to optimize the adaptive beam-steering capabilities of CRPAs for GNSS user receivers	■	■		
EL1-098	Metrics to Assess the Performance of GNSS Authentication Schemes	■			■
EL1-099	Location, Tracking and Salvage support of lost shipping containers at sea		■		■

Table 1 – Proposed procurements' key to prioritisation subjects

4.3. Work Plan 2024 activities

4.3.1. EL1-086: Instantaneous High-Accuracy Positioning based on Hybrid-Meta-Signal Solutions

Meta-signal processing has raised interest in order to enable the achievement of high-accuracy solutions based on the joint exploitation of two or more signal components as a single composite signal. The drawback of this approach is the appearance of multiple correlation peaks, inducing potential biases in the meta-signal pseudoranges when operating in harsh environments.
On the other hand, collaborative positioning exploiting peer-to-peer ranges, for example based on WiFi-Round Trip Time (RTT)/UWB, is a potential candidate to allow positioning in harsh conditions, including indoors.
In this context, hybrid solutions exploiting both meta-signals and peer-to-peer ranges are expected to enable the robust and unambiguous exploitation of meta-signals in urban-to-indoor scenarios.

The objective of this activity is to study, design, implement and demonstrate the achievement of instantaneous high-accuracy positioning based on hybrid solutions exploiting both meta-signals and peer-to-peer ranging.

The tasks to be performed shall include:

- study, design, implement hybrid solutions exploiting meta-signals and peer-to-peer ranging for achieving instantaneous high-accuracy in urban-indoor conditions. As part of this study, new WiFi technology (based on the IEEE 802.11az standard and exploiting bandwidths>160 MHz) shall be benchmarked against UWB and 5G (optional) to serve as source for peer-to-peer ranging. Meta-signal exploiting existing legacy signal combinations and peer-to-peer ranges considering different mass-market technologies are to be considered.
- Demonstrate the potential benefits and applications of the proposed solutions in different user environments and use cases based on test campaigns with real measurements.

The main outputs of the activity will consist of:

- Definition and design of innovative hybrid meta-signal solutions
- Breadboard 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 (EL1-086).

Funding required: 600k€	*Duration: 18 months*	*ITT issue: Apr-2024*

4.3.2. EL1-087: Verifiable AI/ML techniques for PNT applications

Artificial intelligence (AI) is increasingly utilized in the PNT field, enhancing the performance and reliability of Global Navigation Satellite Systems (GNSS), from RF interference detection and mitigation to sensor fusion. The advancement and ever-increasing size of neural networks increase the complexity of applications supported by AI, and with the increasing complexity, verifiability decreases. Unreliable or biased AI systems can have serious consequences, risking damage both to the environment and to human lives, especially in domains like autonomous vehicles, UAVs, and marine applications.

To overcome concerns about data biases, insufficient data, and lack of transparency, effective techniques such as data augmentation, transfer learning, and Explainable AI (XAI) methods can be employed. However, addressing issues like inaccurate specifications and algorithmic biases is even more crucial to avoid incorrect and undesirable outcomes. Therefore, it is essential to develop methods that can verify the behaviour of AI systems.

Verified AI, as defined by the Association for Computing Machinery (ACM), seeks to design AI systems that provide robust assurance, ideally with provable correctness based on mathematically specified requirements. This approach is crucial to ensure reliable and trustworthy operation of AI systems in PNT applications.

The objective of the activity is to study the viability of integrating verifiable artificial intelligence and machine learning techniques to enhance PNT applications.

The tasks to be performed shall include:

- Review of the state-of-the-art verifiable AI techniques and design processes for ML systems in PNT domain
- Develop verification algorithms based on formal specification and formal verification methods to enhance trust and verifiability in AI systems operating in the PNT field, where the human-AI interaction at design level is instrumental in ensuring reliable and transparent performance for the human agent
- Develop a simulator to test few specific use cases in complex environments (e.g., sensor fusion)
- Design a demonstrator to evaluate the performance of the developed verified AI algorithms for PNT.

The main outputs of the activity will consist of:

- Design and development of verifiable AI/ML architectures and algorithms applicable in the PNT domain for autonomous systems (e.g., maritime, road, railway, or aviation)
- Simulator and demonstrator to assess the verified AI algorithms in challenging environments
- Recommendations for best practices for testing AI for PNT applications

It is noted that no Participating State expressed their opt-out for this activity (EL1-087).

Funding required: 400k€	*Duration: 18 months*	*ITT issue: Jan-2024*

4.3.3. EL1-088: Proof-of-concept of advanced navigation algorithms based on factor graph optimization

Factor graph optimization is gaining attention from the community (it has won the Google challenge) as is outperforming traditional positioning algorithms. Factor graph optimization may be used to replace the traditional Weighted Least Square (WLS) or Kalman Filter (KF)-based solutions, both in stand-alone and hybrid positioning solutions in combination with sensors. Thus, its application may be of interest for the derivation of improved positioning solutions for different receiver grades, including low-end/low-quality mass-market receivers.

The objective of the activity is to investigate innovative navigation algorithms exploiting factor graph optimization, both in standalone and in combination with other sensors, and for different receiver grades (including low-quality observables) and ambiguity resolution for high-accuracy. The activity will benchmark both the potential accuracy improvement and the computational cost of the proposed algorithms.

The tasks to be performed shall include:

- Review of the state of the art in factor graph optimization
- Design and development of a test bed including a factor graph navigation algorithm processor and the implementation of a reference algorithm based on KF
- Comparison of reference KF and factor graph implementation in different user scenarios, in particular:
    - when exploiting GNSS observables from different receiver grades (from high-end to low-quality / mass-market receivers for smartphone/IoT applications), and no data of other sensors;
    - when applied for integrating GNSS with other sensors (different types and grades, including, but not limited, inertial sensors);
    - in the presence of different user conditions, including harsh propagation scenarios typical of urban and indoor environments.
- Assess the benefits provided, based on real field measurement campaigns and observables from commercial/mass-market receivers.

The main outputs of the activity will consist of:

- Design of innovative positioning solutions based on factor graph optimization for different receiver grades
- Testbed including commercial/mass-market receivers
- Test report of performance comparison between Factor Graph implementation and reference KF
- Roadmap for commercialization, including potential NAVISP EL2 activities

It is noted that no Participating State expressed their opt-out for this activity (EL1-088).

Funding required: 600k€	*Duration: 18 months*	*ITT issue: Apr-2024*

4.3.4. EL1-089: Modelling Quantum Sensors in a realistic navigation system context

As well as the potential next generation quantum time and frequency sources, the world of quantum systems contemplates evolutions of gyroscopes, accelerometers, gravitational sensors and magnetometers based on quantum effects. Predictions of the performance of these new quantum sensors offer the prospect of accurate navigation without GNSS for long periods of time with some predicting that GNSS will no longer be necessary.
However few models exist to be able to test and show the potential impacts of quantum-based technologies when integrated into a navigation system. Where modelling capabilities exist, they do not factor in realistic environments and dynamics and all potential sources of noise or error that might exist in a mobile system. Similarly, much of the experimentation with quantum sensors for navigation has been laboratory based and there is little experimental evidence of performance in the real world and the degradations that might occur when quantum sensors are integrated into a complete PNT solution.

The objective of the activity is to develop new models for end-to-end navigation solutions that incorporate quantum sensors and account for real world environments and dynamics.
The main innovation is to develop an environment where the benefits, if any, of quantum sensors can be determined before integration in a real system.

The tasks to be performed shall include:

- Review of the existing simulator environments and quantum sensors models and analysis of the sensor model's suitability to be incorporated in simulation environments
- Definition of missing quantum sensor model. The definition of the models for the quantum sensors in this context may need to be supported by laboratory or even field experiments. The state-of-the art in US Quantum PNT has to be considered as a starting point.

The main outputs of the activity will consist of:

- Survey of state of the art on quantum sensors and their models
- New models development and their incorporation in PNT systems

It is noted that no Participating State expressed their opt-out for this activity (EL1-089).

Funding required: 400k€	*Duration: 18 months*	*ITT issue: Feb-2024*

4.3.5. EL1-090: Robust Navigation for Autonomous Driving with Low-Cost/SWaP Arrays of Antennas

The derivation of robust positioning solutions under harsh propagation conditions typical of autonomous driving applications remains an open problem in GNSS.
The application of Multiple-Input-Multiple-Output (MIMO)-GNSS-like processing approaches for robust GNSS positioning with low-cost arrays of antenna platforms has shown important benefits in the presence of obstruction, fading and multipath conditions, and can be exploited as well for the mitigation of interference and jamming. The introduction of a larger number of antenna elements, even if low-cost, allows to improve the PNT solution.
In this context, the signals received from array antenna configurations are proposed to be exploited in the position domain (via Direct Position Estimation), including the exploitation of undesired spatially-correlated signal contributions from different elements, and received from different satellites.
This is to be done exploiting low-cost arrays of antennas in vehicular applications and targeting low-Size Weight and Power (SWaP) processing platforms.

The objective of the activity is to study, design, implement and demonstrate the achievement of robust positioning solutions for autonomous driving with low-cost arrays of antennas in low-SWaP platforms, via the exploitation in the position domain (via Direct Position Estimation) of undesired spatially-correlated signal contributions from different elements, and received from different satellites.

The tasks to be performed shall include:

- study, design, implement and demonstrate robust positioning solutions for autonomous driving based on the exploitation in the position domain of spatially-correlated signal contributions from different elements, and received from different satellites, with low-cost arrays of antennas in low-SWaP platforms.
- Asses the benefits in different vehicular user environments and dynamics for different array configurations (from few elements to above 10 elements) based on test campaigns with real measurements. A car manufacturer should be included in the consortium to discuss and facilitate adoption of the solution.

The main outputs of the activity will consist of:

- Innovative solutions in the position domain exploiting undesired spatially-correlated signal contributions
- Breadboard 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 (EL1-090).

Funding required: 500k€	*Duration: 18 months*	*ITT issue: Jun-2024*

4.3.6. EL1-091: Proof-of-concept of SOOP with broadband satcom signals in Ku/Ka-band

The feasibility of Positioning-Navigation-Timing (PNT) using signals of opportunities from broadband satellite communications systems operating in Ku/Ka-band has been demonstrated in the US in the academic context in recent years. The next step towards potential commercial products is to prove the concept with enabling technologies representative of real-world applications (e.g., form factor, hardware) and with more thorough demonstrations over longer field trials. Such proof-of-concept would build strong confidence about effective performances, support the necessary steps in preparation of commercial follow-up and fertilise Europe's and ESA's member states LEO PNT landscape, with concrete lessons learned on a concept focused on the user segment.

The objective of the activity is to assess and validate the relevance for real world applications of PNT with signal of opportunities from broadband satellite communications systems operating in Ku/Ka-band, which have been demonstrated so far in the US academic context.

This is proposed with a proof-of-concept of user technologies that will address and tailor the following capabilities to representative use cases and form factor:

- Breadboard of the user equipment, including small form factor antenna array and RF front end representative of targeted use cases (e.g., road vehicles)
- User algorithms, including the baseband signal processing algorithms as well as the navigation engine exploiting the observables from the signals of opportunity to demonstrate both autonomous and network-assisted positioning. In autonomous operation, algorithms estimating jointly the satellites' orbital parameters and the user's position will be considered, to overcome the limited accuracy of readily available two-line elements data
- Assistance server to enable the aforementioned network-assisted operations.

The tasks to be performed shall include:

- Survey of the state-of-the-art relevant to the activity's objectives (e.g., concepts and algorithms demonstrated on Ku-band signals, antenna array with small factor, etc.), and definition of use cases and performance targets representative of real-world applications
- Trade-offs of the user equipment architectures and technologies tailored to the targeted use cases and their form factor constrains
- Development, integration and validation of the preferred solution for the user equipment breadboard and algorithms
- Execution of field trials representative of the targeted use cases
- synthesis of the lessons-learned aiming to size the additional efforts to implement a commercial product (e.g. roadmap towards product development or service demonstration, etc.).

The main outputs of the activity will consist of:

- Thorough survey of SOOP with broadband satellite signals
- Design of solutions tailored to representative use cases, resulting breadboard and test report
- Roadmap for follow-up (e.g., commercialization via potential NAVISP EL2 activities), associated to lessons-learned useful for ESA's LEO PNT activities.

It is noted that no Participating State expressed their opt-out for this activity (EL1-091).

Funding required: 800k€	*Duration: 24 months*	*ITT issue: Mar-2024*

4.3.7. EL1-092: Integrity in 5G Private Networks for Industry 4.0

5G private networks have been of interest to industrial applications, such as smart manufacturing, process automation, or logistics, supporting the Industry 4.0 revolution across all verticals. 5G private networks can deliver communications with very low and guaranteed latency and ultra-high reliability, previously only possible through wired solutions.
Besides requiring ultra-reliable and low-latency communication, many emerging industrial use cases require high-accuracy and trustworthy positioning. These use cases include asset tracking, collaborative mobile robots, or autonomous machines. Existing 5G standards and protocols already enable positioning in 5G networks. Delay, phase, and angular measurements estimated on the uplink and/or downlink channels allow to determine the absolute position of 5G terminals. The performance axes receiving the most research attention up to now include accuracy and availability, leaving the means of ensuring integrity with 5G private networks widely unexplored.
The expansion and optimisation of 5G private networks to provide integrity commitments will strengthen the position of 5G PNT and enable its use for new, more demanding use cases. Provision of integrity with 5G private networks will require detailed understanding of the contribution of network elements to the positioning performance (e.g., fault modes characterization) along with necessary commitments, adequate system architectures, and key performance indicators.

The objective of the activity is to study and demonstrate system architectures, solutions, error budgets, and fault modes within 5G private networks enabling integrity for Industry 4.0.

The tasks to be performed shall include:

- To review the state-of-the-art regarding the positioning and integrity with 5G signals and potential hybridization with other navigation sensors.
- To consolidate the use cases, user needs, requirements, and scenarios relevant for integrity-related applications in Industry 4.0.
- To study the nominal error budgets and fault modes within 5G private networks and propose solutions and system architectures optimizing the threat model.
- To propose solutions for time and frequency synchronization of 5G private networks using GNSS, bounding its impact on positioning.
- To design and develop technical means, complemented by monitoring of commercial 5G deployments, to demonstrate and characterize the nominal error budgets, fault models, and proposed system solutions.
- To define expectations and recommendations for users and 5G private networks allowing to meet the user needs.

The main outputs of the activity will consist of:

- Innovative system architectures and solutions of 5G private networks enabling integrity for Industry 4.0.
- Error budgets, fault mode characterization, and relevant key performance indicators.
- Technical means to allow demonstration of the developed solutions.
- The activity will also foster the adoption of 5G private networks for integrity-related applications within Industry 4.0.

It is noted that no Participating State expressed their opt-out for this activity (EL1-092).

Funding required: 600k€	*Duration: 12 months*	*ITT issue: Sep-2024*

4.3.8. EL1-093: Enabling PPP ambiguity resolution in satellite and terrestrial frequency-varying carrier-phase signals

Carrier-phase signals constitute the key observations in Global Navigation Satellite Systems (GNSS) for precise user positioning. To fully exploit these high-precision measurements, one needs to recover the integer nature of ambiguities. The Integer Ambiguity Resolution enabled Precise Point Positioning (PPP) concept, namely PPP-AR, has proven to be capable of delivering centimetre-level positioning for CDMA-based GNSSs, i.e., when the satellites transmit signals on identical frequencies.
The recent developments of Low Earth Orbit (LEO) constellations for communication purposes (e.g., Iridium, Starlink) have raised an interest in the navigation domain. Due to their low altitude, the LEO satellites enable stronger signal reception levels on the ground and their fast geometry change can contribute to faster PPP convergence time. Furthermore, 5G provides new navigation opportunities, on ground and in space, also due to larger bandwidth and higher frequencies.

Used as signals of opportunity, they can efficiently serve in aiding positioning users for improved performance or in realizing alternative positioning. However, this comes at the cost of processing carrier-phase signals with frequency diversity and different multiplexing schemes among terrestrial and satellite transmitters. The fact that the transmitters (LEO, 5G, etc.) transmit signals on different carrier frequencies prevents the users from forming the conventional double-difference and, therefore, integer ambiguities.

Therefore, there is the need to tackle this challenge in order to be able to achieve rapid and ubiquitous centimetre-level positioning with:

- non-GNSS frequency-varying carrier-phase signals for alternative PPP-AR, and
- GNSS/LEO/5G frequency-varying carrier-phase signals for augmented PPP-AR in challenging user environments

The objective of the activity is to define, implement and test algorithms for enabling high-accuracy positioning with IAR in LEO and 5G frequency-varying carrier-phase signals, and to develop a proof-of-concept demonstrator for a GNSS/LEO/5G PPP-AR user positioning setup.

The tasks to be performed shall include:

- State-of-the-art review on the integer-estimability concept in transmitter-dependent carrier-phase measurement systems
- Investigation, definition, design and trade-off analysis of the network and user algorithms to support the full exploitation of frequency-varying carrier-phase signals for IAR-enabled positioning targeting the GNSS/LEO/5G user applications in challenging environments
- Development of a measurement generator for GNSS, LEO and 5G signals suitable for positioning applications
- Development of a software prototype for a) network correction generation and b) PPP-AR positioning using integrated GNSS, LEO, 5G carrier-phase signals
- Prototype verification and performance assessment with representative synthetic measurements for various network configurations and challenging user environments
- Definition, realization, and assessment of 5G and/or LEO test cases with real-world carrier-phase measurements, including identification and resolution of problem areas.

The main outputs of the activity will consist of:

- Design Data package (reports, algorithms, results, etc.) providing a complete understanding of the achievable capabilities of IAR-enabled positioning based on frequency-varying carrier-phase signals
- Emulated-real-time post-processing software and user manual
- Potential Conference papers and patents.

It is noted that no Participating State expressed their opt-out for this activity (EL1-093).

Funding required: 500k€	*Duration: 18 months*	*ITT issue: Feb-2024*

4.3.9. EL1-094: High-accuracy formation flying technologies for future distributed space instruments

More and more advanced sensing systems implement the concepts of distributed instrumentation, in areas ranging from science to telecommunications. Typical illustrations include astronomy with optical and radio-telescopes (e.g., SKA, ALMA), underground sensing, and some implementation of massive MIMO over multiple base stations in 5G/6G networks.
The opportunity of distributed instrumentation has been identified since long for space missions, motivated by the prospects of increasing mission performances without increasing the size the satellites or as enabler for some missions. Application domains include Science, Earth Observation, Exploration as well as Satellite Telecommunication where very large antenna arrays could be achieved thanks to swarm of satellites. Examples of missions include the GRACE/GRACE-FO for gravimetry, and ESA's Proba-3 (Sun's coronagraph by a set of two complementary satellites).

The prospects of more advanced missions, in near Earth orbit inspired by the advent of largely distributed space infrastructure available at low cost, as well as in Deep space or on the Moon, introduce new horizon in terms of needs, towards 3D formation flying and high accuracy over very long baselines. This context motivates investigations of new concepts supporting one order of magnitude improvement in terms of satellite formation flying technologies for Europe.

The objective of the activity is to investigate new concepts for ultra-accurate formation flying systems with long baseline (below 1 mm level, beyond 100 km) and initiate the proof-of-concept on selected critical technologies.

The activity will study and design concepts starting from the state-of-the-art in satellite formation flying and considering cross-fertilisation with technologies currently in use or under development for terrestrial applications (e.g., platooning for vehicles and robots, device-to-device ranging, etc.). Key drivers are the accurate knowledge of satellite relative position, clocks offsets, and attitude, enabled by accurate ranging and attitude determination among satellites using a combination of RF and optical technologies. Frequency combs might be considered in optical systems.
The concept will be validated with the demonstration of the critical enabling technologies such as ranging with RF or optical links. The analysis will trade the nature of the link between RF and optical, for different ranges of accuracies mapped to representative use cases, and depending on the trade-offs, critical elements of that relevant link will be demonstrated (RF or optical).
The activity will not replicate technical solutions used in commercial developments (for example will not consider only relative/differential GNSS for ranging), with the objective to achieve the very high accuracy target stipulated and to be not exclusively dependent on GNSS.

The tasks to be performed shall include:

- Survey of the state-of-the-art (e.g., lessons-learned from formation flying missions, advances in ISL technologies, terrestrial D2D technologies such as V2V and UWB) and consolidation of the targeted performances (ranging, attitude, nature of satellite formation)
- Investigation and trade-offs among candidate technologies and concepts, towards the definition of the preferred solution (architecture, algorithms, enabling technologies) and simulation of the targeted concept performances
- Identification of the critical building blocks to demonstrate with an early proof of concept
- Design, development, and validation of the early proof of concept, and feedback of the measured performances.

The main outputs of the activity will consist of:

- Survey of state of the art, study of the possible concepts, enabling technologies and associated trade-offs
- Breadboards of the critical elements and technologies
- Roadmap for technology maturation up to in-orbit demonstration, for instance in the context of future Navigation Directorate programmes

It is noted that no Participating State expressed their opt-out for this activity (EL1-094).

Funding required: 600k€	*Duration: 24 months*	*ITT issue: Jul-2024*

4.3.10. EL1-095: Exploitation of Geo-spatial Data for Automated Vehicles

The provision of ubiquitous, high-quality, positioning, navigation, and timing information, and the full situation awareness of the environment, belong to the main challenges for Connected, Cooperative and Automated Vehicles (CCAV), that need to be countered in the future. Geo-spatial datasets capturing the topographic surface of the Earth and its overlying features, such as building and roads, can provide information not only for the static environment surrounding a moving agent, but also to assist the navigation engine into providing accurate and trust-worthy position fixes.
Several research works have demonstrated the value of incorporating height information provided by Digital Elevation Models (DEMs). Road Network (RN) data, on the other hand, comprise already an important element of commercial in-vehicle navigations units, and in conjunction with map-matching algorithms can reduce the accuracy of GNSS position fixes down to the road-level (i.e., 2-5m), even in deep-urban environments.
Finally, pre-computed 3D Building Models (3DBMs), ray-tracing and feature matching algorithms offer the unique opportunity of exploiting (instead of detecting and excluding) Non-Light-Of-Sight (NLOS) measurements for positioning purposes, thus eliminating the last critical barrier that degrades the performance of GNSS receivers in challenging environments (i.e., urban and deep-urban).

The objective of this activity is to define and demonstrate the exploitation of Geo-spatial data for Connected, Cooperative and automated vehicles, and identify the key enabling technologies, together with their maturity state, for its realisation.
The main innovation element of this activity will be the detection, and more importantly cost effective and computationally efficient exploitation of heavily biased GNSS measurements for accurate positioning in urban/deep-urban environments, with the aid of a multitude of geo-spatial datasets.

The tasks to be performed shall include:

- User-terminal algorithms are to be developed for the computationally efficient consumption of geo-spatial datasets by the positioning engine. Existing European space assets (e.g., Copernicus mission), but also novel imaging/reconstruction techniques for the generation of relevant geo-spatial products that can be upscaled to future ESA missions are to be considered.

The main outputs of the activity will consist of:

- Survey of state of the art on geo-spatial data products generation methods and instruments
- An end-to-end software emulator of the overall high-accuracy service
- Roadmap for large scale service provision of geo-spatial data products for positioning applications

It is noted that no Participating State expressed their opt-out for this activity (EL1-095).

Funding required: 600k€	*Duration: 24 months*	*ITT issue: May-2024*

4.3.11. EL1-096: Advanced visual INS for high-end handheld devices

Vision-based navigation (e.g., SLAM, visual INS), and its combination with other PNT sensors, is at the core of the positioning engine of many autonomous systems; the prospects for further improvement for autonomous vehicles has been studied in various NAVISP activities (e.g. EL1-026).
Meanwhile, powerful vision and graphical processing units are introduced in handheld devices in combination with more advanced vision sensors (e.g., multiple cameras, stereoscopic capabilities, advanced GPU, etc.). These capabilities can support the tailoring of the navigation engines developed for vehicles (concepts and technologies) for seamless navigation of handheld devices in support of high-end applications such augmented reality, guidance of visually impaired person and reliable APNT solutions for 1st responders.
The adaptation could further consider the combination of advanced Visual INS with positioning sensors available in handheld devices. Furthermore, it could contemplate the growth of remote sensing with 5G (and soon 6G) signals, in support of situational awareness for navigation, derived from bi-static radar sensing.

The objective of the activity is to demonstrate advanced navigation engine for handheld devices, combining vision-based navigation and visual INS, derived from multiple cameras onboard the device, with other PNT sensors available in high-end handheld devices. The design will include an additional sensing element (e.g. 5G or WIFI) to calibrate out the drift from a straightforward combined INS and visual odometry approach.

The tasks to be performed shall include:

- Survey of the state-of-the-art (e.g. Visual INS, SLAM solutions for Autonomous Vehicle, vision-related technologies of high-end handheld devices) and definition of preferred use cases and associated performance targets
- Definition and design of the solution for the proof of concept, starting from trade-offs and tailoring to handheld capabilities of various implementations options derived from technologies developed for automotive and robotic domain, followed by incremental and agile development (innovative tailoring, optimisation), leveraging the ability to perform small scale field trials during design and development phases using available hardware and evaluation platforms
- Proof of concept in real world conditions (but not necessarily utilizing real time processing)
- Synthesis of the technology prospects, which will gather the lessons-learned and will estimate the additional effort to implement algorithms in real time (optimisation of onboard resources and graphical processing units) and will establish the roadmap to commercial products.

The main outputs of the activity will consist of:

- Survey of state of the art on Visual INS and SLAM processing for handheld devices
- Breadboard and test report proving the concept of advanced navigation engine for

handled combining vision-based INS with other PNT sensors
- Roadmap for commercialization, including potential NAVISP EL2 activities

It is noted that no Participating State expressed their opt-out for this activity (EL1-096).

Funding required: 450k€	*Duration: 15 months*	*ITT issue: Nov-2024*

4.3.12. EL1-097: Use of ML techniques to optimize the adaptive beam-steering capabilities of CRPAs for GNSS user receivers

Controlled Reception Pattern Antennas (CRPAs) in GNSS receivers are known as a fundamental resource for jamming and spoofing counteraction; they are excellent for multipath mitigation too as well as NLOS signals exclusion. CRPAs in L-band impose arrays with significant dimensions (more than four antenna elements quickly reaching square-meter areas).
Further improvements can be obtained if a more complex architecture based on space-time adaptive processing (STAP) or space-frequency adaptive processing (SFAP) is used. This generally allows much higher levels of jammer cancellation against a wider range of threats.
Compact arrays, with inter-element spacing significantly lower than the half-wavelength, reduce the physical dimension at the cost of suboptimal spatial filtering performance; on the other hand, the loss can be balanced thanks to an increased number of elements (“dense” array). A trade-off between narrow inter-element spacing and number and placement of antenna elements is worth investigation.
Real-time adaptive beam-steering capability is necessary to maximize the efficiency of the spatial filtering, since the directions of the signals of interest and of the interferers to suppress are unpredictable and vary over the time.
In the perspective of boosting the potential effectiveness of CRPAs for GNSS receivers, advanced real-time adaptive architectures with medium number of antenna elements, compact dimensions, and possibly space-time adaptive processing, are extremely promising with the specific purpose of interference, spoofing and multipath suppression. However, because of the considerable number of variables to adapt in real-time, such an optimization problem is complex to model and to resolve in an efficient way.

The objective of the activity is to investigate the usage of Machine Learning (ML) algorithms for smart antenna arrays design (including the optimisation of array geometry and beamforming), which has been recently discussed in an increasing number of publications, typically addressing the communication domain (5G/6G in particular).
Many ML algorithms exist, for example multi-objective genetic machine learning, multi-label convolution neural network and Support Vector Machine algorithms. However, a clear consensus about the best choice for antenna array optimization has not been reached yet. Furthermore, the training model for the problem of optimizing the space-temporal filtering capability of a compact array, in the presence of unpredictable and time-variant signal geometry, still needs to be identified. Effectiveness of a ML design has to be proven with respect to more conventional CRPAs.

On the subject, the interest of several actors is expected:

- Research institutions for the development of the models, preliminary studies and trade-off analyses
- High-end antenna technology providers, for the identification of the technological constraints and drivers and the validation of the proof of concept
- GNSS receivers' industry, for the understanding of the application context and expected market needs.

The tasks to be performed shall include:

- The proposed activity targets a new approach in the real-time adaptive control of CRPAs for GNSS, based on the use of ML to optimize in real-time the CRPA space-time filter coefficients. The possible use of dense arrays will be investigated, with trade-off analysis with respect to conventional CRPAs. In the ML context, objectives should be the formulation of the optimization problem, the definition of the training model and generation of the datasets.

The main outputs of the activity will consist of:

- Choice of the best ML algorithm family for the adaptive CRPA control
- Trade-off analysis of the addressed CRPA architectures
- ML training model formulation and guideline for the generation
- ML training datasets definition (examples for a few relevant use cases)

It is noted that no Participating State expressed their opt-out for this activity (EL1-097).

Funding required: 800k€	*Duration: 24 months*	*ITT issue: Sep-2024*

4.3.13. EL1-098: Metrics to Assess the Performance of GNSS Authentication Schemes

All 2nd Generation GNSSs are making use of Authentication (civil signal anti-spoofing). The potential spoofing attack vectors are known: Meaconing, record and replay, fake-signal generation.
Different Authentication schemes (system level) will be used and applied as counter-measures in addition to user related measures. However, a gap exists in the evaluation methodology of the robustness performance: it is unclear how the authentication methods perform against meaconing, replay and fake attacks in a quantitative way.
The focus of the project is to develop a set of metrics to measure the anti-spoofing performance of GPSIII(Chimera), BDS III, QZSS.
Possible authentication metrics (see J. Anderson et al. CHIMERA for GPS civilian signals, 2023) as a starting point could be System openness (keys availability), Time-to-First authenticated channel, Time-between-Authentication, bit-strength, correlation loss, authentication error-rate.
For comparison, Galileo (G1G) Navigation Message Authentication and Commercial Authentication Service will be used as a reference.

The objective of the activity is to Develop, test and verify a methodology to evaluate the performance of GNSS authentication.

The tasks to be performed shall include:

- Technical information on authentication schemes across the 2nd generation GNSS (GPS III, BDS III, QZSS, Galileo) have to be collected and analyzed in detail. In the literature, proposed metrics are considered as a starting point, mapped into mathematical descriptions. The potential of the metrics for authentication performance definition has to be evaluated. New possibilities should be proposed. The result is a set of useful evaluation algorithms for authentication robustness and performance.
- Three spoofing cases (meaconing, replay, fake signal) for spoofing attacks are defined in a parametric way. The metrics declared useful, are in a first step tested by S/W simulations and in a second step by using a GNSS constellation simulator and a real receiver. The results for different GNSS are compared.

The main outputs of the activity will consist of:

- Ability to define the performance and robustness of GNSS authentication in a systematic way
- Establish a Learning curve for LEO-PNT authentication

It is noted that no Participating State expressed their opt-out for this activity (EL1-098).

Funding required: 400k€	*Duration: 18 months*	*ITT issue: Oct-2024*

4.3.14. EL1-099: Location, Tracking and Salvage support of lost shipping containers at sea

Each year 226 Million container boxes are shipped. About 1600 boxes/year (0,002%) are lost at sea. The boxes are afloat for days to weeks before they are sinking & grounding. The reasons can be traced to top-heavy container stacks (unstable), increasing bad weather (storms) by climate change and time pressure on ship crews (higher on the supply-chains after COVID).
The number of boxes lost at sea seems to be small. However:

- Economic loss of $ 90 M in cargo value
- Contaminate the ocean and beaches, partly with dangerous goods
- Collision danger for smaller vessels (safety issue)
- Negative effect on sea-life
- IMO sub-committee on the Carrying of Cargoes will focus on this issue. However, no specification of “Tracking and Tracing Devices” elaborated so far.

The objective of the activity is to study, design and develop a location and tracking system for lost containers at sea based on PNT-infrastructure (GNSS, MEO-SAR) plus IoT based PNT-COM package (Tracking & Tracing Device). On of the main innovations is to address the primary problem area: L-Band antenna could be under water (~2m), which causes high absorption loss in RF. It is highlighted that the German Ministry of Transport (BMDV) expressed their interest for the activity.

The tasks to be performed shall include:

- Study the issue of lost containers, consider absorption of RF-Signals in sea-water as function of frequency and penetration depth, establish contact to IMO, discuss possible directions of solutions:
    - Detect loss of cargo effect with accelerometer and last GNSS up-date and fuse with sea-surface current model,
    - Use of redundant (4) antennas or 4 GNSS-IoT’s on a container,
    - Use of mass market MEO-SAR buoy.
- Establish low-frequency tracking transmitter to support salvage, build-up an experimental system, conduct tests in the North Sea.

The main outputs of the activity will consist of:

- Survey and understanding of the problem, realistic directions, IoT design, first experimental result in sea water

It is noted that no Participating State expressed their opt-out for this activity (EL1-099).

Funding required: 500k€	*Duration: 18 months*	*ITT issue: Oct-2024*

5. WORK PLAN 2024 SUMMARY

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

ID	Name	Funding Required (k€)	Duration (months)
EL1-086	Instantaneous High-Accuracy Positioning based on Hybrid-Meta-Signal Solutions	600	18
EL1-087	Verifiable AI/ML techniques for PNT applications	400	18
EL1-088	Proof-of-concept of advanced navigation algorithms based on factor graph optimization	600	18
EL1-089	Modelling Quantum Sensors in a realistic navigation system context	400	18
EL1-090	Robust Navigation for Autonomous Driving with Low-Cost/SWaP Arrays of Antennas	500	18
EL1-091	Proof-of-concept of SOOP with broadband satcom signals in Ku/Ka-band	800	24
EL1-092	Integrity in 5G Private Networks for Industry 4.0	750	24
EL1-093	Enabling PPP ambiguity resolution in satellite and terrestrial frequency-varying carrier-phase signals	500	18
EL1-094	High-accuracy formation flying technologies for future distributed space instruments	600	24
EL1-095	Exploitation of Geo-spatial Data for Automated Vehicles	600	24
EL1-096	Advanced visual INS for high-end handheld devices	450	15
EL1-097	Use of ML techniques to optimize the adaptive beam-steering capabilities of CRPAs for GNSS user receivers	800	24
EL1-098	Metrics to Assess the Performance of GNSS Authentication Schemes	400	18
EL1-099	Location, Tracking and Salvage support of lost shipping containers at sea	500	18
	Total	7,900	

Table 2 - Activities' funding required and activities' duration

Table 3 summarizes the timeline for all the activities, considering the expected time 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	2024												2025												2026											
		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
EL1-086	Instantaneous High-Accuracy Positioning based on Hybrid-Meta-Signal Solutions				ITT																																
EL1-087	Verifiable AI/ML techniques for PNT applications	ITT																																			
EL1-088	Proof-of-concept of advanced navigation algorithms based on factor graph optimization				ITT																																
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EL1-090	Robust Navigation for Autonomous Driving with Low-Cost/SWaP Arrays of Antennas						ITT																														
EL1-091	Proof-of-concept of SOOP with broadband satcom signals in Ku/Ka-band			ITT																																	
EL1-092	Integrity in 5G Private Networks for Industry 4.0									ITT																											
EL1-093	Enabling PPP ambiguity resolution in satellite and terrestrial frequency-varying carrier-phase signals		ITT																																		
EL1-094	High-accuracy formation flying technologies for future distributed space instruments							ITT																													
EL1-095	Exploitation of Geo-spatial Data for Automated Vehicles					ITT																															
EL1-096	Advanced visual INS for high-end handheld devices											ITT																									
EL1-097	Use of ML techniques to optimize the adaptive beam-steering capabilities of CRPAs for GNSS user receivers									ITT																											
EL1-098	Metrics to Assess the Performance of GNSS Authentication Schemes										ITT																										
EL1-099	Location, Tracking and Salvage support of lost shipping containers at sea										ITT																										

Table 3 - Activities' ITT and Contract execution planning