ESA/PB-NAV(2017)17, rev.1
Paris, 30 May 2017
(Original: English)

EUROPEAN SPACE AGENCY

NAVIGATION PROGRAMME BOARD

Revision of NAVISP Element 1 Workplan for 2017

Subject

This revision shows on page 24, the change requested by delegations during the PB-NAV Meeting #102, on 18 May 2017, on the NAVISP Element 1 Workplan 2017 activities document (ESA/PB-NAV(2017)17).

Required action

PB-NAV is invited to take note of the content of this document which has been approved by the Participating States in NAVISP Element 1 on 18 May 2017.

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1. INTRODUCTION

The main objective of NAVISP is to facilitate the generation of innovative Space-Based PNT (Positioning, Navigation and Timing) propositions with Participating States and their industry, in coordination with the EU and its institutions.

It will support European industry in succeeding in the highly-competitive and rapidly-evolving global market for Satellite Navigation, and more broadly PNT technologies and services, while supporting Participating States in enhancing 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 & Deployment Programmes and the existing industrial base of the European GNSS sector. It does not duplicate nor does it change the basis on which the strategy and approach for R&D related to the evolution of the Galileo and EGNOS systems is determined and controlled through the established EU mechanisms.

The NAVISP programme is structured according to three Elements that 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 shall 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 would have to be developed in order to respond to the unveiled demands of the PNT sector, so far not yet leveraging the full potential space-based solutions have and will offer. In return, the net effect of this dynamic will be to enable a cross-fertilisation of expertise between different stakeholders of the PNT domain and to facilitate the presence of the EGNSS infrastructure in the future challenges of the PNT world.

The specific objectives of this Element are:

- Perform feasibility studies and viability analysis for the emergence of new concepts in the PNT world;
- Contributing to the formulation and implementation of PNT technology innovation;
- 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 to be approved by Participating States in NAVISP Element 1.

The preparation of the annual workplan is carried out through appropriate consultation with the Participating States, the European Commission (EC) and the European GNSS Agency (GSA).

In particular, the implementation of Element 1 requires a timely coordination between ESA and the EC/GSA. The principles and procedures of *ex-ante* coordination with EC and GSA are defined in the document '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), coherently with the approach outlined in the 'Concept note on space-based applications in ESA' (ESA/C/WG-M(2016)18).

This document presents the workplan of Element 1 for the year 2017.

2. NAVISP ELEMENT 1 WORKPLAN 2017 PREPARATION

For the preparation of the Element 1 workplan for 2017 and in order to collect the most promising ideas and proposals, the Executive has implemented the 'funnel scheme' as presented at previous PB-NAV meetings.

The Executive has set-up an ESA-wide consultation in order to populate the Element 1 workplan for 2017 according to the following guidelines:

- Ensuring relevance to the Element 1 objectives and scope;
- Avoiding duplication with ESA internal activities performed or in the pipeline in other ESA programmes (e.g. TRP, GSP, GSTP, IAP);
- Ensuring completeness and maturity of the preparatory analysis supporting each proposed activity.

The ESA-wide consultation for Element 1 has generated a considerable number of proposals, which have been assessed according to the above guidelines. Proposals rely on desk research, previous outreach activities and external interactions with stakeholders, though obviously limited and not systematic for the large spectrum of themes and areas to be potentially addressed. Therefore the process to generate this first workplan has strongly relied on accumulated knowledge on an ESA-wide basis and the know-how of individuals in the PNT sector.

3. STATUS OF COORDINATION WITH EC AND GSA

This Element 1 workplan for 2017 has been shared with EC and GSA during its preparation in line with the document ‘Coordination between the EC-GSA and ESA on NAVISP Programme Activities’ (ESA/PB-NAV(2016)34). Comments received by EC and GSA have been taken into account and text describing the proposed activities has been updated as the result of the coordination.

It is foreseen that experts of EC and GSA will participate in the implementation of activities as result of the coordination.

4. RATIONALE AND DESCRIPTION OF PROPOSED ACTIVITIES

The Element 1 workplan for 2017 is the first proposition in a new multi-year programmatic framework and, as such, it faces the expectations, opportunities and challenges typical of any novel undertaking.

The 2017 workplan supports the foundations for future innovative PNT developments with the aim of attracting the interest of industries in the wider PNT domain and offering 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 workplan have been grouped according to the following themes:

- 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 initial grouping balances the specific Element 1 objectives, the type of proposals collected according to the guidelines provided, and their degree of maturation.

This grouping may evolve in the future, in particular if the intended outreach and external consultation activities for the preparation of the next workplans provide specific strategic orientations and themes to be addressed and pursued as a priority within Element 1.

4.1. Theme 1: Emerging New Space Based PNT Concepts

Today, a very wide range of applications rely on GNSS for positioning or synchronisation. Together with a growing concern about the resilience of GNSS, the dependency of the global economy on GNSS is becoming a major issue.

In the US, the PNT Advisory Board (PNT AB) provides advice to the White House on the evolution of their national PNT infrastructure (both terrestrial-based and space-based). In the last two years, resilience and dependency on GNSS have been two of the main concerns of the PNT AB.

In parallel to the afore-mentioned institutional concerns on GNSS resilience and dependency, the demand for localisation/synchronisation is increasing in different market segments, with very diverse requirements. With PNT being increasingly considered a utility, users naturally presume that applications will work regardless of where they are and whether they are in a fixed location indoors or on the move outdoors.

Although GNSS is the only global, free, comprehensive technology providing absolute PNT data to users worldwide, its performance has its limitations especially in urban canyons and indoor locations, mainly due to possible link obstructions between satellites and the user and the low power of signals broadcast from a Medium Earth Orbit (MEO) altitude.

Another unique feature of GNSS is that its use is based on passive ranging signals, which is very attractive in terms of scalability cost, especially under benign conditions and secured environments. However, if other infrastructures can be leveraged, then the cost of scalability becomes less relevant. For example, wireless wide area networks such as those used in cellular telecommunications offer signals similar in wavelength and bandwidth to those used by GNSS. At present, approximately 70% of the world's population enjoys 3G, and when considering the world's urban population, this figure increases to 90%. Exploiting this resource also for radionavigation may overcome some of the limitations of GNSS passive ranging without incurring the cost of a dedicated duplicated infrastructure.

Considering the above, alternative PNT methods and solutions have been developed and are expected to further enhance their capabilities to better satisfy the growing market needs for ubiquitous localisation. However, alternative PNT technologies also present their own limitations and, therefore, PNT applications must rely on multiple hybridised techniques that individually may not provide the required performance under all operational conditions.

Supported by this environment and trends, as well as by institutional investments, innovative PNT systems are emerging in the US (ground-based such as Locata and NextNav, or space-based such as Satelles, the latter exploiting Iridium infrastructure to provide PNT signals on a global basis).

The same trends underpin Radio Access Network (RAN) operators' recommendations for the approach on 5G positioning *[Ref.: 3GPP RAN Plenary recommendation for the approach on 5G positioning, New Orleans, September 2016]* which, among other things, defines design targets for commercial PNT use cases in various domains based on hybridisation, scalability, high security and high availability.

In this framework, it appears necessary to develop a proper understanding of the emerging trends and to investigate complementary or alternative PNT technologies aiming to stimulate European industry to reap the benefit from these potential developments.

4.1.1. Complementary PNT infrastructure in LEO

Considering the renewed interest in large LEO constellations, involving major European players and expertise, PNT innovation investigations should focus as a priority on Space-Based PNT in LEO.

An on-going ESA TRP activity on advanced payload for LEO PNT is performing a preliminary investigation of the potential of large constellations, focusing on mission level aspects (use cases, associated ITU frequencies) and understanding the constraints set by the "low cost" approach on a potential PNT payload (hosted payload, dedicated satellite or use of existing signals for PNT services). This TRP study will identify preliminary use cases and concepts at system level, including potential new frequency bands.

There is a need to introduce a thorough system analysis addressing LEO-based alternative PNT benefiting from the increasing number of satellites in LEO. It will address multiple LEO scenarios (e.g. homogeneous or heterogeneous constellations, standalone or disciplined to GNSS for ODTS), the overall system architecture, specific aspects such as ground mission segment, user equipment technologies (assuming the frequency bands might be different from those used by GNSS), and, it will anticipate the technical implications deriving from potential regulatory constraints.

The tasks to be performed will include:

- Consolidation of use cases, and the state-of-the-art in complementary / alternative PNT (mostly, output of PNT AB in the US and information from existing Alternative PNT (APNT) such as NextNav, Locata and Satelles);
- Identification of potential system scenarios relying on LEO constellations: homogeneous systems, and heterogeneous systems;
- Technical investigation of these scenarios, including ground mission segment and user segment aspects;
- Mapping to use cases;
- Conclusions and recommendations for future activities.

The results of the study will provide guidance for planning future activities including system and technological enabler development, testing and proof of concept activities and further studies along the entire value chain

Funding required: €450k	*Duration:* 18 months	*ITT issue:* 4Q 2017

4.1.2. Trusted radionavigation via two-way ranging

Wireless positioning systems based on passive ranging, as used in GNSS today, are very attractive and represent the most pragmatic and cost-beneficial solution for worldwide positioning in benign, secured environments; however, this may no longer be a one-size-fits-all solution for modern radionavigation usage as the need for complementary solutions offering adaptability, reliability and trust is continuously increasing.

The use of two-way ranging for radionavigation offers enhanced robustness against vulnerability to malicious compromise via spoofing or meaconing, which are typically suffered by passive one-way ranging systems such as GNSS.

Rather than operating on the principles of time-of-arrival ranging, a two-way ranging technique can form ranging estimates based on infrastructure interrogation, using cryptographic distance-bounding techniques, thereby firmly asserting the validity of the channel estimates. This scheme derives position estimates based on provably secure observations.

Recent research has proposed a variety of mechanisms for the secure position computation and verification of the positions of wireless devices. Often termed ‘verifiable multilateration’ (VM), these mechanisms are based on the measurements of the time of radio signal propagation, combining conventional multilateration with cryptographic distance bounding, or authenticated ranging. This enables verification of user terminal positions through the interrogation of a set of points in the communication system infrastructure. These schemes require reasonably wideband, duplex wireless communication, which is becoming increasingly available due to the demand for mobile broadband internet access.

There is a need to study the degree to which existing wireless communication networks can be exploited for two-way ranging and position determination, striving to offer a level of adaptability, reliability and trust not currently provided by passive one-way ranging. The activity should provide both a prototype of what is currently possible, and insights into how future communication networks could be optimised to support radionavigation with an emphasis on hybridising the use of the spectrum rather than adding single-purpose signalling.

Exploitation of communication networks, even at the application layer, may patch current GNSS vulnerabilities by utilising secure, bidirectional time-transfer techniques such as Precision Time Protocol (PTP) or Network Time Protocol (NTP). Elaboration of this concept at the physical or data-link layers, using challenge-response mechanisms, might offer further improvements in accuracy. Notably, secure time-transfer and, by extension, secure distance-bounding, is by necessity a two-way technique.

As a stand-alone positioning system, the further features of a bidirectional link can be exploited to enhance availability, efficiency and accuracy. The instantaneous spectrum dedicated to a given two-way link might be tailored. For example, though channel estimation and equalisation is generally used to improve data delivery, the same mechanism represents a means by which a user terminal might command a particular ranging waveform, to better suit its needs, whether narrowband or wideband, or having unimodal or multimodal spectrum. Similarly, the natural frequency separation of the uplink and downlink bands already offers some of the benefits of dual-frequency ranging, in terms of frequency diversity in fading channels.

The proposed activity shall develop a demonstration of secure radionavigation based on verifiable multilateration using existing wireless communication networks (e.g. 3G, LTE, WiFi). The platform will be based on a reconfigurable RF transceiver, complemented with software-defined radio communication functionality. Further evolution of the concept may seek to integrate space-based communication infrastructure (such as a HTS, or Iridium).

Two paradigms will be explored. The use of two-way ranging firstly as an augmentation to GNSS offering sporadic secure anchor points for an otherwise GNSS-based solution; and secondly as a stand-alone system, operating only on two-way ranging.

In order to ensure timeliness and a high probability of success, the activity will focus on leveraging pre-existing infrastructure and consumer off-the-shelf hardware, complemented with novel signal-processing techniques and cryptographic algorithms.

The result of the activity is expected to deliver a functional proof-of-concept of two-way ranging techniques to provide enhanced secure positioning. A prototype will support testing, thereby assessing suitability and limitations of current communication infrastructure, and offering insight into how future generations of communication standards could evolve to enable complementary secure ground or space-based PNT.

The tasks to be performed will include:

- performing feasibility studies and viability analyses for the emergence of a new concept in the PNT world: the development of secure radionavigation;

- contributing to the formulation and implementation of PNT technology innovation: the novel integration of verifiable multilateration with GNSS for trusted positioning;

- proof of concept of promising PNT-based services: the need for a secure radionavigation service demonstrated using verifiable multilateration from terrestrial or space communication infrastructure.

For the above tasks, the use of existing communication infrastructure should ensure relevance and avoid procurement/development delays. A software-defined radio approach should reduce development-cycle times, and reduce the fundamental development cost. Given the repeated success of this approach in the assessment and development of novel GNSS-based techniques in recent years, it seems appropriate to follow a similar approach.
If successful, this test may immediately stimulate further activities. Beyond a basic demonstration, it is likely that further activity in the development of bespoke protocol or signal design will be desired as a contribution to the definition of complementary space-

based PNT. Furthermore, a successful demonstration will naturally lead to the need for a more formal security assessment and the development of adversarial test scenarios, allowing a direct comparison with what is available through concepts of secure-GNSS.

Funding required: €450k	*Duration:* 18 months	*ITT issue:* 3Q 2017

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

In the commercial downstream sector of PNT, space solutions based on GNSS have already permeated all the application markets and created new ones. Already in the 90's, many added-value services (e.g. Fugro's dGPS) were created without any need for public subsidy or incentives, based on genuine commercial strategies and risk capital.

Complementary, there are a number of captive PNT market segments where there is potential to introduce or increase the penetration of space-based PNT and, in particular, GNSS. Typically these pertain to regulated markets in domains requiring a high degree of standardisation managed at institutional level (e.g. IMO for maritime, ERTMS for railways), with high resistance to change and dominated by legacy technology.

The introduction of innovative space-based PNT services in such captive domains often requires public support for their prototyping and demonstration, which often constitute a prerequisite before such services can effectively reach the relevant user communities and their take-up be sustained.

The process to generate proposals for Theme 2 of the Element1 workplan for 2017 has strongly relied on previous outreach activities carried out through existing ESA mechanisms for external interactions with stakeholders in the railway and maritime domains, and through regular coordination with the GSA for the establishment of joint sectorial roadmaps as detailed below.

- **Railway Roadmap**

Interoperability and harmonisation have been key drivers of growth for ERTMS and the European railway signalling supply industry, enabling the development of a single market through economies of scale, and a reduction in certification and testing. The creation of harmonised, transparent rules for railway operators and the railway supply industry in Europe has resulted in non-EU countries following suit with the adoption of ERTMS. The use of GNSS in rail operations has been identified as a key R&D direction for the signalling/ICT market segment as part of a continued investment in innovation to ensure Europe retains its competitive position.

In 2015, the European Railway Agency (ERA) presented the ERTMS evolution roadmap, identifying new capabilities and game-changers for the relevant systems. Amongst these capabilities are satellite-based functions such as virtual balises to be realised using GNSS. In this framework the 'European GNSS in Rail Signalling Roadmap' was developed in cooperation with GSA and in agreement with the European

Railway Agency, UNISIG, industry and stakeholders such as the Shift2Rail Joint Undertaking.

- **Maritime Roadmap**

Maritime transport is currently facing new challenges. These include 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, at the same time, a vessel's environmental impact.

To handle these new challenges, IMO, the International Maritime Organisation is promoting the e-NAV strategy. This strategy foresees the harmonisation and the standardisation of the information to be exchanged by electronics means to enhance berth-to-berth navigation and related services for safety and security at sea and protection of the marine environment.

The IMO NCSR (Navigation, Communication and Search and Rescue) Subgroup established a Correspondence Group in 2016, which worked on the development of Guidelines for Shipborne Position, Navigation and Timing Data Processing.

These IMO guidelines are aimed at defining a high-level framework for the processing and combination of data of multiple systems and sensors in a maritime PNT receiver.

In parallel, RTCM Special Committee 131 was formed with the intention of developing and maintaining appropriate standards, studies, reports, and recommendations for Multi-system Shipborne Navigation Receivers with a view to their use as the basis for eventual IMO, ITU and/or IEC standards or recommendations. RTCM SC-131 plans to define a more detailed standard during 2017 based on the framework provided by the IMO guidelines.

In this context, a joint Maritime GNSS Roadmap has been drawn up and agreed by the European Navigation Maritime Service Providers (NMSP) Technical Group, with the support of ESA and the GSA, notably identifying the main R&D lines of activity to be pursued for GNSS innovation in the context of IMO e-NAV strategy.

4.2.1. System suitability study for train positioning using GNSS in the European Rail Traffic Management System (ERTMS) in 2020

ERTMS is an EU initiative with the aim of improving safety and increasing interoperability of rail transport through a Europe-wide standard for train control and command systems, replacing existing national systems. ERTMS consists of two parts: the European Train Control System (ETCS), an automatic train protection system providing in-cab train control; and GSM-R, a radio system based on GSM for voice and data communications between the train and trackside.

ETCS uses odometry for positioning. The train position confidence interval, which includes the odometer error, is reset when a train passes over a physical balise. They are transponders mounted on the track that communicate with a train passing over it. GNSS is being considered for use in a virtual balise concept, in which it would be used to detect virtual balises. The aim of virtualising the balise transmission system is to reduce wayside infrastructure capital and operating expenditure associated with physical balises, removing the need for (almost) all balises in low-speed / low-density railways. The concept additionally provides increases in reliability due to a decrease in exposure to theft and vandalism.

A key issue for the use of GNSS in a safety critical train control system is the lack of confidence in the residual positioning error. Feared events from the system and local environment contribute to positioning errors that can lead to an increased risk of hazardous misleading information (i.e. position is not bounded by confidence interval). To date, track-area augmentation systems have been considered as a mechanism to provide barriers against system feared events in the railway environment. While SBAS potentially offers the possibility to leverage existing investments made for aviation, it is necessary to determine whether the system is suitable and determine the feasibility of current system allocations for the envisaged ERTMS applications.

The proposed activity focuses on the current generation of SBAS (GPS L1 only), addressing the time frame of 2020.

The objective is to study the suitability of the current generation of SBAS for use in the evolution of the European Rail Traffic Management System (ERTMS) with virtual balise detection using GNSS, confirming the feasibility of current system allocations.
This activity is a necessary enabler on the system side for GNSS to be used in Safety of Life applications in the railway environment. It is expected that the activity will enable the development of innovative downstream applications such as virtual balise detection in ERTMS, leveraging existing investments in SBAS to further improve the value proposition of these applications.

This activity is also in line with the above mentioned E-GNSS in Rail Signalling Roadmap.

The tasks to be performed will include:

- review of inputs from other activities including ERTMS virtual balise concept of operations, apportionments and translation of feared events in the railway environment;
- detailed analysis of the suitability of the current generation of SBAS for use in the ERTMS virtual balise detection application, including applicability of safety barriers to the railway context to mitigate feared events, identifying gaps and issues;

- assessing achievable safety performances with SBAS for ERTMS virtual balise detection applications;
- review of assumptions on the receiver, receiver processing and applicability;
- determining the suitability of the existing safety case for cross-acceptance by railway safety authorities, methodology for building safety case for rail and provide recommendations.

It is expected that the study outcome will support the railway industry in refining safety assumptions and allocations towards GNSS in the ERTMS virtual balise reader subsystem.

Provisions will be taken so that results can also be made available for follow-on R&D activities of EC/GSA.

Funding required: €480k	*Duration:* 18 months	*ITT issue:* 3Q 2017

4.2.2. Multi-system multi-sensor maritime PNT Test Equipment

Current IMO work on guidelines for shipborne PNT data processing will define a high level framework for the processing and combination of data of multiple systems and sensors in a maritime PNT receiver.

The definition of IMO guidelines are expected to significantly progress in the course of 2017. Therefore, it is considered of paramount importance to complement this work with further studies on the combination of different sensors and systems in multi-system maritime PNT receivers in order to characterise and group the achievable performance.

The objectives of the proposed activity are to:

- study methods and techniques for the combined use of multiple systems and sensors in maritime PNT receivers to characterise achievable classes of performance;

- implement an experimental platform for a multi-system multi-sensor maritime PNT receiver testing the combination of methods and techniques studied.

As a baseline, a subset of the sensors and the systems which are, according to IMO SOLAS Convention, mandatory for all cargo and passengers vessels (irrespective of their tonnage) are expected to be considered in possible integration schemes with (augmented) GNSS measurements.

The tasks to be performed will include:

- assessment of IMO Guidelines for Shipborne Position, Navigation and Timing Data Processing;

- assessment of RTCM SC-131 draft standard for multi-system maritime PNT receivers;
- studying, defining and trading off methods and techniques for the combination of data of multiple sensors and multiple systems for each of the parameters identified;
- development of a PNT maritime receiver test platform using different sensors and systems (based on COTS components) in order to test the performance achievable from the different data combination methods and techniques;
- identification of selected nautical tasks and relevant performance parameters to be tested;
- planning and executing experimentation campaigns for the above test cases.

The activity outcome will be instrumental to the development of resilient multi-system multi-sensor maritime PNT receivers and associated standards.

The test platform will constitute an initial tool available to ESA and industry to test future options for maritime PNT standards in still-to-be-regulated domains, such as the navigation of autonomous vessels.

Provisions will be taken so that results and/or test equipment can also be made available for follow-on R&D activities of EC/GSA.

Funding required: €400k	*Duration:* 24 months	*ITT issue:* 3Q 2017

4.2.3. Multipath & interference error mitigation techniques for future maritime e-NAV services

One of the major findings of NMSPs in the elaboration of the MARSOL roadmap has been that the concept of integrity currently applied by the maritime community to comply with IMO Resolutions and related standards largely differs from the approach traditionally used for aviation.

In particular, currently applicable IMO Resolutions and related standards are not prescriptive for the characterisation, modelling and mitigation of local source of errors in the maritime user environment, such as multipath and interference.

Relevant error mitigation techniques are left to the design choices of maritime user equipment manufacturers for implementation into receivers.

It is expected that in order to implement future space-based PNT services according to the IMO e-NAV strategy, it will be necessary to have the local errors modelled and under control, at least for the most critical operations.

Therefore, the study, characterisation, modelling and mitigation of multipath and interference in maritime environments for different operational scenarios are considered of paramount importance and very urgent.

The objectives of the proposed activity are to:

- study and characterise the levels of multipath and interference experienced by PNT receivers, in particular GNSS, in maritime environments;

- derive suitable error models and mitigation techniques to be used in future maritime space-based PNT services.

The tasks to be performed will include:

- review of inputs from other activities related to multipath and interference characterisation with a focus on maritime environments (port, inland waterways, coastal navigation and open sea);

- field campaigns for GNSS data collection in several maritime environments and environmental conditions paying special attention to sea state;

- analysis and characterisation of the collected data and derivation of error models for multipath and interference, with apportionment to different maritime operational scenarios and environmental conditions. In particular, for the multipath error models, this task shall include the identification of suitable techniques to separate the multipath events due to the vessel structure;

- studying and proposing possible mitigation techniques for the identified multipath and interference errors, based on state-of-the-art techniques.

The results of the activity will provide:

- a maritime multipath model that bounds the errors in a variety of operational scenarios (port, inland waterways, coastal and open sea) to be used in support of new PNT space-based services;

- a characterisation of the main interference sources in maritime broken down per operational scenario;

- a set of multipath and interference mitigation techniques to combat the ones identified in the activity.

The definition of proper models for the local sources of error will also pave the way for the use of a number of techniques (e.g. Receiver Autonomous Integrity Algorithms, RAIMs) which will allow the user maritime receiver to autonomously check the consistency of GNSS observations. Once consolidated, the models for local sources of error, together with the associated mitigation techniques, will constitute a key element for the IMO e-Navigation strategy.

Provisions will be taken so that results can also be made available for follow-on R&D activities of EC/GSA.

Funding required: €450k	*Duration:* 24 months	*ITT issue:* 3Q 2017

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

One of the ambition of the Element 1 workplan is to form the basis for future innovative PNT techniques and technologies by attracting the wider interest of space and non-space industry in developing and testing new solutions.

A key ingredient to satisfy this ambition is to put at the disposal of the PNT industry the space know-how developed at ESA, together with tools and facilities which can be made available to interested third parties in order to carry out experiments to prove innovative PNT concepts.

In particular, the opportunity is available for industry to exploit ESA know-how and facilities especially in those areas which are still in transition from professional arena and not yet ready to be exploited by the commercial markets without considerable R&D risk and cost.

An internal across-ESA survey has identified that the Agency can offer, as a start, to support proof of concept activities in the fields of Precise Point Positioning (PPP), Time and Frequency, and science spin-offs. Accordingly, activity proposals have been collected in these domains.

- **The e-GPC Test Facility**

A key role for the proof-of-concept activities proposed for the 2017 Element 1 workplan is played by the Evolution GIOVE Processing Centre (e-GPC) Test Facility, which is briefly described here.

The current Time and Geodesy Verification Facility (TGVF) is based on developments started in the early 2000s, in particular the GSTB-V2 project intended to support the GIOVE satellites mission with a functional, representative Ground Segment. Since then it has evolved to support the qualification of the Galileo Ground Mission Segment and prototype the Time Service Provider (TSP) and Geodetic Reference Service Providers (GRSP) in the formal In-Orbit-Validation and FOC campaigns of the Galileo System. Additionally, the TGVF started to support the IOT campaigns providing orbit and on-board atomic clock characterisation and also support anomaly investigations at System and Satellite level providing in-depth performance and telemetry analyses.

The eGPC, which is the evolution of the TGVF GPC at ESA-ESTEC, offers a unique possibility to prototype and embed new ideas and algorithms that can then be exercised in realistic environments using real data and taking advantage of collocated experts.

4.3.1. Pulsar timescale demonstration

The Galileo System Time (GST) timescale is the cornerstone for the operations and performance of the Galileo System. It should be stable, traceable and always available. The current system time is provided via a physical on-ground clock which limits the performance.

A time scale built with pulsar measurements, i.e. measurements from celestial objects emitting radiation in pulses, would typically be less stable than one built using atomic or optical clocks in the short term, but could be competitive in the very long term (several decades, a period over which atomic clocks will cease to work). An additional advantage is that it would be independent of the clock technology for the generation of the oscillation mechanism (neutron star rotational period as opposed to atomic transitions in Rubidium, Caesium or Hydrogen atoms).

The objective of this activity is to demonstrate the effectiveness of Pulsar Timescale for the generation and monitoring of PNT and GNSS time in general, and of GST in particular. For the latter, the capabilities of the eGPC in terms of access to Galileo Experimental Sensor Stations and data processing capabilities, will be made available. For access to pulsar measurements, a collaboration with a telescope facility will be required.

The Pulsar Time concept application would be demonstrated in the Monitoring and Generation contexts:

- **Monitoring:** A physical clock will be built by using radiotelescope measurements from pulsars which have periods in the milliseconds range, thereby feeding a Galileo Experimental Station (GESS) with 1Hz/10MHz timing input signals, and generating a time scale for GST monitoring purposes. The current approach is that GST is monitored against UTC, which is fed to the GESS. The GESS measurements are then processed in an Orbit Determination and Time Synchronisation filter to determine GST-Pulsar Time.

- **Generation:** In addition, the Pulsar measurements will be incorporated suitably in a “Paper clock” concept implementation, to be made available at the eGPC, along with navigation ranging measurements and possibly Satellite Laser Ranging measurements, thereby generating directly an alternative System Time Scale taking the benefits from Atomic Clocks and Pulsar Clocks simultaneously.

An eGPC Interface Control Document (ICD), Guidelines for Integration and a Developer Manual will be made available to allow SW Configuration Items or Equipment to be connected and integrated in the eGPC.

The results of the demonstration shall provide guidance for planning future activities, ranging from introduction in future PNT systems, to recommendations for tools updates and design methodologies updates.

Funding required: €400k	*Duration:* 18 months	*ITT issue:* 4Q 2017

4.3.2. Cooperative navigation and cloud processing

The current evolution of the Internet of Things (IoT) and Smart Cities, together with the proliferation in the last years of cloud platforms where storage and processing of data can, ideally, be handled on demand, has boosted the appearance of new applications and services in the positioning domain of potential interest for specific use cases.

In particular, the processing in the cloud of GNSS signal snapshots can be of interest when targeting a gain in terms of power consumption or computational burden, offloading the local device or chipset from the full GNSS processing. Moreover, cloud processing allows the application of complex or advanced positioning or navigation solutions that require a high computational burden, or depend on the usage of heavy assistance information (e.g. radio and magnetic fingerprinting maps, detailed 3D maps, etc.). And, of course, new positioning applications or processing techniques can be derived from, or take advantage of, the crowd-sourced and/or cooperative processing of the GNSS signal snapshots and other sensor data gathered by the low-end devices connected to the Internet. Some of the potential applications and techniques based on the concepts of cooperative navigation and cloud processing have undergone preliminary studies. Nevertheless, the maturity of the topic is relatively low, with few applications covered so far, and multiple techniques and applications of high potential interest, still to be studied and assess in detail.

Following on from previous studies on Peer-to-Peer which have been performed in the ESA TRP program, the proposed activity shall study and develop new innovative positioning and navigation techniques relying on the exploitation of crowd-sourced data and GNSS signal snapshots from low-end sensors or devices connected to the Internet, enabled by high-data-rate and low-latency wireless communication networks, and based on the cooperative and cloud-processing of the data.

The tasks to be performed will include:

- study, design and performance assessment of snapshot-based and cooperative cloud-processing of GNSS signals based on signal snapshots grabbed with low-end devices and other crowd-sourced data of interest for different use cases;

- studying potential crowd-sourced data and/or signals of potential interest to be exploited for the improvement of the positioning solution (e.g., in terms of sensitivity, robustness, accuracy) or of interest to generate assistance information to be exploited later in the cloud, like fingerprinting maps (of any type);

- study and design a flexible architecture for a concept demonstrator based on the exploitation in the cloud of the signal snapshots and data gathered by a network of sensors or devices, based on existing wireless communications infrastructures and commercial cloud processing platforms;

- implementation and preliminary demonstration of the proposed techniques and cloud architectures, and quantification of the benefits provided for different use cases of interest;

- mapping of technological solutions/enablers and use cases, and derivation of conclusions and recommendations for future activities.

The results of the study will provide guidance for planning future activities including further studies, testing and proof of concept activities possibly integrated with follow-on tests from other activities

Provisions will be taken so that results and/or test equipment can also be made available for follow-on R&D activities of EC/GSA.

Funding required: €400k	*Duration:* 12 months	*ITT issue:* 3Q 2017

4.3.3. Weather monitoring based on collaborative crowdsourcing

The use of GNSS observations from reference stations for the derivation of Integrated Water Vapour and assimilated into Numerical Weather Prediction Models has been demonstrated and is in use for weather prediction. With the emergence of multi-constellation and multi-frequency GNSS the possibilities of weather prediction with GNSS are increasing dramatically.

Furthermore, with the emergence of powerful handheld GNSS receivers, with multi-frequency capability and access to both code and carrier-phase observables, the possibility of GNSS weather monitoring with collaborative crowdsourcing is emerging as a very promising field.

This activity, therefore, is needed in order to assess the use of GNSS carrier-phase and multi-sensor localisation in smartphones and similar devices for monitoring extreme weather and supporting weather forecasting. Furthermore, the development and testing of a complete end-to-end demonstrator of this innovative concept is hereby proposed to prove the concept.

Some of the innovation aspects proposed are the following:

- use of low-quality sensors (namely fitted in handheld devices) but in a very large number, allowing a very large sample of observations and spatial resolution accuracy;

- maximising the exploitation of GNSS data for weather forecasting, in particular the use of code and carrier-phase observables (future chipsets will provide these new observables for multi-constellation, driven by the Android version providing those), and preferably dual-frequency (new feature for handheld receivers), in particular for the derivation of integrated water vapour (IWV) measurements for assimilation in weather prediction models (this requires a high-precision processing approach). The use of this observable has not yet been exploited because they were not available until very recently.

The tasks to be performed will include:

- a thorough assessment of all existing GNSS technologies and GNSS data processing in support of this proposed weather monitoring (e.g. determining water vapour content);
- understanding of the potential of other weather-sensitive sensors built in to mobile phones (existing or that could be integrated);
- assessing the exploitation of mobile weather sensitive geo-location and collaborative crowdsourcing for weather monitoring and forecasting;
- an end-to-end representative demonstrator.

A natural follow-on to this activity could include the setting up of an operational version of the proposed weather monitoring service and its actual commercialisation.

It is to be noted that this proposed activity was identified and supported by ESA's GNSS Science Advisory Committee (GSAC), notably during the dedicated GNSS Science Workshop held at ESAC in July 2016, which was held to support ESA in the identification of future areas of interest in the scientific field of GNSS.

Funding required: €300k	*Duration:* 12 months	*ITT issue:* 3Q 2017

4.3.4. Space GNSS receiver for in-orbit demonstration of Precise Point Positioning (PPP)

The current approach for precise orbit determination (POD) with GNSS is based on the collection of code and carrier phase measurements from space GNSS receivers and computation of precise orbit with ground post-processing tools. This approach is currently adopted in multiple missions (*e.g.* Earth Observation LEO missions), but it has the principal limitation of not being in real time. This limitation is currently not a limiting factor for Earth observation missions, but is definitely a problem for advanced concepts such as formation flying, autonomous docking and rendezvous and high autonomy of spacecraft.

The availability of real-time on-board centimetre-level position accuracy in space would open the door to myriad applications, one clear market being the envisaged LEO constellations as e.g. OneWeb.

Centimetre-level accuracy is currently achievable on ground via RTK and PPP. While RTK relies on the corrections provided by a ground station in proximity to the user terminal, PPP is based on the dissemination of precise orbit and clock information for GNSS satellites via geostationary satellites (current approach for the majority of the commercial providers of PPP services). This approach can be adopted in space. In addition, the space usage has the great advantage of being bounded by a relative stable dynamic (orbital dynamic) with respect to a ground user whose dynamic cannot be easily predicted. Finally, the troposphere does not impact space users and the effect of the ionosphere can be removed with dual frequency or through accurate modelling, so potentially the accuracy that can be achieved is higher than the ground users.

The concept of real-time high-precision PPP in space for POD is novel and it would be of great interest to demonstrate its applicability for space users through:

- analysis of the new concept of real-time POD algorithms using PPP techniques and both kinematic and dynamic sequential Kalman filter approaches (adopting the more advanced force models for orbit propagation);
- design and development of a complete receiver ready for an IOD (In Orbit Demonstration) cubesat-like mission in order to prove the concept in space;
- identification of potential space mission of opportunities for IOD;
- supporting the demonstration of Space Service Volume (SSV) for European GNSS.

The tasks to be performed will include:

- conceptual analysis and adaptation of PPP techniques to POD real-time space users;
- receiver design encompassing identification of hardware platform capable to perform GNSS processing of dual frequency Galileo and GPS signals and assessment of characterisation aspects needed for POD (e.g. antenna phase centre characterisation);
- receiver development including hardware testing for integration of all hardware components in a cubesat-size board;
- receiver testing with real signals;
- identification of IOD missions that would allow in-space proof of concept;
- demonstration of Space Service Volume (SSV) for European GNSS.

The development of this receiver will allow proof of concept for cubesat missions (which are relatively more accessible than other bigger missions). For use in typical ESA missions (*e.g.* from microsatellites to standard LEO spacecraft) further activities will have to be performed to achieve EQM level, based on standard ECSS requirements.

Funding required: €400k	*Duration:* 15 months	*ITT issue:* 3Q 2017

4.3.5. Low-cost GNSS antenna arrays for improved performance, anti-spoofing, and meaconing and interference mitigation

GNSS antennas in user receiver devices are relatively simple. More sophisticated antennas could be designed to bring spatial diversity and gain, and to be more resistant against spoofing and meaconing, as well as reducing other sources of interference, for instance by nulling the gain of the antenna in this direction. Using arrays of dynamic elements (phase/gain controlled) would also make it possible to adapt to the geometry of GNSS satellites in space, and improve receiver performance.

Today, the concept of beamforming for GNSS antenna remains a high-grade solution for very specialised, niche markets (e.g. defence, military aircraft, etc.) where resources and cost are less of an issue. The challenge to make it a viable option for wider or even mass markets, like railway, automotive, or handheld, requires application-specific enablers allowing cost, space, accommodation constraint reduction and optimisation of performance and reliability.

Solutions for cars, in particular, will be more challenging due to the tighter integration with the myriad of other RF sensors available to the self-driving car and different vehicle dynamics. Automotive solutions will also need to aim for higher volume and much lower cost.

The objective of the proposed activity is to design, simulate and prototype an enhanced multi-element antenna for automotive users able to mitigate different types of interference, especially targeting Advanced Driver Assistance Systems (ADAS).

The activity will focus on antenna arrays for the automotive use case, where antenna elements can be spread a few metres apart. The objective is to improve the performance optimising accommodation, form factor and number of low cost elements, together with dynamic beamforming algorithms able to discriminate between wanted signals (from satellites) and unwanted signals (interference or spoofing).

The tasks to be performed will include:

- analysis and consolidation of application-specific requirements taking into account performance objectives envisaged in the automotive sector for ADAS, relevant standards, and outcome of similar activities;

- review of state-of-the-art techniques and technologies for low-cost antenna arrays (not limited to GNSS), and selection of the most promising ones suitable for the activity as a starting point. Re-use of COTS elements is encouraged;

- trade off/selection of the antenna architecture and high-level design (e.g. geometry, phase/gain control, front end, beamforming algorithms);

- design of the antenna elements with simulations, breadboarding, and testing;

- design and development of the antenna array system and of the beamforming algorithms. Proof-of-concept and testing.

The results of the study will provide guidance for planning future activities including further enhancements, and identification of other possible applications (e.g. UAV and robotics).
Provisions will be taken so that results and/or test equipment can also be made available for follow-on R&D activities of EC/GSA.

Funding required: €400k	*Duration:* 24 months	*ITT issue:* 3Q 2017

5. SUMMARY

Activity Funding & Duration	Funding Required (€k)	Duration (months)
Theme 1		
Complementary PNT Infrastructure in LEO	450	18
Trusted Radionavigation via Two-Way Ranging	450	18
Theme 2		
System Suitability Study for Train Positioning Using GNSS in ERTMS in 2020	480	18
Multi-System Multi-Sensor Maritime PNT Test Equipment	400	24
Multipath & Interference Error Mitigation Techniques for Future Maritime e-NAV Services	450	24
Theme 3		
Pulsar Timescale Demonstration	400	18
Cooperative Navigation and Cloud Processing ~~*~~	400	12
Weather Monitoring Based on Collaborative Crowdsourcing ~~*~~	300	12
Space GNSS Receiver for In-Orbit Demonstration of PPP	400	15
Low-Cost GNSS Antenna Arrays for Improved Performance, Anti-Spoofing, and Meaconing and Interference Mitigation ~~*~~	400	24
Total	4.130	

~~* C(3): Activity restricted to SMEs & R&D organisations, preferably in cooperation~~

~~(ESA/IPC(2005)87, rev4)~~

Activity Schedule	2017				2018				2019			
Theme 1												
Complementary PNT Infrastructure in LEO					■	■	■	■	■	■		
Trusted Radionavigation via Two-Way Ranging				■	■	■	■	■	■			
Theme 2												
System Suitability Study for Train Positioning Using GNSS in ERTMS in 2020				■	■	■	■	■	■			
Multi-System Multi-Sensor Maritime PNT Test Equipment				■	■	■	■	■	■	■	■	
Multipath & Interference Error Mitigation Techniques for Future Maritime e-NAV Services				■	■	■	■	■	■	■	■	
Theme 3												
Pulsar Timescale Demonstration					■	■	■	■	■	■		
Cooperative Navigation and Cloud Processing				■	■	■	■					
Weather Monitoring Based on Collaborative Crowdsourcing				■	■	■	■					
Space GNSS Receiver for In-Orbit Demonstration of PPP				■	■	■	■	■				
Low-Cost GNSS Antenna Arrays for Improved Performance, Anti-Spoofing, and Meaconing and Interference Mitigation				■	■	■	■	■	■	■	■	