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ESA/PB-NAV(2017)38
Paris, 20 October 2017
(Original: English)

EUROPEAN SPACE AGENCY

NAVIGATION PROGRAMME BOARD

NAVISP Element 1 Workplan for 2018

Subject

This document presents the NAVISP Element 1 Workplan 2018 activities.

Required action

The participating States in NAVISP Element 1 are invited to approve, by simple majority, the Element 1 Workplan for 2018.

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1. INTRODUCTION

The main objective of the Navigation Innovation and Support Programme (NAVISP) is to facilitate the generation of innovative space-based PNT (Positioning, Navigation & Timing) proposals with participating States and their industry, in coordination with the EU and its institutions.

The programme will provide support to European industry enabling it to be successful in the highly competitive and rapidly evolving global market for satellite navigation, and more broadly PNT technologies and services. At the same time, it will help participating States enhance their national objectives and capabilities in the sector.

NAVISP is an important element in the overall European PNT landscape, capable of leveraging both ESA expertise gained through the European GNSS development and deployment programmes and the existing industrial base of the European GNSS sector. It does not duplicate or change the basis on which the R&D strategy and approach related to the evolution of the Galileo and EGNOS systems is determined and controlled through the established EU mechanisms.

NAVISP is structured according to three Elements, which complement each other and contribute to the above programme objectives:

- Element 1: Innovation in Satellite Navigation
- Element 2: Competitiveness
- Element 3: Support to Member States.

The distinctive nature of each Element is tailored to meet both industry demands and participating States' national objectives.

The main goal of Element 1 is to generate innovative concepts, techniques, technologies and systems linked to the PNT sector, along the entire value chain. In the highly dynamic PNT environment, the GNSS component will not be considered in isolation but in combination with other PNT technologies to enable the emergence of attractive solutions. Such a context calls for a new paradigm, where new concepts, new capabilities and a new culture are developed in response to needs as yet to emerge of the PNT sector, which is to date not leveraging the full potential that space-based solutions have to offer. In return, the net effect of this dynamic will be to enable cross-fertilisation of expertise between different stakeholders in the PNT domain and facilitate the presence of the EGNSS infrastructure in the future challenges facing the PNT world.

The specific objectives of this Element are to:

- Perform feasibility studies and viability analysis for the emergence of new concepts in the PNT world;
- Contribute to the formulation and implementation of PNT technology innovation;
- Carry out proof of concept of promising PNT-based services.

Activities under Element 1 are defined and implemented according to an annual workplan to be prepared and proposed by the Agency, and approved by States participating in NAVISP Element 1.

The annual workplan is prepared on the basis of appropriate consultation with the participating States, the European Commission (EC) and the European GNSS Agency (GSA).

In particular, the implementation of Element 1 requires timely coordination between ESA and the EC/GSA. The principles and procedures of ex-ante coordination with EC and GSA are defined in “Coordination between the EC-GSA and ESA on NAVISP Programme Activities” (ESA/PB-NAV(2016)34).

Furthermore, internal coordination within ESA is implemented through the “Inter-Directorate Advisory Group on Space Applications” (IAG-SA), and in keeping with the approach outlined in the “Concept note on space-based applications in ESA” (ESA/C/WG-M(2016)18).

This document presents the Element 1 workplan for 2018.

2. PREPARATION OF NAVISP ELEMENT 1 WORKPLAN FOR 2018

To prepare the Element 1 workplan for 2018 and collect the most promising ideas and proposals, the Executive has implemented the ‘funnel scheme’, which proved to be a successful process for approval of the 2017 workplan.

The Executive has again engaged in an ESA-wide consultation to populate the Element 1 workplan for 2018, along the following guidelines:

- Ensuring relevance to the Element 1 objectives and scope;

- Avoiding duplication with ESA internal activities being performed, or in the pipeline, under other ESA programmes (e.g. TRP, GSP, GSTP, IAP);

- Ensuring completeness and maturity of the preparatory analysis underlying each activity proposed.

This ESA-wide consultation for Element 1 has again generated a considerable number of proposals, which have been assessed according to the above guidelines. However, unlike with the previous workplan, proposals have relied not only on accumulated knowledge ESA-wide and the know-how of individuals in the PNT sector, but also on consultative workshops organised by participating States (PB/NAV(2017)28, NAVISP Status Report) and on comments received through the intermediate round of formal consultations with the EC, GSA and participating States on the ‘Draft NAVISP Element 1 Work Plan 2018’ (ESA/PB-NAV(2017)27) presented at the 103rd PB-NAV meeting.

3. STATUS OF COORDINATION

The Element 1 workplan for 2018 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 by 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 activities implementation as requested during coordination. Furthermore, as recommended by the EC and GSA, there will be careful coordination with them on the projects addressing application domains calling for the involvement of institutional stakeholders at EU level.

4. RATIONALE AND DESCRIPTION OF PROPOSED ACTIVITIES

The NAVISP Element 1 workplans 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 2018 workplan have again been grouped according to the same broad themes as proposed for the previous workplan, 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.

This broad grouping balances the specific Element 1 objectives, the type of proposals collected according to the guidelines provided, and their degree of refinement.

For the preparation of the next workplans, the Executive intends to step up outreach and external consultation activities in order to provide specific strategic innovative orientations and themes to be addressed and pursued as a matter of priority within Element 1. This may also affect the thematic classification, which could evolve in the future.

Moreover, further to the above-mentioned consultative workshops organised by participating States, it has been suggested that proposed activities could also be classified according to more granular subject areas, for instance:

- Timing techniques, clock technologies, quantum technologies and clocks;
- Low-power technologies;
- Autonomy;
- Mobile devices:

- Resilience and trust;
- PNT for environmental matters:
- Role of GNSS for in-orbit servicing;
- Complementary non-GNSS positioning.

Indeed, the activities proposed under each theme could correspond to one or more subject areas.

4.1. Theme 1: Emerging New Space-Based PNT Concepts

The underlying rationale of Theme 1 has already been described and shared in the approval process for the previous Element 1 workplan for 2017. Ultimately, the objective of the theme is to contribute to detailed understanding of emerging trends and investigate PNT technologies complementary to or alternative to GNSS aimed at stimulating European industry to reap the benefit of these potential developments.

In addition to the activities proposed in the previous workplan, which encompass terrestrial and space-based trends similar to those already emerging in the US and worldwide (e.g. 5G positioning, Locata, NextNav, Satelles), the 2018 workplan also addresses some promising new areas of fundamental research and longer-term innovation for alternative or complementary PNT.

4.1.1. NAVISP-El1-011: Resilient, Trustworthy, Ubiquitous Time Transfer

Secure and reliable time transfer is a key enabler for the next generation of services worldwide. A number of different applications such as 5G mobile broadband, mobile multimedia broadcast, power grids, terrestrial positioning services, financial operations, IoT, big data and cloud processing will require accurate, secure and reliable time information to be able to work consistently and efficiently. The time information will need to be transferred not only securely, but also in a seamless and ubiquitous manner.

The most accurate and ubiquitous time transfer is currently realised through GNSS. Given high-quality frequency reference, a GNSS-based time source can keep time error with less than 30 ns error to UTC. There are a number of techniques to realise GNSS-based time transfer, including but not limited to: direct computation of Position, Velocity and Time; fixed mode (static) receiver solving for time only (not position); common GNSS satellite time only transfer; etc.

However, a common weakness of all GNSS-based time transfer techniques is that these methods are sensitive to spoofing (limited security), jamming and signal blockage (deep indoors).

On the other hand, traditional telecom-based time transfer methods that use two-way time transfer protocols (e.g. NTP or IEEE 1588v2 PTP) over terrestrial wire or wireless media are far more resilient to jamming and signal blockage. These media (and protocols) are far more secure (due to multiple layers of security), yet are limited in terms of accuracy due to inherent latency and asymmetry in the packet-based networks.

The main objective of the proposed activity is to put forward innovative and complementary methods of time transfer, focusing on the use of non-GNSS technologies. In order to enable an overall seamless provision of secure, ubiquitous and reliable time information, alternative solutions will be conceived to complement the current GNSS time transfer techniques with the emerging fixed and mobile services (e.g. autonomous vehicles, terrestrial positioning, 5G mobile broadband, 5G eMTC, and 5G V2X) and with space-based PNT services (e.g. Satelles).

The tasks to be performed will include:

- Review of requirements for different use cases, with the main focus on new emerging fixed and mobile services being studied by relevant working groups (e.g. ITU, 3GPP);
- Identification of enabling technologies including architecture, algorithms and protocols;
- Design, development and demonstration of the technology concepts;

The expected outputs are:

- Report on the requirements and use cases for new concepts being studied by relevant working groups (e.g. ITU, 3GPP);
- Report on the analysis of different enabling technologies, architectures, algorithms and protocols relevant to secure, reliable and ubiquitous time transfer;
- A test platform, to consolidate assumptions made on performance methodologies, models and techniques;
- Recommendations for follow-up activities, with the focus on standardisation of the proposed solutions.

Funding required: €350k	*Duration:* 12 months	*ITT issue:* Q1 2018

4.1.2. NAVISP-El1-012: High-Altitude Pseudo-Satellites for PNT

High-Altitude Pseudo-Satellites (HAPS) are airships “quasi-”stationed at a height of 20-30 km, in an altitude range where atmospheric winds are milder. HAPS are normally solar powered, unmanned, large, helium filled and semi-rigid; they can be operational for several years.

HAPS have been studied in the telecom domain (ESA GSP HAPPIEST study), where they were briefly considered as:

- An additional source of ranging signals (pseudo-satellite) in urban environments or deep valleys;
- A means to broadcast GNSS differential corrections, assisted data or SBAS data, at high latitudes, in deep valleys or in urban environments, as a gap filler with respect to current broadcast solutions (e.g. satellite or terrestrial networks);
- A means to enable advanced navigation applications and scientific research, such as GNSS reflectrometry, radio-occultation, ionosphere characterisation in areas with a low density of ground receivers (e.g. ocean).

HAPS may be competing with or complementary to other satellite solutions, such as LEO mega-constellations, inclined geosynchronous orbit satellites or simply multi-constellation or terrestrial pseudolites.

A number of distinct HAPS features with respect to other alternative PNT solutions are the following:

- Regional coverage, deployed where needed;
- Tens to hundreds of km of coverage per airship, i.e. much more than terrestrial pseudolites;
- Higher received power on ground than MEO and LEO;
- No ionosphere disturbance;
- Use of COTS components/subsystems;
- Re-usability and maintainability advantages;
- Support two-way navigation-related services;
- Short time-to-market.

HAPS face important technical challenges to be assessed, such as power supply, station keeping, time synchronisation and antenna pointing stability. On these issues, there have been significant improvements over the last few years, for instance regarding HAPS station-keeping performance by two leading European airship platform manufacturers.

The main objectives of this activity are to:

- Study the benefits of HAPS for GNSS augmentation in harsh environments, interference monitoring/location and alternative/complementary PNT;
- Study the different candidate architectures and downlink signal plans of HAPS for PNT objectives, possibly in combination with communication services/systems, assessing end-to-end system performance;
- Perform a HAPS PNT payload technology trade-off;
- Perform a HAPS platform suitability assessment and high-level requirements;
- Assess potential future demonstrations.

The tasks to be performed will include:

- Assessment of the benefits of HAPS with respect to other space-based or terrestrial systems for selected PNT objectives;
- Study and trade-off of the different HAPS functional architectures and downlink signal plans (UHF, L-, C-band and others) for the identified PNT objectives, possibly in combination with communication services;
- Detailed performance analysis of different HAPS functional architectures and configurations for PNT;
- Description of selected system concept(s) for HAPS for PNT;
- HAPS PNT payload technology trade-offs and high-level definition;
- HAPS platform suitability assessment and high-level requirements, considering available platforms and their expected evolutions;
- Assessment of potential future demonstrations for possible use in the definition of future activities and programmes.

The results of the activity will provide:

- Feasibility of HAPS for PNT for the selected objectives;
- Architecture of the HAPS system (phase 0 level);
- HAPS PNT payload high-level definition and platform constraints;
- Initial definition of future demonstrations.

Funding required: €250k	*Duration:* 12 months	*ITT issue:* Q2 2018

4.1.3. NAVISP-El1-013: Quantum-based sensing for PNT

The exploitation of quantum physics has already enabled revolutionary technical applications and industries of enormous economic scale. The semiconductor industry alone is currently a €500 billion market, giving rise to industries on an even larger scale (smartphones, computing, software, etc.).

Quantum physics is now again set to radically change several industries, including communications, encryption, sensing, and computing, through the use of even more fundamental quantum effects such as superposition and entanglement. The counter-intuitive aspects of such phenomena allow tasks that are not otherwise possible to perform and could open up radical innovation opportunities in many application domains.

Because quantum effects are inherently fragile and sensitive to the outside world, they can be used to create exquisitely sensitive and precise devices for measuring (e.g. gravity, magnetic fields, and rotation). This can boost accuracies for inertial- and magnetic-based navigation by orders of magnitude.

Inertial-based navigation relies on measurements of acceleration and angular rates only. While autonomy is the key advantage, the accumulation of errors over time is limiting accuracies, e.g. a ship travelling from Portsmouth to New York would need initial attitude to 5e-5° to achieve GNSS-like accuracy. Today various technologies are available on the market, which vary in price and accuracy. Low-cost consumer markets are using MEMS (1-1e3 °/h), while the highest stabilities are achieved with Ring Laser Gyros (1e-3 °/h). Quantum-based sensing techniques promise a significant improvement of the accuracies by several orders of magnitude, which could enable high-precision navigation with long autonomy times.

Fundamental laboratory experiments tests have shown promising results, using, however, large equipment unsuitable for portable applications. Quantum-based sensors may step in for areas where satellite navigation is inaccessible, and provide a robust complement.

The main objective of the proposed activity is to demonstrate the potential of quantum effects, in particular:

- Develop a system concept for combined space-based and quantum sensor navigation (e.g. gravity/magnetic field mapping data and absolute position calibration);
- Identify critical technology developments for overall system and sensors;
- Demonstrate initial feasibility of the concept in the field by means of existing prototypes.

The tasks to be performed will include:

- Review of the state of the art / technology trade-offs;

- Selection of sensing concept / preliminary testbed design;
- Detailed design;
- Experimental field study and analysis.

The technology starting point could be based on cold atom laser gravity measurements, gravity mapping, etc. This could lead to a game changer for autonomous navigation due to the drastically boosted accuracies of inertial-based systems. It would enable user independence in challenging environments or redundancies in safety-critical PNT applications. Demonstration of this innovative PNT concept in a field experiment has not yet been performed.

The results of the activity will provide:

- Research and commercial state of the art, including roadmaps, competitive landscape and technology trade-offs;
- Prototype testbed and experimental results;
- Recommendations for future developments.

Funding required: €450k	*Duration:* 18 months	*ITT issue:* Q2 2018

4.1.4. NAVISP-El1-014: PNT using Neutrino Particles

This proposed activity represents an innovative concept to realise Positioning, Navigation and Timing using neutrino particles. At present, standard navigation approaches – including satellite navigation – rely on direct line-of-sight RF and optical communications. Neutrinos move at around the speed of light, have no electric charge and are low mass, thus showing very low interaction with normal matter. These extraordinary characteristics could enable the use of neutrino beams for communication, navigation and time dissemination with buried or submerged craft and even distant planets, without the need to deploy antennas or use relay satellites. All those current PNT applications could of course also be candidates for this new approach.

The use of neutrino beams for communication is an old idea, put forth by several authors and for various purposes, such as for interstellar or even intergalactic communication. The use of neutrinos for communication with a submarine deep under the ocean has recently been considered.

In certain environments, such as those where nuclear-powered submarines operate, unlimited submerged endurance is required. However, the need for these craft to communicate and position themselves ultimately ties them to the surface. Therefore, communication at operational speed and depth is highly desirable.

Currently, only radio transmission at extremely low frequency (ELF) of less than 100 Hz is able to provide communication at speed and depth. ELF data rates are very low, of the order of one bit per minute, due to the very low bandwidth, the high noise levels and the difficulty in generating high-powered signals. Instead, radio transmission at frequencies of a few kHz (very low frequency, VLF) is used, providing data rates around 50 bps; however, the seawater penetration of VLF is limited.

The application of neutrinos for communication and navigation was considered until 2009 not to be a feasible approach. This changed when the problem was re-examined in view of the latest technological advances. Recently, several works have demonstrated that a neutrino beam from a muon storage ring can be detected by sensors mounted on the hull of a submarine. This would enable establishing a one-way communication link at speed and depth with data rates in the range of 1 to 100 bps, improving the current solution, based on ELF and VLF, by a factor of 1 to 3 orders of magnitude.

In 2009, the first concepts of navigation based on the detection of neutrinos coming from the Sun were proposed and patented. The proposed method involves measuring the angle of arrival of neutrinos emitted by a source and tagging the neutrino measurements using an accurate clock. The method and system further involves processing the tagged neutrino measurements through a computational model of a neutrino generator and combining the processed measurements with navigational aids to provide location information. A system and method in accordance with an embodiment measures the angle of arrival of neutrinos generated by the Sun, thus deriving navigation information obtainable deep underground or under water. Additionally, the system provides robust navigation, without drift, in the absence of other common navigation systems such as global positioning systems.

The objective of the proposed activity is to demonstrate the feasibility of the concept for PNT applications. It aims at formulating a technical concept for further validation. In order to achieve this, the activity will also identify candidate facilities for later testing, including discussions on pre-agreements with potential facility owners. The activity includes analysis of message coding and decoding, estimation of neutrino beam channel parameters and derivation of a “link budget” for neutrino PNT applications.

The tasks to be performed will include:

- Studying the state of the art and potential benefits of neutrino navigation for future PNT;
- Trade-off of different technologies and providing candidates for practical solutions for PNT;
- Developing a theory and simulation concept, including message coding and decoding, the estimation of neutrino beam channel parameters and the derivation of a “link budget”;
- Identifying critical functions for technology demonstration;
- Defining a detailed proof of concept.

The results of the activity will provide:

- Technology feasibility report based on theoretical demonstration;
- Definition of proof of concept of neutrino-based PNT and follow-on demonstration activities;
- Identification of candidate facilities and discussion with facility owners for later demonstration.

Funding required: €200k	*Duration:* 12 months	*ITT issue:* Q2 2018

4.1.5. NAVISP-El1-015: Feasibility study of a space-based relativistic PNT system

All GNSS in operation at present are based on Newtonian physics and rely on global reference frames fixed to Earth. Relativistic effects are treated as deviations that need to be corrected for. Precision and stability over time of the reference frames is provided via ground stations and they are limited by the Earth's dynamics (e.g. variations of the Earth's rotation rate, plate tectonics, tidal crustal effects) and atmosphere.

An RPS (Relativistic PNT System) would consist of a constellation of satellites, with each one broadcasting not only its proper time at emission but also the proper times that it receives from the other satellites. It would inherently establish a local reference frame based only on the dynamics of the satellites and, as a consequence, would be completely independent of a terrestrial frame. This local reference frame would be the Autonomous Basis of Coordinates (ABC) system that requires no time synchronisation. At each space-time event (user location) reached by the signals, the received times (at least four) would enable the emission coordinates of this event to be defined with respect to the ABC. In order to use the system on the Earth surface, a limited ground segment network would be required to define the transformation of the ABC system with the currently used inertial and terrestrial time coordinate reference systems.

The main advantages of RPSs is that they naturally incorporate general relativity, are independent of any terrestrial frame and provide an independent, robust and self-consistent navigation solution, with potentially higher performance. Potential benefits of using these systems would be more accurate and robust positioning solutions for standard applications and a new framework for new scientific applications. A sub-millimetre level of accuracy of satellite positions would have major impacts in different fields. In astronomy, space physics and Earth sciences, increased precision of space and time localisation of events is associated with better knowledge of the phenomena studied. Thus, for example, the following advances could be possible:

- Geophysics: Earth shape, continental drift and tides would be measured with unprecedented precision to model Earth crust stress, leading to reliable earthquake prediction;

- Fundamental physics: accurate measurements of the space-time curvature around the Earth could lead to the detection of gravitational waves and the measurement of other physical phenomena;
- Metrology: RPS could be used itself as an independent clock with long-term stability;
- Space exploration: remarkable advances would be possible in orbit determination and space navigation; as a universal, independent and autonomous positioning system, RPS would be possible anywhere in the Solar System.

Theoretical formulations of such a system have been proposed in literature (Coll 2006, Delva 2011, Saez 2014, Kostic 2015) considering that a satellite broadcasts not only its proper time at emission but also the proper times that it receives from the other satellites (via cross-satellite links). However, none of the proposed approaches were intended to be practical. Going from those to systems that can actually be deployed would entail further developments in the required numerical tools and technology. The expected advantages are presumed to be significant; however, the main practical feasibility challenges of such a system still need to be assessed.

The objective of this activity is to analyse the advantages of Relativistic Positioning Systems (RPS) for specific timing and positioning applications.

This analysis aims at performing high-level system analysis, including key trade-offs, and addressing the main practical feasibility/implementation challenges of a global space-based relativistic PNT system (onboard hardware, such as atomic clocks, cross-links, and ground based infrastructure) taking into consideration current and near-future available state-of-the-art technology.

The activity will initially assess two use-cases less affected by the terrestrial frame:

- the realisation of system time in space, and its dissemination to users, without the need for ground synchronisation;
- the positioning of space-based users who do not necessarily need to be linked to a terrestrial reference frame.

The tasks to be performed will include:

- study of the RPS state-of-the-art and theoretical basis, and assessment of its benefits;
- definition of a suitable relativistic autonomous time-space reference system (ABC) based on RPS and its connection with the currently used inertial and terrestrial time and coordinate reference systems (UTC, ICRF and ITRF);
- preliminary high-level system design and assessment of practical implementation aspects;
- analysis of RPS application for the selected use-cases.

The results of the activity will provide:

- RPS maturity and feasibility assessment for PNT applications;
- requirements for an RPS satellite proof of concept based on current and near-future available state-of-the-art technology.

Funding required: €150k	*Duration:* 12 months	*ITT issue:* Q2 2018

4.2. Theme 2: Innovative Use of Space-Based Solutions in the PNT Context

Theme 2 focuses on the captive PNT market segments where there is potential for introducing or increasing the penetration of space-based PNT.

As already described in the 2017 workplan, these typically pertain to regulated market domains requiring a high degree of standardisation, dominated by legacy technology and with high resistance to change. It was also explained that the process of generating proposals for Theme 2 of the Element 1 workplan for 2017 had strongly relied on outreach activities carried out through existing ESA mechanisms for external interactions with stakeholders and regular coordination with the GSA for the establishment of joint sectorial roadmaps. Similarly this applies for Theme 2 of the Element 1 workplan for 2018.

4.2.1. NAVISP-El1-016: GNSS/non-GNSS Sensor Fusion for Resilience in High-Integrity Aviation Applications

GNSS technology has demonstrated its capability to provide very good performance in Europe up to LPV 200 based on GPS L1 (single frequency, single constellation) and is expected to reach CAT I Autoland with the future DFMC mode (Dual Frequency, Multi Constellations – GPS & GAL).

It is very challenging to improve this performance, more specifically the 6-second Time To Alert (TTA) that seems intrinsically difficult to reduce for space-based products.

Improving system resilience to external perturbing factors (signal occultation, jamming, spoofing, etc.) is also a very important contribution to offering better system availability and/or continuity.

Other R&D projects have addressed performance enhancement in the GNSS-only domain by augmenting a third constellation (in addition to GPS and Galileo).

GNSS data and those from other sensors, such as barometers and inertial sensors, may already be combined in the avionics, however only after GNSS processing. The innovative approach proposed here is to combine GNSS data with other avionics measurements in the same integrity processing.

Sensor fusion is a promising path to overcoming performance limitations and improving the resilience of individual systems. A combination of GNSS with various types of additional measurements, ranging data (LIDAR, Vision-aided, TAWS) or non-ranging data (IMU) could improve in-flight awareness of airplane position and trajectory or could be used to mitigate continuity events, making for less stringent requirements for the design of individual systems.

A preliminary list of candidate sensors for fusion with GNSS comprises:

- IMU (Inertial Measurement Unit);
- LIDAR (Laser Imaging Detection And Ranging);
- Vision sensors (forward- and down-looking cameras);
- TAWS (Terrain Awareness Warning Systems).

The objectives of the proposed activity are to:

- Investigate the benefits of avionics sensor fusion in order to overcome the current limitations of GNSS (Protection Levels, Time To Alert, continuity, for example) and improve system resilience to external perturbing factors;
- Evaluate the impact this fusion would have on the user positioning algorithm.

The tasks to be performed will include:

- Identification and characterisation of on-board avionics sensors that could be used, distinguishing between airliners and light aircraft;
- Identification of the sensor added value (PL, TTA, availability, continuity, etc.);
- Identification of non-GNSS input bounding;
- Development of a new integrity monitoring and prediction concept to combine multi-source multi-sensor data;
- Impact assessment of receiver complexity;
- Prototyping of an innovative user positioning algorithm to handle additional ranging and non-ranging data from various avionics sensors;
- Characterisation of the achievable level of integrity and performance using synthetic and/or real measurements;
- Identification of the possible impacts of the sensor fusion on international PNT/GNSS standards.

Ultimately, improved airplane position and trajectory awareness could help to target more stringent flight conditions (CAT II, CAT III, etc.) and contribute to future plans to set up an in-flight demonstration with real-time measurements.

The outcome of the proposed study could also contribute to defining future PNT requirements, in particular for GNSS.

Funding required: €300k	*Duration:* 12 months	*ITT issue:* Q2 2018

4.2.2. NAVISP-El1-017: Techniques supporting Resilience for High-Integrity Train Control Applications

The objective of the proposed activity is to study GNSS carrier phase integrity techniques for application in railway safety of life applications, and in particular, the evolution of the European Rail Traffic Management System (ERTMS) with virtual balise detection using GNSS.

Carrier phase positioning can achieve a significantly better performance than code-based positioning; however, to date there are no certified integrity concepts applicable to these techniques. Such techniques are expected to provide significantly better accuracies, enabling the use of GNSS in ERTMS operations and scenarios that are not possible today with the performance of existing GNSS code-based integrity concepts.

A significant challenge in the use of carrier phase techniques is bounding of errors and management of discontinuities caused by the railway propagation environment, which is characterised by strong multipath and non-line of sight effects, frequent obscuration and discontinuity of satellite signals and high levels of electromagnetic interference.

Amongst the new “game changing” capabilities foreseen in the evolution of ERTMS, is the realisation of a virtual balise concept using GNSS.

The key industry stakeholders and supporting agencies (European Union Agency for Railways, European GNSS Agency and ESA) have developed a set of coordinated activities to support the roadmap for the realisation of this concept. While this roadmap focuses on the short/medium term with proven solutions to address requirements, there are a number of open problem areas concerning the longer-term evolution that will require innovative solutions.

GNSS carrier phase positioning techniques may offer the required performance if integrity and safety issues can be addressed. Two indicative cases are:

- Positioning for Start of Mission, whereas Precise Point Positioning (PPP) currently lacks certified algorithms providing integrity instead;
- Positioning in Virtual Balise Detection, based on the Relative RAIM (RRAIM) concept which facilitates coasting between safe measurements (measurements stored for the duration in which the reception of integrity alarms from the ground monitor can be guaranteed).

In both the above cases, resilient integrity mechanisms need to consider the railway environment and the prevalence of electromagnetic interference, multipath and non-line of sight conditions. In addition to determining suitable error models, issues such as carrier phase discontinuities and the possibility to repair (possibly using other sensors) should be considered. In the long-term context, use of dual frequency (L1-E1B / L5-E5a) multi-constellation (GPS/Galileo) can be assumed.

The tasks to be performed will include:

- Review of requirements for ERTMS related to start of mission and requirements related to the ERTMS virtual balise concept;

- Review of carrier phase positioning techniques, processing modes, applicability in the railway environment and potential issues for development of a resilient integrity concept;
- Safety analysis for each candidate positioning technique;
- Proposing integrity algorithms for mitigation and bounding residual errors for candidate positioning techniques;
- Experimentation and verification of integrity algorithms using railway measurement data sets.

The results of the activity will, amongst others, provide recommendations for suitability of techniques supporting resilience for high-integrity train control applications, identifying gaps and future work.

The Executive will ensure coordination with on-going GSA activities in the frame of H2020, in particular the STARS project, which is characterising the rail environment via field tests. The activity will also build on available results of the H2020 RHINOS project developed around high-integrity concepts for trains, even if different from the one proposed here, which is based on GNSS carrier phase positioning techniques.

Funding required: €450k	*Duration:* 18 months	*ITT issue:* Q2 2018

4.3. Theme 3: Proof of concept of promising PNT Techniques and Technologies

As already described in detail in the previous workplan, the aim is that Theme 3 should form the basis for future innovative PNT techniques and technologies by attracting the wider interest of the space and non-space industry in developing and testing new solutions.

For the Element 1 Workplan for 2018 too, proposals range across diverse domains, addressing a wide variety of PNT techniques and technologies, with development of testing platforms which could be made available to industry for follow-on developments in NAVISP or in other programmatic frameworks at ESA or outside.

4.3.1. NAVISP-El1-018: Low-RF Fast Deployable Systems for Emergencies in Difficult Environments

There exist a number of applications requiring reliable and accurate navigation services in environments difficult to access where available commercial products struggle to satisfy the variety of user demands. Such applications include very deep indoor applications, for which navigation accuracy and timely operations are critical to users, as for example in emergencies or underwater/urban-canyon situations.

For the most challenging scenarios, for example in-depth indoors or even disasters resulting from avalanches, flooding, etc., a solution based only on GNSS will not adequately support the PNT functions and operations required for the different environments and operation modes. On the other hand, customised deployable navigation systems will require a highly flexible configuration, to provide robustness along with high-accuracy navigation and timing performances to the distressed users and core operating rescue teams. This will be needed for the entire operation to cope with the dynamic, unpredictable environments and performance requirements. The input design parameters of such a system therefore need to be defined and consolidated, capturing the trade-offs in the parameters critical to its performance, considering different crisis modes, user needs and user surroundings.

The main objective of the proposed activity is to:

- Set up a proof-of-concept platform able to meet the selected challenges, with sufficient versatility to address crisis situations in very harsh environments.

The tasks to be performed will include:

- Review the existing and firmly planned systems and the potential environment of applications that cannot be accessed by existing PNT system solutions. Define the requirements for such applications in terms of PNT with the associated figures of merit;

- Identify the most appropriate carrier for the broadcast platform (drone, helicopter, tethered balloon, small zeppelin, transmitter installed on roof of nearby building, large birds equipped with small transceivers, GNSS transceivers, etc.);
- Investigate the impact on RF propagation of the various environments where this system will be operational to assess the benefits of different signal types, (i.e. frequency bands, bandwidths, transmission mode) per environment (material, environment structure: building, potentially collapsed construction, block, city, etc.);
- Assess the benefits of Radio Frequency for Underwater PNT cases, integrating the benefits of platforms that can provide wide area availability to the applications and services;
- Trade-off pros/cons of potential platform solutions using custom RF signals or making use of GNSS signals, provided that the system operator owns a license, and identify the benefits and advantages with respect to the Rx complexity, re-using current receivers. Define the requirements for the user receiver technology to extract the benefits of such a system;
- Assess the pros and cons of different system architectures, including signals, for the different user cases based on PNT figures of merit. Trade-off and identify the optimal working points of the signal types, versus user conditions, performance requirements and technological constraints;
- Study and derive innovative techniques for the provision of service robustness and enhancements for the PNT links in local environments and different application areas. Define the required technological aspects for the implementation of a networked system to support flexibility in the targeted application;
- Develop a platform, capable of assessing and testing in representative conditions (environment, system architecture), the critical technologies and key enablers (for instance, different signal configuration, network architecture of deployable platform, target performances).

The results of the activity will provide:

- A proof of concept by means of field data collection, for different user environments and PNT target performances;
- Recommendations for follow-on activities aiming at development of a prototype system.

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Funding required: €400k	*Duration:* 18 months	*ITT issue:* Q2 2018

4.3.2. NAVISP-El1-019: Ultra-Low Power Device Positioning Concepts

There are an increasing number of IoT applications, and projections show that global Low Power Wide Area (LPWA) connections will increase by almost one order of magnitude in the next five years. Terrestrial networks are continuously targeting evolutions of the IoT markets. For example, the latest release of 3GPP standards has introduced modifications to their standard (e.g. NB-IoT) to comply with the ultra-low energy requirements of 10+years of battery life for Massive Internet of things communication. At the same time (while NB-IoT is still to be deployed), 3GPP is starting to define a new air interface (called enhanced Machine Type of Communications e-MTC) to be scalable to the evolution of IoT requirements. In addition, LPWA networks with proprietary technologies (such as Sigfox, Lora) are providing dedicated solutions for very long battery lifetime IoT devices (up to 20 years). There is therefore a growing market targeting the concept of “install and forget an IoT device”, which calls for ultra-low energy and low-cost devices.

However there are difficulties with the inclusion of positioning capabilities within an IoT device in terms of complying with the ultra-low-energy requirements (10+/15+ years of battery life) especially for space-based PNT capabilities.

The main objective of the proposed activity is to:

- design, assess feasibility, develop and demonstrate new concepts and paradigms of PNT for ultra-low energy (and low-cost) devices for hybrid terrestrial/satellite networks and space-based PNT systems.

The activity will investigate opportunities offered by both present and future standards/technologies of terrestrial networks in hybridisation with current/future GNSS and/or satellite-based communication and PNT services. It is expected to leverage on concepts like access network, use of protocols, apportionment of processing between user and network, apportionment of data transfer and energy consumption between communication and positioning functions, duty cycles, air interface, etc., both from system perspectives and at user level.

The tasks to be performed will include:

- Review of requirements and use cases, with review of assumptions and requirements for IoT devices based on several combinations of hybridisation among (present and future) LPWA terrestrial networks, satellite communication systems and space-based PNT systems (either GNSS or complementary/alternative satellite based systems);
- Identification of the apportionment of requirements (e.g. power budget, data transfer) between PNT and communication;
- Preliminary design, with identification of promising concepts, mode of operations, receiver architectures and techniques to enable ultra-low energy IoT devices using tracking by satellite-PNT services in standalone and in hybrid mode with terrestrial LPWA networks and satellite networks. Mapping of solutions to identified use cases. Definition of simulator for analysis;

- Consolidated design and analysis, with consolidation of design, implementation of simulator and analysis of performance of most promising concepts, mode of operations, receiver architecture and techniques;
- Cost-benefit analysis.

The results of the activity will provide:

- Feasibility of the identified concepts with identification of impacts on the space-based PNT systems, terrestrial and satellite networks and IoT devices;
- Guidance for planning future activities, including further studies, testing and proof-of-concept activities possibly integrated with follow-on tests from other activities;
- Recommendations on how identified gaps and issues can be addressed in future activities;
- Recommendations to system designers and users regarding requirements and solutions.

Funding required: €250k	*Duration:* 18 months	*ITT issue:* Q2 2018

4.3.3. NAVISP-El1-020: Artificial Intelligence / Machine Learning Sensor Fusion for Autonomous Vessel Navigation

Maritime transport is currently facing new challenges such as significant increases in transport volumes, more stringent environmental requirements and a shortage of seafarers in the future.

One of the many new concepts having the potential to overcome these challenges is autonomous ship navigation. In particular, the concept is expected to allow for more efficient and competitive ship operations while reducing the vessels' environmental impact.

The objectives of this activity are to:

- Study artificial intelligence and machine learning techniques for the combined use of multiple sensors in maritime PNT receivers for autonomous vessel navigation;
- Implement a proof-of-concept prototype autonomous navigation PNT receiver using the techniques identified;
- Study the feasibility of implementing an autonomous vessel navigation PNT service leveraging current and future European GNSS using the techniques identified.

The tasks to be performed will include:

- State-of-the-art review of artificial intelligence algorithms (neural networks, machine learning, decision trees, etc.) applied to sensor fusion for general navigation;
- Analysis of operational requirements in terms of at least the accuracy and integrity of unmanned vessels for at least two representative maritime operations;
- Study, define and trade-off artificial intelligence methods and techniques for the combination of data from multiple sensors and propose more defined architectures for autonomous vessel navigation;
- Create a proof-of-concept autonomous navigation PNT receiver prototype using different sensors and systems (based on COTS components) to test the artificial intelligence methods and techniques identified;
- Perform laboratory tests and simulations on the proof-of-concept prototype in a variety of situations with a particular focus on assessing performance with regard not only to accuracy but more importantly to resilience and integrity (for example under interference situations) linked to the selected maritime operations;
- Perform a training phase and testing campaign on a vessel using the proof-of-concept autonomous navigation PNT receiver prototype in order to assess the performance of the artificial intelligence methods and techniques implemented;
- Identify areas and technologies that will require further evolutions to achieve operational requirements whose feasibility is not possible with current and planned European GNSS systems.

The activity outcome will be instrumental for the development of autonomous vessel navigation and future standards on the topic. The proof-of-concept prototype will constitute an initial tool available to ESA, industry and third parties to test future options for maritime autonomous vessel navigation.

The Executive will ensure coordination with EC and GSA, in particular for the task related to analysis of operational requirements and for dissemination of joint information papers at IMO and IALA.

Funding required: €400k	*Duration:* 24 months	*ITT issue:* Q1 2018

4.3.4. NAVISP-El1-021: Integrity Monitoring and Prediction Concept for Autonomous Car Resilience and Safety

Autonomous driving is seen by many as a coming technology disruption that will have profound impacts on industry, society and the economy. One of the great hopes of autonomous driving proponents is the realisation of huge safety improvements. According to the World Health Organization, road accidents account for 3,400 deaths every day around the world. This is more deaths than those caused, for example, by HIV-related illnesses. By reducing or even removing entirely the element of human error, autonomous driving has the potential to transform road transport to unprecedented safety levels. Furthermore, due to the efficiency gains possible when road vehicles do not require drivers, autonomous driving may bring about cost savings, as well as environmental savings through more efficient use of resources.

One of the key enabling technologies for autonomous driving is accurate and reliable PNT. According to some experts, autonomous driving requires positioning accuracy of 30 cm or even better, a level which cannot be attained by standalone GNSS positioning methods. Perhaps even more demanding are the requirements for reliability and integrity, and the only way to meet these demands is by integrating dissimilar and redundant technologies.

At present, autonomous vehicles are being tested in many test environments and on public roads in different parts of the world. Many of the key developers in autonomous driving are based in Silicon Valley in the USA (e.g. Google), whereas others are based, for example, in central Europe.

'Google cars have autonomously travelled an impressive 1.5 million miles. A purely experimental, complete proof that Autonomous Passenger Vehicles (APVs) match the level of safety of human driving would take about 400 years at Google's current testing rate (of approximately 250,000 test miles per year). This is assuming that no fatalities occur during that time, that no major APV upgrade is performed, and that the testing environment is representative of all US roads. Consequently, other methods must also be employed to ensure APV safety. Mass adoption of APVs requires confidence by public that APVs are safe. And this imperatively implies that a level of safety must be guaranteed. Autonomous vehicles thus require multi-sensor PNT, including laser scanners or radars, whose raw information must be pre-processed before it can be used for navigation. It is therefore necessary to continuously predict integrity in a dynamic environment'. [1]

The objective of the proposed activity is to further develop and prove the practical feasibility of Integrity Risk monitoring and the prediction concept for autonomous vehicles. This concept will be based on the Feature Extraction (FE) and Data Association (DA) techniques, considering the integration of multi-sensors and space and/or ground-based PNT data. It will be based on a derivation of the concept of integrity used in aviation. The activity includes the development of a demonstrator. The activity will assess the key elements, in particular space-based PNT data, to enable faster mass adoption of autonomous vehicles and increase safety in this field.

This activity will include the following tasks:

- Review of available research papers, latest developments, and integrity monitoring and prediction techniques in the field of autonomous vehicles;

[1] "NRI: Receding Horizon Integrity—A New Navigation Safety Methodology for Co-Robotic Passenger Vehicles" *Research Project Proposal to the U.S.A. National Science Foundation*; M. Joerger, M. Jamoom, M. Spenko, B. Pervan, "Integrity of Laser-Based Feature Extraction and Data Association". *Proc. IEEE/ION PLANS 2016* .

- Development of an innovative integrity monitoring and prediction concept for autonomous vehicles, based on the FE and DA techniques. The use of multi-source multi-sensor PNT will be considered by the algorithms;
- Characterise the achievable level of integrity, demonstrating that the target level required for autonomous vehicles can be met;
- Development of a demonstrator;
- Field trials with the developed demonstrator, possibly with partner test sites.

The results of the activity will provide:

- An assessment of achievable integrity performance under the identified scenarios;
- An assessment of the suitability and cost effectiveness of the developed integrity monitoring and prediction concept(s);
- Recommendations for introduction of the developed integrity concept in the domain of autonomous vehicles.

The Executive will ensure coordination with relevant on-going and planned new activities at GSA in the frame of Fundamental Elements (e.g. ESCAPE project) and H2020 (e.g. INLANE and INDRIVE projects).

Funding required: €300k	*Duration:* 12 months	*ITT issue:* Q1 2018

4.3.5. NAVISP-El1-022: Low-cost multi-frequency multi-constellation GNSS antenna for CubeSats

Satellites flying in LEO are relying more and more on Precise Orbit Determination (POD) through GNSS and in particular the computation of real time on-board POD with accuracy at centimetre level. Receivers for in-orbit demonstration of Precise Point Positioning (PPP) currently under development under NAVISP (NAVISP-EL1-009: ‘Space GNSS Receiver for Un-Orbit Demonstration of PPP’) and the current activity will complement this development with an optimised antenna to be connected to such receivers. The availability of real-time on-board centimetre-level position accuracy in space will open the door to a myriad of applications (e.g. mega-constellations). Large platforms can afford costly and bulky antennas for very high performance. Smaller and cheaper platforms such as Cubesats need to embark low-cost, low-profile antenna solutions. Moreover, to exploit all the benefits of GNSS, a multi-frequency, multi-constellation solution is desirable. Current solutions available on the market are either too expensive or too bulky or limited in capability (e.g. single frequency). In addition to receiving navigation signals, modern receivers could potentially use the INMARSAT L-band as a communication channel for Precise Point Positioning (PPP). For this reason, it is considered beneficial to have a receive antenna covering the INMARSAT L-band too. In order to enhance performance in terms of multipath reduction, antennas mounted on high impedance surfaces (e.g.

EBGs, meta-surfaces) could be a compact alternative to metallic chokes (choke rings). The space user antenna will be compliant with stringent phase centre stability requirements and have a low cost and low profile compatible with CubeSat missions.

Based on the above, the objective of the activity is to design and qualify a low-profile, low-cost antenna covering GNSS frequencies and INMARSAT L-band for CubeSat missions.

The tasks to be performed will include:

- Definition/consolidation of antenna requirements;
- State-of-the-art review of antenna concepts and technologies for GNSS space users;
- Design of the multi-frequency (L1/E1, L2/E6, L5/E5a and INMARSAT L-band), multi-constellation GNSS space user antenna, with a focus on high accuracy (very stable phase centre), low cost (<10 keuro) and low profile (< 1cm height);
- Manufacturing and testing of the GNSS space user antenna;
- Qualification of the GNSS space user antenna, in line with tailored ECSS for CubeSat.

The development of this antenna will bring advantages in the integration, footprint and performance of GNSS receivers for Precise Point Positioning for CubeSat missions.

The availability of real-time on-board centimetre-level position accuracy in space will open the door to a myriad of applications (e.g. mega-constellations).

Funding required: €400k	*Duration:* 12 months	*ITT issue:* Q1 2018

5. SUMMARY

Activity funding & duration	Funding required (€k)	Duration (months)
Theme 1		
NAVISP-El1-011: Resilient, Trustworthy, Ubiquitous Time Transfer	350	12
NAVISP-El1-012: High-Altitude Pseudo-Satellites for PNT	250	12
NAVISP-El1-013: Quantum-based sensing for PNT	450	18
NAVISP-El1-014: PNT using Neutrino Particles	200	12
NAVISP-El1-015: Feasibility study of a space-based relativistic PNT system	150	12
Theme 2		
NAVISP-El1-016: GNSS/non-GNSS Sensor Fusion for Resilience in High-Integrity Aviation Applications	300	12
NAVISP-El1-017: Techniques supporting Resilience for High-Integrity Train Control Applications	450	18
Theme 3		
NAVISP-El1-018: Low-RF Fast Deployable Systems for Emergencies in Difficult Environments	400	18
NAVISP-El1-019: Ultra-Low Power Device Positioning Concepts	250	18
NAVISP-El1-020: Artificial Intelligence / Machine Learning Sensor Fusion for Autonomous Vessel Navigation	400	24
NAVISP-El1-021: Integrity Monitoring and Prediction Concept for Autonomous Car Resilience and Safety	300	12
NAVISP-El1-022: Low-cost multi-frequency multi-constellation GNSS antenna for CubeSats	400	12
Total	3900	

El1 ID	Activity Title	2018				2019				2020			
	Theme 1												
011	Resilient, Trustworthy, Ubiquitous Time Transfer	ITT		■	■	■	■						
012	High-Altitude Pseudo-Satellites for PNT		ITT		■	■	■	■					
013	Quantum-based sensing for PNT		ITT		■	■	■	■	■	■			
014	PNT using Neutrino Particles		ITT		■	■	■	■					
015	Feasibility study of a space-based relativistic PNT system		ITT		■	■	■	■					
	Theme 2												
016	GNSS/non-GNSS Sensor Fusion for Resilience in High-Integrity Aviation Applications		ITT		■	■	■	■					
017	Techniques supporting Resilience for High-Integrity Train Control Applications		ITT		■	■	■	■	■	■			
	Theme 3												
018	Low-RF Fast Deployable Systems for Emergencies in Difficult Environments		ITT		■	■	■	■	■	■			
019	Ultra-Low Power Device Positioning Concepts		ITT		■	■	■	■	■	■			
020	Artificial Intelligence / Machine Learning Sensor Fusion for Autonomous Vessel Navigation	ITT		■	■	■	■	■	■	■	■		
021	Integrity Monitoring and Prediction Concept for Autonomous Car Resilience and Safety	ITT		■	■	■	■						
022	Low-cost multi-frequency multi-constellation GNSS antenna for CubeSats	ITT		■	■	■	■						