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EUROPEAN SPACE AGENCY

NAVIGATION PROGRAMME BOARD

NAVISP Element 1 Work Plan for 2020

Subject

This document presents the NAVISP Element 1 Work Plan 2020 activities. This Work Plan also covers the activities that will be funded under Phase 2 of the NAVISP Programme. At the PB-NAV held on 8 November 2019 States interested in participating in Element 1 under Phase 2, to which they intend to subscribe at Space 19+, will be asked to acknowledge and take note of the Work Plan.

Required action

The Participating States in NAVISP Element 1 are invited to approve, by simple majority, the Element 1 Work Plan for 2020.

Voting rights and required majority

Simple majority of the Participating States in the Element 1 of the NAVISP Programme (AT, BE, CZ, D, DK, FI, FR, NL, NO, RO, CH, UK) representing at least half of the contributions to this Element.

Legal Basis

Act in Council on the Introduction of Weighted Vote in the Agency's Optional Programmes (ESA/C/CCXXIX/Act 1 (Final) attached to ESA/C(2012)102).
Article 3 (d) of the Implementing Rules of the NAVISP Programme.

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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 on the basis of appropriate consultation with the participating States and ex-ante coordination with the European Commission (EC) and the European GNSS Agency (GSA).

This document presents the Element 1 Work Plan for 2020.

2. PREPARATION OF NAVISP ELEMENT 1 WORKPLAN FOR 2020

In order to collect the most promising ideas and proposals and be able to prepare the Element 1 Work Plan for 2020, the Executive has again applied the well-proven 'funnel scheme', which was instrumental for the approval of Work Plans 2017, 2018 and 2019.

The funnel scheme is based on:

- an ESA-wide consultation, to populate the work plans according to well-established guidelines;
- external input, not only based on recommendations from recognised experts in the PNT sector, but also from consultative workshops organised by Participating States;

In particular, this proposed workplan contains input and recommendations from NAVAC in terms of activities content, type, size and duration, together with a new proposal for their categorisation.

Proposals have taken into account preliminary comments received through the intermediate round of formal consultations with the EC, GSA and participating States on the 'Draft NAVISP Element 1 Work Plan 2020' (ESA/PB-NAV(2019)17) presented at the 111th PB-NAV meeting.

3. STATUS OF COORDINATION

The Element 1 Work Plan for 2020 has therefore been shared with the EC and GSA through two rounds of formal consultation 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 from the EC and GSA have been taken into account, and text describing the proposed activities has been updated for the sake of clarity.

EC and GSA experts will support the implementation of activties as requested during coordination.

4. RATIONALE AND DESCRIPTION OF PROPOSED ACTIVITIES

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

The activities proposed in the 2017, 2018 and 2019 Work Plans had previously been grouped according to three broad themes, i.e.:

- Theme 1: Emerging New Space-Based PNT Concepts;
- Theme 2: Innovative Use of Space-Based Solutions in the PNT Context;
- Theme 3: Proof of concept of promising PNT Techniques and Technologies.

In its assessment of NAVISP, NAVAC has also introduced the key indicator ‘Innovation Category’ depending on whether an activity addresses a new technology, a new market or both. This is deemed to uit particularly well Element 1, which features the specific ambition to address PNT innovation.

The activities proposed in the 2020 Work Plan have therefore been grouped according to the NAVAC Innovation Categories, as follows:

- Category 1: Existing Technology and Existing Market;
- Category 2: New Technology and Existing Market;
- Category 3: Existing Technology and New Market;
- Category 4: New Technology and New Market.

Besides proposing input for specific activities in the 2020 Work Plan, reviewing them and advising on priorities during their selection, NAVAC has also recommended to increase the budget of individual projects and, possibly, reach the stage of proof-of-concept, beyond feasibility studies.

The Work Plan 2020 addresses all NAVAC recommendations.

4.1. Category 2: New Technology / Existing Market

4.1.1. NAVISP-El1-038: Application of Machine Learning Technology for GNSS IoT Data Fusion

Recent advances in technology have contributed to the deployment of a "de-facto" large GNSS receiver array based on affordable smart devices that are easy to find in the consumer market (dual band smartphones, raw GNSS data recording, new sensors).

These devices, evolving fast with each new generation, feature an increasing number of capabilities and sensors able to collect a variety of measurements and provide improved GNSS performance. Among these capabilities, Galileo dual band smartphones receivers and Android’s support for raw GNSS data recording represent a major step forward for PNT data processing improvements.

Meanwhile, the growing number of IoT GNSS devices, the expansion of ground-based networks of fixed GNSS receivers and the availability of GNSS spaceborne receivers has resulted in an increasing availability of GNSS products (GNSS Big Data).

Effective crowdsourcing of GNSS data is also flourishing across different science disciplines (e.g. space weather, water vapour measurement, geo-hazard detection).

Crowdsourced GNSS Big Data repositories provide a unique opportunity to apply innovative Machine Learning techniques to characterise multiple error sources, providing a unique opportunity for identification of singularities and correlations, particularly across the above GNSS-related disciplines.

The objectives of the proposed activity are:

- validate the application of Machine Learning, Big Data and Data Mining techniques to vast amounts of data resulting from diverse GNSS data sources for a set of use cases (e.g. improved tropospheric / ionospheric characterisation and earth's magnetic field mapping);
- set the basis of a unique infrastructure for the identification of singularities and correlations across GNSS related domains (e.g. space weather, water vapour measurement, geo-hazard detection, among others);
- crowdsource and integrate GNSS data also from ground-based IoT sources (e.g. smartphones, smart-cities and wild life tracking devices) and space-based ones, much beyond classical GNSS data collection networks.

The tasks to be performed will include:

- survey and assess existing and potential providers for GNSS crowdsourced data to complement accessible space-based data repositories (e.g. the GNSS Science Support Centre located at ESAC);
- define the implementation approach for a set of use cases, focussing on the areas of Fundamental Physics, Metrology, Earth and Space Science;

- assess state-of-the-art Big Data Machine Learning models to be applied to the selected use cases;
- implement and validate a GNSS Big Data repository and the Machine Learning algorithms for the selected use cases, deploying community engagement measures to ensure crowdsourcing support;

The main results of the activity will provide a better characterisation of received GNSS signals and an improved understanding of GNSS-related scientific domains.

Results from previous, related ESA activities, such as NAVISP El1-008 "Weather Monitoring based on Collaborative Crowdsourcing", will be duly considered and assessed.

The proposed activity is supported by ESA's GNSS Science Advisory Committee (GSAC).

Funding required: €500k	*Duration:* 18 months	*ITT issue:* Q2 2020

4.1.2. NAVISP-El1-039: Earth Moon GNSS Spaceborne Receiver for In-Orbit-Demonstration

Current GEO and GTO missions already exploit GNSS signals for in-orbit PNT. NASA's MMS mission has recently demonstrated that tracking of GPS signals is possible up to 150,000 km from Earth surface (half-way the distance to the Moon).

The feasibility of extending the use of GNSS for missions to the Moon has also preliminarily been assessed by ESA via GSP. These preliminary studies have concluded that navigation to the Moon using GNSS may be feasible, if specific high sensitivity techniques are implemented in GNSS spaceborne receivers. Multiple publications, in some cases complemented by tests with hardware in the loop, have demonstrated the potential for 100-200 metre accuracy of the orbit determination performance at Moon altitude using standalone GNSS.

GNSS spaceborne receivers could be used for different types of lunar missions:

- Earth to Moon transfer orbit and Moon to Earth transfer orbit (MTO);
- Moon orbit (in particular for Halo orbits such as the one proposed for the Lunar Orbital Platform - Gateway mission);
- Moon landing and lunar surface operations.

With the recent NASA announcement to return to the Moon by 2024, it is of strategic importance for Europe to develop the technology to support such a mission, with GNSS as a potential key enabling element.

The objectives of the proposed activity are:

- develop and qualify a GNSS spaceborne receiver for lunar applications, including procurement of antenna and auxiliary components;
- prepare an In-Orbit Demonstration (IOD) of the performance achieved by standalone GNSS for the different types of Lunar missions identified

The tasks to be performed will include:

- develop a flight model of a GNSS spaceborne receiver to be integrated in the hosting Earth-Moon IOD flight opportunity;
- develop a representative unit for ground testing and anomaly investigation

The results of the activity will:

- enable GNSS receiver technology for orbit determination, velocity and time estimation of spacecraft orbiting to / from and around the Moon;
- reduce operational costs of lunar missions, avoiding implementation of specific Earth-to-Space links.

Results from previous related ESA activities, such as "NAVISP-EL1-023: Earth-Moon Navigation: System Study and development of a high-sensitive spaceborne receiver", developing an early prototype of the receiver will be duly considered and assessed.

The proposed activity is supported by ESA's GNSS Science Advisory Committee (GSAC).

Funding required: €1000k	*Duration:* 18 months	*ITT issue:* Q1 2020

4.1.3. NAVISP-EL1-040: Next Generation network-assisted PNT assurance

PNT assurance against malicious threats like spoofing relies on four main enablers:

- authenticity of the information relating to the nodes used for computing the position (e.g. clock and ephemeris data of GNSS satellites). It can be built and distributed in a network-assisted configuration, for instance by monitoring the PNT system or accessing directly the original information;
- authenticity of the ranging signals, enabled by unpredictable signals. Such unpredictability is featured by encrypted GNSS signals but is also widely spread in telecom signals, such as signals of opportunity (SOOP), satcom

signals from LEO, MEO, GEO, signals from cellular networks, airborne communications;

- assurance of the User Equipment time offset to a reference system time, from receiver initialisation onwards. Besides being necessary to enable a-posteriori processing of information involved in the protection of ranging signal, this is also an efficient barrier against meaconing/replay;
- integrity messages providing information about accuracy and availability of GNSS signals.

Together, these capabilities can provide connected users with a comprehensive PNT assurance mechanism, highly scalable with minimal requirements for key management and avoiding the need for security modules.

The objectives of the proposed activity are:

- define an innovative concept of network-assisted PNT assurance, integrating consistently all capabilities, enabling processing inside the user equipment with the assistance of data provided by the network and increasing scalability by relying on broadcast channels to subscribing users;
- develop a demonstrator for such End-to-End PNT assurance concept and service, relying on multiple sources of unpredictable signals (e.g. GNSS, Satcom, SOOP) and integrating all enablers and building blocks (satellite and terrestrial signals, network assistance and user equipment technologies) to prove the concept.

The tasks to be performed will include:

- assess the effective protection achievable for different types of user equipment. This analysis will take into account different levels of time synchronisation as regards RF front end quality;
- assess the technical capabilities and limitations of current COTS components in supporting this service (for instance, considering the diversity of signals sources spread on a large spectrum of frequencies);
- test in laboratory and field trials to demonstrate End-to-End concept and performance.

The results of the activity will provide:

- breadboards implementing the proof-of-concept (e.g. User Equipment, server);
- field trial demonstration of End-to-End performance, enabling a unique hands-on experience on innovative concepts for resilient PNT technologies applied to selected use cases;
- a roadmap for prototyping and product development, which could be further pursued in other NAVISP Elements.

Funding required: €750k	*Duration:* 24 months	*ITT issue:* Q3 2020

4.1.4. NAVISP-El1-041: Quantum Metrology for secure PNT

Quantum metrology techniques show great potential to enhance both precision and security of existing PNT techniques. It has been shown that, by probing physical quantities using quantum states of light and/or matter, one can achieve a precision beyond the theoretical limit set by classical mechanics. This effect has been demonstrated in a variety of contexts and is particularly useful in optical metrology applications

Quantum states of light can be used to enhance the precision of both interferometric and time-of-flight based ranging techniques. For example, so-called 'squeezed states' of light allow the noise of a coherent state of light to be suppressed along a certain quadrature, enabling more precise measurements. This technology has found large-scale engineering applications (for example, squeezed states have been used to enhance the precision of the long-baseline interferometer of the LIGO gravitational wave detector). Furthermore, numerous protocols exist to carry out precise ranging and/or clock synchronisation by utilising the timing correlations between pairs of entangled photons. Such protocols have been demonstrated over optical fibres, and have achieved an improvement of around an order of magnitude compared to classical time-of-flight protocols. Squeezed states of optical frequency combs have also been used to achieve time transfer with a precision beyond classical limits. There are a number of proposals to use such systems for GNSS orbit determination applications.

Quantum metrology techniques also show a variety of security benefits relative to classical techniques. Entanglement-based ranging techniques have been demonstrated to be more robust to jamming than their classical counterparts. Furthermore, protocols have been demonstrated which, through the exchange of quantum signals, prevent spoofing of ranging protocols by the interception and resending of photons. A quantum clock synchronisation protocol has also been proposed, which is secure to both passive and active photon delay attacks.

While many of the aforementioned positioning/timing quantum metrology techniques have been demonstrated in lab conditions or over optical fibres, this technology has yet to be demonstrated over large distances in free space.

The main objective of the proposed activity is to develop a free space quantum metrology system for PNT, which is robust and miniaturised enough to be deployed in a mobile context or in space.

The tasks to be performed will include:

- design and implement a free-space ranging and/or clock synchronisation system based on quantum metrology techniques;
- demonstrate long-distance free-space quantum metrology with the system;
- demonstrate enhanced precision and/or security relative to comparable classical techniques;
- work on miniaturising the system and making it robust enough to deploy in space-ground applications.

The main results of the activities will provide:

- a working system for free space quantum metrology;
- detailed characterisation of the precision of the system and analysis of noise sources;
- a working system for free space quantum metrology;
- security analysis of the system, as regards eavesdropping, jamming and spoofing;
- a roadmap for implementing the system in PNT applications, including deployment in space.

Funding required: €750k	*Duration:* 18 months	*ITT issue:* Q3 2020

4.1.5. NAVISP-El1-042: Next Generation Motion Sensors for Hybrid GNSS INS Solutions in high accuracy machine control applications

Robotics, machine control, industry automation require high accuracy positioning, as well as very robust PNT to support autonomous operations. Relative motion sensors (e.g. IMU) are key to complement GNSS in case of outage or for enhanced robustness and sustained high accuracy. In open sky, the state-of-the-art of GNSS and IMU provide good performance. However, cost-efficient IMUs still face shortcomings in filling the gaps of long GNSS outages (urban, large factory plants, canopy, etc.) or in supporting very high-accuracy positioning.

Intense R&D efforts (e.g. DARPA) are invested to prepare the next generation of inertial navigation systems (INS) with the goal of achieving chip-scale sized sensors that simultaneously are able to meet the performances of tactical grade IMUs. For multiple reasons, the outcome of those investments might not reach the industrial and commercial markets until in 10 years or more, and the cost of high performance IMUs will remain high.

Meanwhile, composite motion sensors, which combine multiple low-cost technologies, could provide a relevant path to satisfy the growing need for cost-efficient, high-performance INS in domains such as robotics in industry automation, machine control and high-precision agriculture automation.

Typically, camera and mmWave radar are able to provide relevant motion measurements (odometry as well as attitude). Such technologies are individually reaching a good TRL level, the challenge lies in their cost-efficient integration, tuned to the adequate use cases, which requires advanced sensor fusion, for which Artificial Intelligence seems to be the most suitable technique to apply.

The objective of the proposed activity is the development of the next generation of motion sensors based on massive (low-cost) sensor fusion and Artificial Intelligence/Machine Learning, to enhance calibration and sensor fusion. Design and performance will be tuned for integration with GNSS in use cases requiring robust, high-accuracy positioning (e.g. robots used in Precision Agriculture or in logistics on large factory plants outdoors).

The tasks to be performed will include:

- development and proof of concept of a disruptive composite motion sensor, merging multiple low cost technologies such as mmW radar, camera (attitude/odometry) and low cost MEMS (gyro-, accelero- and baro-meter);
- tuning for the targeted uses cases (e.g. machine / robot control operating in challenging environment and seeking robust high accuracy) both in term of multi-sensor architectures and AI-training;
- assessment and demonstration of multi-sensor End-to-End performance, representative of the targeted use cases.

The main results of the activity will provide:

- a breadboard of the developed new composite motion sensor;
- results of test trials and benchmark with state-of-the-art GNSS/IMU solutions in various environments;
- a roadmap towards prototyping and a product, paving the way for industrial products, for instance through activities in NAVISP Element 2.

Funding required: €600k	*Duration:* 24 months	*ITT issue:* Q3 2020

4.1.6. NAVISP-El1-043: Interference Monitoring from Space

A great number of civilian and military applications relies on GNSS for PNT, however its availability could be put at risk by threats such as local interference, amongst others.

GNSS spectrum monitoring is essential for:

- detecting, characterising and localising interference sources, which could endanger the adequate reception and processing of GNSS signals;
- initiating a justified request process for interferer elimination;
- warning in a timely way GNSS users exposed to the interference on the expected service degradation.

Ground-based monitoring stations can only provide coverage equal to the effective horizon of the station's antennas (not taking into account blockage). In order to enable higher resolution localisation, these stations would also require sophisticated equipment to derive angle/direction of arrival and distance to interference sources. Space-borne interference-monitors at LEO can be a very effective solution with a worldwide coverage, including monitoring of interference over sea. For instance, the number of ground-based monitors for a service over continental Europe would be very high compared to the required number of space-based monitors.

Moreover, monitors can also act as real-time warning beacons over affected areas. Flight experiments by means of a radio-occultation GNSS receiver on board the International Space Station (ISS) have been performed by the U.S. Naval Research Laboratory (NRL), and have demonstrated successfully the monitoring feasibility ("Serendipitous Observations of GPS Interference by GROUP-C on the ISS"). However, the topic is still unexplored to a large extent. Space-borne monitors offer very appealing features such as worldwide coverage (over both land and seas) and non-dependency on local/on-site equipment.

The main objective of the proposed activity is to study and define a GNSS spectrum monitoring-system, tailored to non-PRS applications, based on space-borne monitors, enabling worldwide detection, characterisation and localisation of GNSS interferers, and enabling a warning for users regarding possible presence of interference.

The tasks to be performed will include:

- constellation dimensioning, including analysis of planned LEO mission opportunities or analysis of dedicated constellations of mini-satellites;
- space-borne monitor equipment(s) definition and performance analysis;
- software demonstration of monitor performance in an emulated environment;
- study of possible real-time communication channels for warning GNSS users;
- implementation and development plan.

The main results of the activities will provide feasibility analysis and conceptual design of a system for worldwide detection, warning, characterisation and localisation of GNSS interference.

Coordination with the Interference Monitoring Task Force (EGITF) will be ensured through EC and GSA.

Funding required: €500k	*Duration:* 18 months	*ITT issue:* Q2 2020

4.1.7. NAVISP-El1-044: Hollow Corner Cube Retro-Reflectors In-Orbit PNT

Optical solid Corner Cube Retro-reflector (CCR) arrays are often implemented to allow laser tracking of satellites from ground. In order to achieve a measurable return signal, such arrays are typically rather large, and as conventional corner cubes are made of glass, the arrays are typically high in mass. However, in recent years, interest has grown in using hollow corner cubes for space applications, partly due to the possible mass reduction they enable.

A hollow CCR, made of three orthogonal flat mirror surfaces, offers theoretically superior performance in comparison with arrays of small solid reflectors, which are currently in common use. The main advantage of hollow CCRs is their capability to tune the far field characteristics, i.e. the maximized energy distribution, to the specific needs of tracking.

However, technologically there are still too many disadvantages and uncertainties for hollow cubes to be considered a viable option. Currently the mass advantage that hollow cubes could potentially allow is lost by the need for a stable opto-mechanical support structure, and the tolerance accuracy achievable does not match that of solid cubes.

Despite this, there is still a clear interest in qualifying hollow cube technology for satellite PNT. It will possibly provide added value in the form of mass reduction, and improved ranging precision (which enables better independent precision orbit determination, as well as geodesy applications). Additionally, it could be deployed on the Moon for Earth-Moon distance measurements, which is strongly desired by the scientific community.

Hollow CCRs have the potential to deliver the same functionality as solid CCRs, and with improved performance and lower mass. However, an advance in technology is required to achieve long-term mechanical stability and accurate control of the corner cube angles.

The main objective of the proposed activity is to develop a lightweight and space-qualifiable hollow corner cube with high thermo-mechanical stability for improved in-orbit ranging.

The task to be performed is the development of a hollow Corner Cube Retro-reflector for space PNT applications. A potential starting point for that could be the existing hollow corner cubes built for other applications (e.g. Fourier Transform Spectrometers). This activity will require innovation within mirror design for high-thermo-mechanical stability, precision alignment, assembly, mounting and coating techniques.

The main results of the activity will provide:

- a feasibility assessment;

- a Proof-of-concept of an opto-mechanical design for a hollow Corner Cube Retro-reflector for space PNT, which in comparison to solid cubes should have reduced mass and improved ranging performance.

The relevant development does not intend to prepare for next generation Galileo Laser Retro-reflectors for ODTS purposes.

Funding required: €500k	*Duration:* 24 months	*ITT issue:* Q3 2020

4.1.8. NAVISP-El1-045: Multi-layer PNT for SAR

Satellite Search and Rescue (SAR) standards are set and overseen by COSPAS-SARSAT. SAR instruments are currently flying on board MEO satellites in several GNSS constellations. These platforms complement the existing LEOSAR and GEOSAR satellites. Existing LEO/GEOSAR are slow in detecting an active beacon due to several limitations in design (limited satellites, fast orbits, no independent location capability, etc.). MEOSAR exceeds the individual advantages of each of the other options but they are not perfect either, e.g. accuracy is still in the order of km and localisation of moving fast-moving beacons is not possible.

After the incident in March 2014 when the Malaysian Airlines MH370 flight disappeared from radar screens leaving very little information about its location, the International Civil Aviation Organization (ICAO) requested COSPAS-SARSAT to work on SAR capabilities, particularly on the context of flight tracking during a distress event.

Combining High Altitude Pseudo Satellite (HAPS) with multi-layer LEO/MEO/GEOSAR ranging would improve beacon localisation. HAPS can also be quickly moved over a specific location within the designated service area. Another HAPS benefit is the improved link budget, between 30 and 40 dB, depending on its altitude. Furthermore, TOA/FOA measurements with considerably increased SNR are expected to improve the independent localisation of distress beacons.

Additionally, HAPS platforms deployed in the sky could complement locally existing surveillance systems by:

- extending coverage and add redundancy:
- enabling ad-hoc communications between Rescue Team and person in distress:
- enabling real-time video feed over the area of interest, which is expected to be useful for planning and coordination of rescue operation.

The overall objective of the activity is to conduct a feasibility study on the use of HAPS platforms as a mean of local augmentation to SAR services.

The tasks to be performed will include:

- review of LEO/MEO/GEOSAR in terms of vulnerabilities, current and future needs, and stakeholders;
- critical analysis of HAPS layer in SAR, with identification of benefits and limitations;
- defining a technical concept making use of HAPS for SAR and evaluating its implementation feasibility;
- developing simulation models for the technical concept to perform trade-offs; validating the technical concept based on simulations.

The main results of the activity will provide:

- a clear picture on the fitness of HAPS platforms as a potential future complementary local augmenting global SAR services (for which EU has a regular coordinated approach with Cospas-Sarsat);
- a simulation tool capable to support trade-offs and technical analysis of HAPS for SAR.

Funding required: €350k	*Duration:* 18 months	*ITT issue:* Q2 2020

4.1.9. NAVISP-El1-046: Combining ELF signals with GNSS for improved PNT

The need for a robust PNT to complement or back up GNSS in critical infrastructure/critical application is widely acknowledged. This translates into actions taken by stakeholders to further raise awareness (e.g. radio navigation plans in the US and Europe) and for some, pave the way towards some deployment (e.g. recent Request for Information initiated by the US Department of Transport for a timing infrastructure independent of GPS). This yields a renewed interest for Extremely Low Frequency (ELF) and Very Low Frequency systems, such as eLORAN or PTB, identified by some as a very relevant candidate to back up GNSS in timing applications.

However, the programmatic context around ELF and VLF technologies is diverse, with some countries having initiated the decommissioning of their infrastructure, others maintaining them, and some also considering investing in new eLORAN infrastructures. The understanding of the potential benefits and shortcomings of ELF and VLF technologies is not as widespread as it is for GNSS. Further investment in R&D in that area is recommended.

The objectives of the proposed activity are:

- develop a proof-of-concept of an innovative ELF/VLF PNT technique in combination with (or alternative to) GNSS for critical infrastructure and applications;

- test key use cases and scenarios of the combined GNSS/ELF/VLF proposed concept for improved PNT.

The tasks to be performed will include:

- selecting an innovative concept that uses ELF / VLF technologies (infrastructure, user equipment, RF properties, processing algorithms, etc.) for use in PNT (timing or navigation systems, signal of opportunity, etc.);
- defining and developing a proof of concept through simulation and trials for a number of scenarios;
- assessing potential benefits, including combined use with GNSS, and shortcomings of ELF / VLF PNT technologies.

The main results of the activity will provide:

- an improved understanding of ELF/VLF innovation potential in complementing GNSS for improved PNT solutions;
- new opportunities for resilient PNT and associated developments for European industry.

Funding required: €600k	*Duration:* 18 months	*ITT issue:* Q3 2020

4.2. Category 3: Existing Technology / New Market

4.2.1. NAVISP-El1-047: An Innovative concept for the Risk Assessment of Geologic Hazards using GNSS and Solid Earth Tides Modelling

It is long debated whether a relation exists between the tidal stress produced by the Moon and the Sun on the Earth crust and the occurrence of difference geologic events, in particular large earthquakes and volcanic eruptions. Clear evidence for this relation has been elusive for a long time. However, the analysis of more complete global earthquake catalogues has shown that a significant statistical correlation exists between earthquake sizes/frequencies and the tidal Sun-Moon influence.

Like in the case of ocean tides, solid Earth tides are strongly modulated by local conditions and context. Underlying composition and structure, tectonics and surface geomorphology are factors that critically condition the response of the crust terrain to tidal perturbations.

Currently, local effects are not modelled for use in GNSS geodetics, PPP and OD&TS. However, their impact could be relevant and modelling them would mark the difference with other approaches. Only a systematic use of GNSS would allow local measurement of tidal distortion of terrain and modelling of local tidal effects.

The local tidal effect model can then be correlated with existing geological events to forecast associated hazards.

The main objectives of the activity are:

- undertake a step forward in the assessment of geological hazards with implications in forecast strategies, providing a complementary observable as a contribution to earthquake forecast;
- use GNSS time series as a form to model local solid Earth tides;

The tasks to be performed will include:

- development, implementation and validation of GNSS Data Processing tools for the measurement of solid Earth tides;
- analysis and modelling of solid Earth tides and their relation with geologic events: seismic and volcanic events, landslides and avalanches

The main results of the activity will provide a practical demonstration of the concept by:

- processing GNSS data captured in real scenarios to measure solid Earth tides;
- local modelling of solid Earth tides for the forecast and assessment of the risk of geologic hazards.

For this purpose, it is proposed to use worldwide data provided by the International GNSS Service (IGS) together with GNSS stations deployed in locations with identified geological hazards.

The proposed activity is supported by ESA's GNSS Science Advisory Committee (GSAC).

Funding required: €250k	*Duration:* 15 months	*ITT issue:* Q1 2020

4.3. Category 4: New Technology / New Market

4.3.1. NAVISP-El1-048: User Antenna Diversity for efficient multipath mitigation

The impact of multipath and fading in harsh propagation conditions is still among the main sources of errors in PNT solutions for mobile users. Besides code-based positioning accuracy, they affect convergence time of carrier-based solutions (e.g. PPP) and may prevent ambiguity resolution. For handheld user equipment (HH-UE) such as smartphones and tablets, antenna performance is traded against integration and cost, which yields degraded multipath rejection and positioning performance compared to solutions using high-end antennas (or even standard patch antennas, as used for instance in automotive applications).

Despite significant R&D efforts (e.g. novel design, innovative materials) and very promising results, solutions to mitigate multipath still yield high costs for HH-UE.

In wireless communications, capabilities of antenna diversity algorithms are well known and widely used to mitigate channel impairments (multipath and non-line-of-sight signals). HH-UE mounting multiple low-performance antennas is being considered for future wireless systems.

Antenna diversity algorithms and architectures for HH-UE could be considered as a relevant alternative to enhance performance and multipath mitigation without sacrificing complexity and cost. With the advent of GNSS chipsets with two RF front-ends (supporting dual-frequency which could also support two antennas) for HH-UE, antenna diversity may be among the future trend to enhance performance of mass-market handheld applications.

The main objective of the proposed activity is to investigate user antenna diversity algorithms and architectures to enhance multipath mitigation on handheld devices using low cost antennas.

The tasks to be performed will include:

- assessing algorithms exploiting both spatial diversity (different location of the antennas on the smartphone or tablet) and polarisation diversity;
- developing antenna diversity architectures based on low cost HH UE;
- implementing and testing selected solutions in real conditions (e.g. urban environment);
- assessing resulting performance, to be benchmarked against off-the-shelf solutions (e.g. smartphones, mass-market chipsets with high-end antennas).

The main result of the activity will provide a concept demonstrator, together with assessment implementation of different spatial diversity algorithms and architectures in real test conditions.

Results from related GSA H2020/FE projects will be duly considered and assessed.

Funding required: €300k	*Duration:* 12 months	*ITT issue:* Q2 2020

4.3.2. NAVISP-El1-049: Cooperative Positioning and Integrity Concept in Vehicle Platooning

Vehicle platooning is a scenario in which vehicles automatically follow each other in a sequential formation known as the platoon. Autonomous Vehicle Platooning is a promising feature that could be provided by future self-driving cars, trucks and other vehicles. It involves a human driver that is either physically present or is remotely controlling the vehicle at the platoon lead. Autonomous Vehicle Platooning implies a less constraining safety level compared to fully Autonomous Passenger Vehicles (APVs).

Compared to APVs, Autonomous Vehicle Platooning exploits a trajectory for each vehicle as well as for the whole platoon. Enabling elements are:

- Relative ranging and cooperative positioning;
- Inter-vehicular communication and situational awareness;
- Suitable positioning and integrity algorithms.

In this context, GNSS could constitute a key enabler of cooperative positioning by hybridising Moving Base RTK technology with Vehicle-to-Vehicle (V2V) relative ranging. V2V can be achieved by mixing mmWave radar, Ultra Wide Band (UWB) sensors or exploitation of future Vehicle-to-Everything (V2X) technologies, realised by Dedicated Short Range Communication (DSRC).

GNSS would act as a primary source for time and frequency synchronisation of the link between vehicles in 3GPP Cellular-V2X (C-V2X) technology.

Development of algorithms achieving lane-level accuracy, situational awareness and integrity data could also exploit cooperative positioning supplemented by Artificial Intelligence (AI) and map matching algorithms.

A set of suitable cooperative positioning and integrity algorithms is yet to be proposed in the frame of vehicle platooning and such investigations are deemed to carry significant innovations.

The objectives of the proposed activity are:

- study and develop cooperative positioning and integrity algorithms for Autonomous Vehicle Platooning, based on cooperative RTK, V2V relative ranging and V2X communications;
- develop a test platform for field trials.

The tasks to be performed will include:

- definition of the positioning concept and algorithms based on relative RTK technology complemented by V2V relative ranging and V2X communication;
- conceptual definition and performance assessment of the timing mechanism proposed for V2X communication and V2V ranging;
- identification and definition of cooperative positioning algorithms that could supplemented by AI and map matching algorithms;
- definition of testing scenarios, development of a software simulator and development of a test platform for proof-of-concept.

The results of the activity will provide:

- innovative positioning and integrity concept and set of algorithms based on cooperative RTK, V2V relative ranging and V2X communication;
- software simulator and test platform usable to foster development of future algorithms and concepts;
- promotion of GNSS-based solution as a key enabler of vehicle platooning and effective transportation.

The activity will benefit from coordination with GSA to obtain stakeholders' view in this application domain. It will also take into due account related regulatory/ standardisation aspects (e.g. C-ITS delegated regulation, CEN's GPSTART project). Available results of integrity analyses performed by GSA will be duly considered and assessed.

Funding required: €800k	*Duration:* 18 months	*ITT issue:* Q2 2020

4.3.3. NAVISP-El1-050: Proof of concept of hybrid 5G-NR/GNSS Positioning with ad-hoc overlay

GNSS has become the corner stone of worldwide positioning applications, and in particular for those requiring high-accuracy. The outstanding performances in open sky and very competitive performances in degraded environments of GNSS are widely acknowledged, but also the need to complement GNSS by other technologies to address specific needs in challenging environments.

In this context, 5G appears to be among the most suitable candidates to complement the GNSS & IMU technology-mix currently representing the state-of-the-art for robust and high-accuracy applications. 5G technologies could provide high performance TDoA measurements under specific assumptions, which include very good synchronisation among nodes (e.g. 5G nodes disciplined to GNSS), and Line-of-Sight conditions between the node and the user equipment (UE). The latter assumptions may be considered reasonable within dense, local positioning infrastructures, also known in the 5G landscape as enhanced positioning service area.

For this, 5G also features interesting capabilities to support a cost-efficient deployment of local networks or private networks dedicated to positioning (e.g. local overlay, either static or mobile, in which it is supported by nodes on vehicles or on UAVs). For instance, with 5G, a Mobile Network Operator or smart city could invest in local infrastructures to enhance GNSS in addressing specific needs where and when needed by customers, for instance:

- enhanced coverage in terms of robustness, accuracy or availability, in e.g. smart cities aiming at enhanced service in some places with high commercial potential, temporary coverage of special events, or during public work in deep urban canyons to enhance machine control capabilities;
- enhanced secure positioning/waypointing or bootstrapping of the UE, thanks to distance bounding and secure time transfer over 5G, e.g. along a road, where the overlay would act as a gantry to control GNSS-enabled positioning.

In addition, with the potential advent of the so-called 5G non-terrestrial networks (e.g. UAVs, HAPS, LEO satellites), one could also envisage to use such 5G signals in a wide area or even a global coverage scenario. This landscape carries multiple opportunities to foster the use of GNSS as a key enabler to 5G positioning capabilities, for which a proof-of-concept is required, this could be done using an MIMO SDR as a starting point.

The proposed activity has as its main objective a proof of concept of a hybrid positioning system using GNSS with 5G TDoA/angular measurements in ad-hoc overlay, aiming to enhance local GNSS capabilities. This will include several first-of-a-kind technical achievements, e.g:

- GNSS-disciplined 5G signals and positioning nodes;
- hybrid positioning algorithms involving GNSS, 5G-TDoA/Angular measurements and dead-reckoning;
- bootstrapping of GNSS functions with 5G.

The tasks to be performed will include:

- selection and consolidation of targeted use cases for proof-of-concept;
- system definition and preliminary design of a test-bed (which is to include: positioning nodes disciplined on GNSS, enablers for TDoA and Angular

measurements, SDR for the UE, hybrid positioning algorithms and reference trajectory mechanism);

- development of the breadboards for the user equipment (UE) and positioning nodes using SDR (the latter disciplined to GNSS signals), including the UE algorithms;
- validation and fine tuning of the algorithms and concept in non-real time;
- implementation of the most suitable concepts for the UE's SDR, if possible in real time, and validation with laboratory tests;
- demonstration of performance through field trials.

The main results of the activity will provide:

- breadboards constituent of the testbed and associated data package;
- output data from field trials and benchmark with off-the-shelf GNSS solutions.

Funding required: €950k	*Duration:* 18 months	*ITT issue:* Q2 2020

4.3.4. NAVISP-El1-051: New Concept for Evolutive Mitigation of RFI to GNSS

Radio frequency interference, intentional or not, is considered to be among the main threats to safety-critical and commercial GNSS applications. This includes out-of-band emissions, privacy-protection devices (PPD) also known as in-car jammers, etc. Consequently, many COTS GNSS receivers nowadays integrate mitigation strategies for RF interferences (jamming and spoofing). Moreover, one can note that PPDs are continuously evolving, becoming more complex and consequently introducing new challenges to RFI mitigation. Usually RFI mitigation is a built-in feature, and even if based on some adaptive signal processing algorithms, those features are static and do not evolve over time. Therefore, they cannot not really adapt to the evolution of the RFI landscape, which may include new out-of-band emissions or new interferences with different signatures.

In the field of IT security, antiviruses and anti-malware protection are regularly updated to cope with new threats, as those are continuously monitored and used to design those updates.
A similar approach could be applied to GNSS, where new RFI threats could be discovered and managed over time. By having a flexible and reconfigurable DSP frontend monitoring the GNSS bands, before the usual baseband stages of a GNSS receiver, it could detect the presence of interference and apply the relevant mitigation. The processing could be implemented in software modules with FPGA (Field Programmable Gate Array) support for real-time operation with reduced energy consumption. These modules would be continuously improved by service

centers/operators monitoring the RFI signatures, which updates the user equipment as an antivirus would do.

The objective of the proposed activity is to develop a new concept of RFI mitigation technology for GNSS, taking inspiration from IT antivirus and antimalware protection strategies, and leveraging on low cost Software-Defined Radios (SDR). The mitigation strategies will also leverage on Machine Learning and Artificial Intelligence, in combination with established RFI mitigation building blocks (notch filter, blanker, etc.).

The tasks to be performed will include:

- identification and consolidation of use cases for mass-market and commercial applications;
- identification and preliminary design of candidate architectures;
- design, implementation and validation of the UE, and implementation of the training process for AI;
- testing in controlled environment, as laboratory.

The main results of the activity will provide:

- breadboard of the new RFI mitigation strategy, benchmarked with off-the-shelves solutions;
- recommendations for the way forward, relating to both the technological aspects of the proposed activity (increased robustness for GNSS UE) and relating to a potential business model in GNSS, which could pave the way towards prototyping and products, for instance in the frame of NAVISP Element 2.

Results from related GSA H2020/FE projects will be duly considered and assessed.

Coordination with the Interference Monitoring Task Force (EGITF) will be ensured through EC and GSA.

Funding required: €450k	*Duration:* 12 months	*ITT issue:* Q1 2020

5. SUMMARY

Activity funding & duration	Funding required (€k)	Duration (months)
Category 2		
NAVISP-El1-038: Application of Machine Learning Technology for GNSS IoT Data Fusion	500	18
NAVISP-El1-039: Earth Moon GNSS Spaceborne Receiver for In-Orbit Demonstration	1000	18
NAVISP-El1-040: Next Generation network assisted PNT assurance	750	24
NAVISP-El1-041: Quantum Metrology for secure PNT	750	18
NAVISP-El1-042: Next Generation Motion Sensors for Hybrid GNSS INS Solutions in high accuracy machine control applications	600	24
NAVISP-El1-043: Interference Monitoring from Space	500	18
NAVISP-El1-044: Hollow Corner Cube Retro-Reflectors for In-Orbit PNT	500	24
NAVISP-El1-045: Multi-layer PNT for SAR	350	18
NAVISP-El1-046: Combining ELF signals with GNSS for improved PNT	600	18
Category 3		
NAVISP-El1-047: An Innovative Concept for Risk Assessment of Geologic Hazards uing GNSS and Solid Earth Tides Modelling	250	15
Category 4		
NAVISP-El1-048: User Antenna Diversity for efficient multipath mitigation	300	12
NAVISP-El1-049: Cooperative Positioning and Integrity Concept in Vehicle Platooning	800	18
NAVISP-El1-050: Proof of concept of hybrid 5G-NR/GNSS Positioning with ad-hoc overlay	950	18
NAVISP-El1-051: New Concept for Evolutive Mitigation of RFI to GNSS	450	12
Total	8300	

El1 ID	Activity Title	2020				2021				2022			
	Category 2												
038	Application of Machine Learning Technology for GNSS IoT Data Fusion		ITT										
039	Earth Moon GNSS Spaceborne Receiver for In-Orbit Demonstration	ITT											
040	Next Generation network assisted PNT assurance			ITT									
041	Quantum Metrology for secure PNT			ITT									
042	Next Generation Motion Sensors for Hybrid GNSS INS Solutions in high accuracy machine control applications			ITT									
043	Interference Monitoring from Space		ITT										
044	Hollow Corner Cube Retro-Reflectors for In-Orbit PNT			ITT									
045	Multi-layer PNT for SAR		ITT										
046	Combining ELF signals with GNSS for improved PNT			ITT									
	Category 3												
047	An Innovative Concept for Risk Assessment of Geologic Hazards uing GNSS and Solid Earth Tides Modelling	ITT											
	Category 4												
048	User Antenna Diversity for efficient multipath mitigation		ITT										
49	Cooperative Positioning and Integrity Concept in Vehicle Platooning		ITT										
50	Proof of concept of hybrid 5G-NR/GNSS Positioning with ad-hoc overlay		ITT										
51	New Concept for Evolutive Mitigation of RFI to GNSS	ITT											