INSPIRe

D0.6 - Executive Summary Report

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EXECUTIVE SUMMARY REPORT

Integrity of navigation information is a key need and enabler for the current and future maritime sector

According to the Centre for Economics and Business Research, in 2019, the maritime sector contributed an estimated £55.5 billion in direct turnover to the UK economy [1], across activities including shipping, ports, renewable energy, aquaculture, and leisure.

Maritime users are heavily reliant on trustworthy (i.e. high-integrity) navigation information to conduct safe and compliant operations. The need for trustworthy navigation information is becoming ever more vital as maritime traffic grows, the sea space becomes ever more complex, and as vessels become more autonomous.

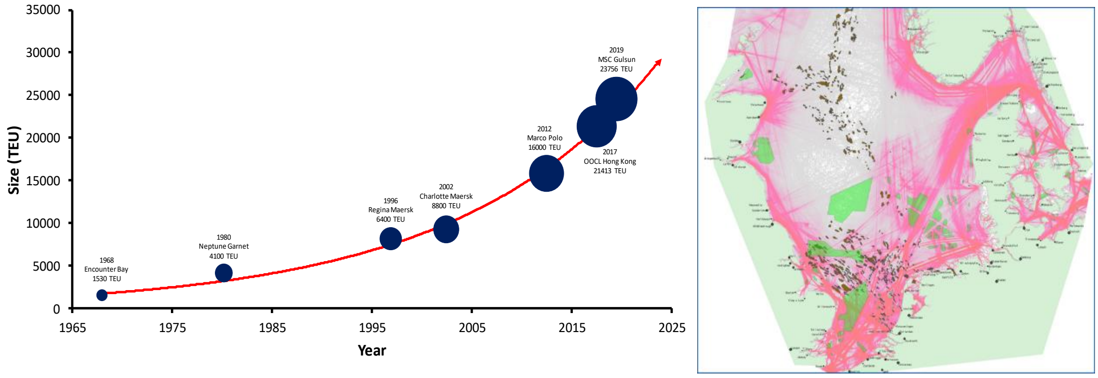

Figure 1: Right: Maritime AIS data demonstrating traffic density and the complex navigational environment in the North Sea. Left: Increasing size of container ships Source: MarRINav

A maritime user's navigation system usually relies on satellite derived GNSS signals as the primary source of positioning for navigation. GNSS is often supplemented by dead reckoning navigation systems such as inertial navigation, but this is subject to compounding drift errors so is not a sufficient fallback over sustained periods of time. Additionally, GNSS signals are also vulnerable to threats and faults, for example due to interference, satellite errors, atmospheric conditions and intentional disruption. This can deny the user access to satellite signals meaning the vessel is unable to determine its true position, or lead to hazardously misleading information (HMI) being received by the user which can result in a risk to operations.

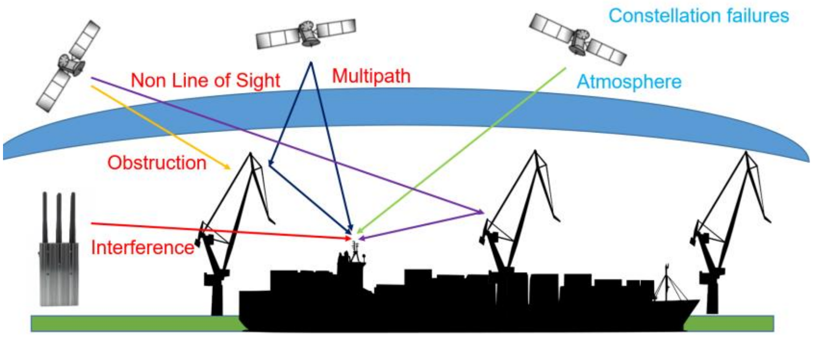

Figure 2: Common threats and faults which impact a user's GNSS positioning solution

In the maritime sector, the performance requirements for a vessel's navigation system are specified by the IMO and the IEC. The relevant standards stipulate accuracy and availability requirements for a GNSS navigation system, however they are not consistent or thorough in the specification of integrity. This results in an inconsistent and limited application of integrity monitoring across vessels globally, which increases risks for the mariner and compromises the development of future use cases which rely on high-integrity navigation.

The INSPIRe (Integrated Navigation System-of-Systems Position, Navigation, and Timing (PNT) Integrity for Resilience) project has considered several use cases with a high mission criticality, where the impact of signal interruption is particularly critical, both for current operations and for future operations. These include:

- Operations with high traffic density and large vessel sizes,
- Offshore energy – Oil, Gas and renewables,
- Aquaculture,
- Ship-to-ship transfers,
- Fisheries,
- Bio-economy,
- Carbon Capture and Storage (CCS), and
- Ocean energy.

The economic loss of GNSS for a 7-day period is estimated to cost the UK maritime economy over £1.5 billion [2], and the loss of positioning, navigation and timing (PNT) services is considered a risk of significant impact in the UK National Risk Register 2023 [3].

The ability to determine the validity of positioning information and the resulting navigation solution will be crucial to achieving resilient PNT capability as a Critical National Infrastructure (CNI) in accordance with the aims of the UK's Space Based Positioning, Navigation and Timing Programme (SBPP) [4].

Significant improvement to integrity monitoring capabilities for maritime navigation is therefore urgent to provide the level of performance and safety guarantee required for current and future maritime operations, and as a crucial step towards resilient PNT.

INSPIRe has developed technical solutions which monitor the integrity of GNSS positioning information to alert the user when there is a problem

INSPIRe, funded by ESA under NAVISP Element III, has investigated and developed integrity monitoring approaches which provide means for users to monitor the integrity of their GNSS derived positioning information.

The project assembled industry leading R&D and engineering expertise from across the maritime and PNT sectors to develop eight next-generation integrity solutions aligned with the needs of the maritime sector. Each solution represents advancements in integrity monitoring capability. The solutions complement each other and are designed to be integrated as a system-of-systems integrity architecture. They aim to alert the user when there is a problem with the navigation system to ensure trust, and form part of a wider solution that is required to address the need for an increasingly resilient PNT capability.

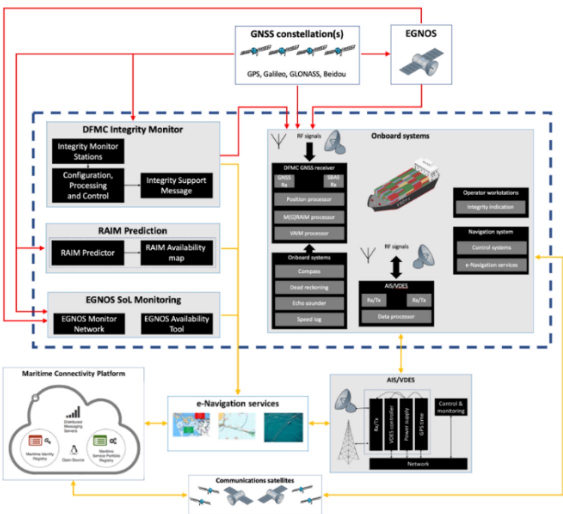

Figure 3: Conceptual integrity architecture incorporating the solutions developed within INSPIRe

To ensure a consistent development approach to the integrity solutions, the project developed a set of project requirements. These requirements represent both the current needs of mariners and future developing needs which will become increasingly relevant as future use cases are adopted. The requirements were developed considering key maritime use cases, and the results of previous studies including the MarRINav project [5]. They were validated with maritime and PNT stakeholder communities to ensure that they provided a representative requirement set. Each integrity solution developed by the project has been validated against these project requirements throughout the development process

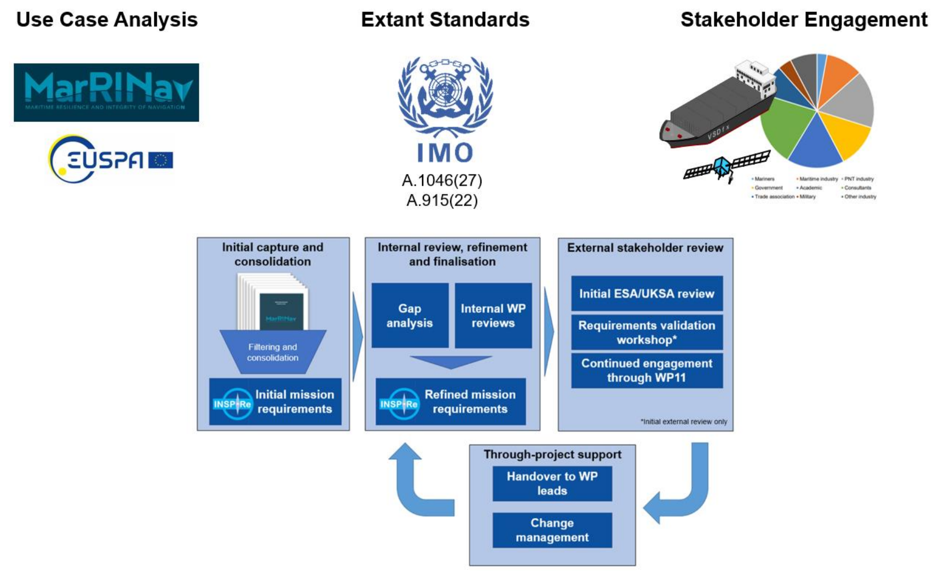

Figure 4: Summary of the requirements development process adopted in INPSIRe, completed in consultation with industry experts from the maritime and PNT communities

Ship-borne receiver algorithms at the user-level provide integrity monitoring onboard the vessel

At the user-level (consisting of ship-borne algorithms within users' receivers) four integrity monitoring solutions have been developed with each providing advancing capability:

- MG-RAIM (Maritime General Receiver Autonomous Integrity Monitoring) provides a simple to implement algorithmic approach which requires minimal changes to receivers, providing improved user-level integrity aligned with existing maritime navigation performance requirements.
- M-RAIM (Maritime Receiver Autonomous Integrity Monitoring) adapts the aviation-derived ARAIM approach to the horizontal domain to increase its suitability for maritime users, considering future receiver equipment and looking to future navigation performance requirements to provide integrity monitoring which can be configured to the mariner's environment.
- VAIM (Vessel Autonomous Integrity Monitoring) integrates the MG-RAIM and M-RAIM approaches with dead reckoning navigation to provide an additional layer of integrity monitoring, further improving the integrity monitoring capabilities.
- Crowd-sourcing methods are considered to demonstrate how signals of opportunity such as ranging sensors and sharing of PNT information between vessels can further benefit integrity monitoring.

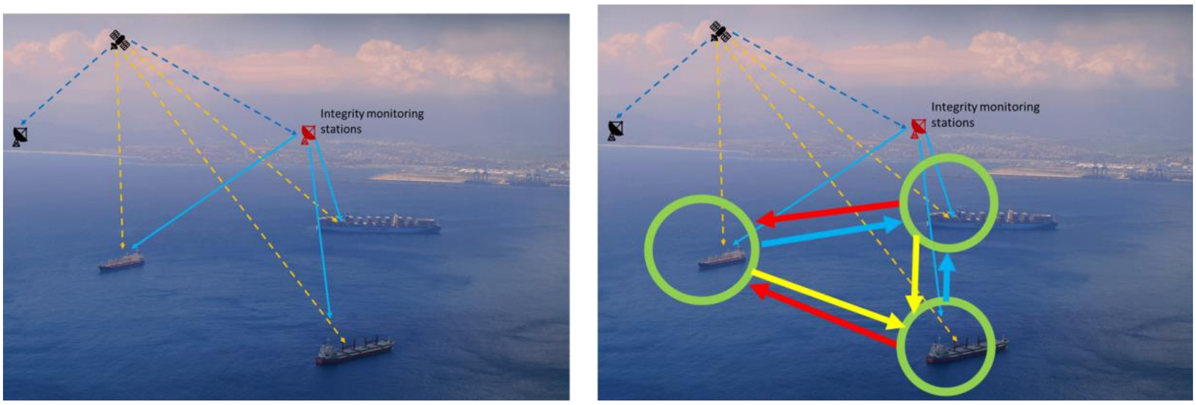

Figure 5: Illustration of crowd-sourced integrity monitoring concept at the user-level

These user-level solutions provide algorithms with increasing integrity monitoring performance. They aim to support the technical development of standards which can in turn support a widespread adoption of integrity in maritime both nationally and internationally, for current use cases and for future systems. Specifically, the results of this project provide validated algorithms, identify the development activities required to refine the solutions to the necessary maturity for implementation in standards, and demonstrate the potential performance of such solutions.

These solutions provide algorithms that can be implemented immediately in receivers where mission criticality is low (recognising that further development is required to fully mature and assure the solutions for critical applications). For example, the leisure sector provides a sector ripe for implementation where innovations can be quickly implemented. Such early deployment will support the ongoing education of the benefits of integrity monitoring and provide example implementations that can used to further validate the integrity monitoring approaches. This will then enable improved assurance of GNSS information for specialised use cases to allow GNSS to be utilised in scenarios with high mission criticality

System-level concepts provide supporting infrastructure which can alert users to threats and faults in the satellite constellations

At the system-level, two integrity monitoring concepts have been developed which utilise shore-based monitoring infrastructure:

- The DFMC Integrity Monitor provides integrity monitoring of GNSS constellations using a network of receiver stations across the UK landmass to identify integrity status of signals and disseminate integrity flags to users within the UK Exclusive Economic Zone (EEZ).
- The EGNOS Monitor provides a means to assure the use of the European SBAS's Safety of Life service for users within the UK EEZ.

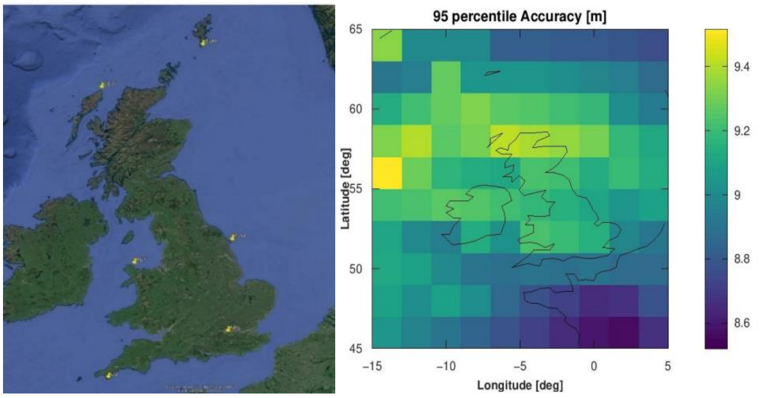

Figure 6 Illustration of monitoring network deployment and availability tool for the EGNOS monitor

These system-level solutions provide candidate systems which can be implemented to support a national resilient PNT capability within the UK EEZ. The results of this project demonstrate the potential performance of the systems, but acknowledge that ongoing development, and investigation of user needs, liability provision and safety assurance will be required to implement the systems to the required level of guarantee.

Supporting concepts demonstrate further ways integrity can be implemented to support the user

Two additional supporting solutions were developed within the project:

- RAIM Performance Prediction Tool provides a supporting tool to enable users to predict the integrity and performance of their GNSS information over a voyage when implementing MG-RAIM or M-RAIM.
- Novel Error Characterisation techniques were investigated to demonstrate means of better characterising errors in integrity monitoring algorithms to improve performance.

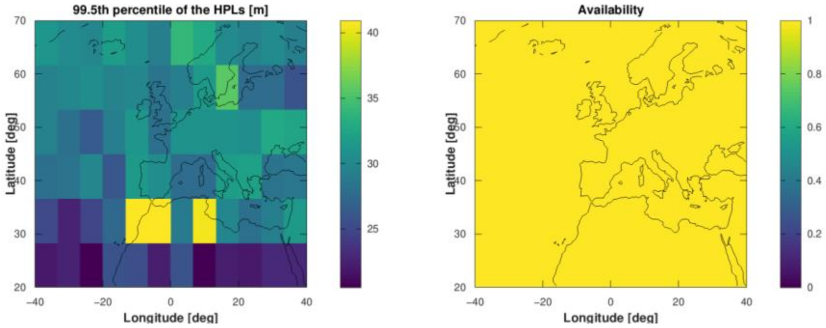

Figure 7: Sample outputs of the RAIM Performance Prediction Tool, demonstrating Protection Level and Availability predictions.

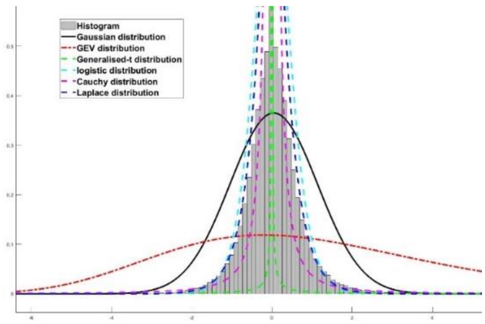

Figure 8: Investigation of error distributions demonstrating algorithmic modelling of threats and faults.

The RAIM Performance Prediction tool also provides potential for immediate benefit. The tool provides a concept which can be implemented in voyage planning software to enable users to plan their mission with knowledge of the predicted integrity of their GNSS solution over their voyage.

The Error Characterisation research presents an opportunity to further develop integrity monitoring to better model complex threats and faults at both the user-level and the system-level, improving detection capability.

A co-ordinated approach to development is required to ensure that integrity can be implemented whilst providing the greatest benefits to users

The results of the project demonstrate some of the key technical capabilities available today across both user-level and system-levels, representing solutions with maturities of Technology Readiness Level (TRL) between 2 and 4, according to the ESA definition of TRL [6].

An indicative roadmap has been developed to illustrate potential timelines for implementing the integrity architecture considered by the project, including consideration of the interactions required between the user-level and the system-level.

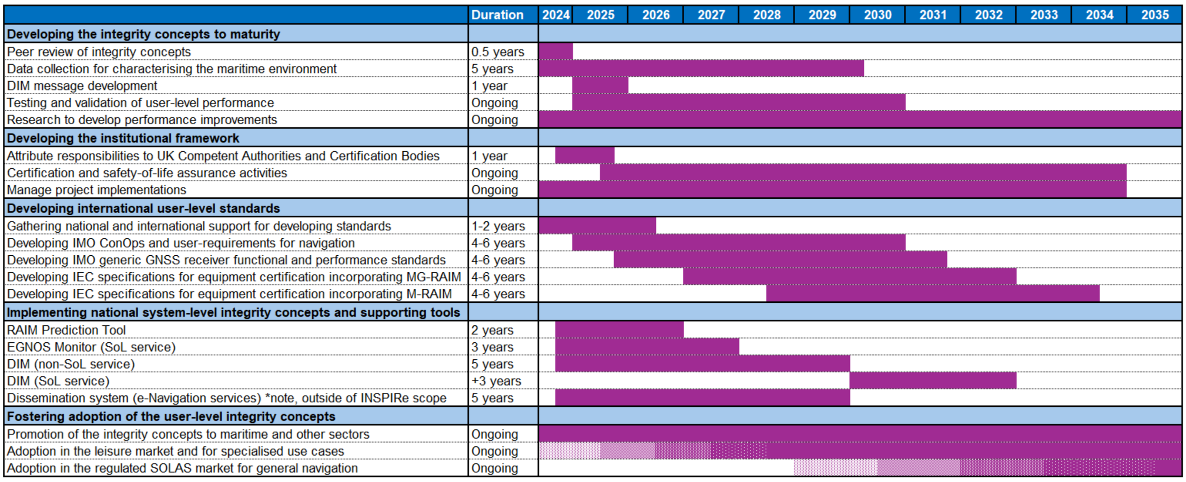

Figure 9: Indicative roadmap for the implementation of the integrity solutions over an ongoing period

The roadmap identifies that parallel development of the user-level and system-level is required, both at a technical research and development level to mature, improve and implement the solutions, but also centrally to ensure thorough capture of user needs and to ensure that development of solutions is co-ordinated and provides the greatest benefit to users.

Key to achieving the roadmap is therefore buy-in for the need for integrity, both from users and government, to ensure that technical solutions meet the needs of users, the required institutional framework is put in place and that practical and beneficial international standards are developed.

The Cost-Benefit Analysis demonstrates that substantial benefits can be realised in the maritime sector

The functionality and performance currently demonstrated by INSPIRe's integrity architecture shows the potential to provide net socio-economic benefits of up to £2.2bn over a 20-year period when applied to a selection of critical current and developing use cases in the maritime sector. The benefit is achieved through alerting the user to an integrity failure when threats and faults are present in the GNSS solution such that they can mitigate the hazardous scenario.

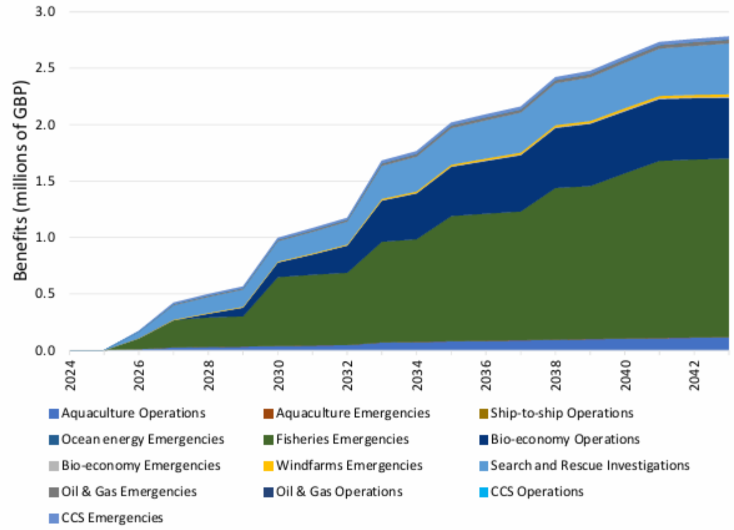

Figure 10 Estimated benefits by sector

The implementation of the integrity architecture represents a benefit-cost ratio of 7:1 when scaled nationally and when considering the costs associated with implementing the system-level solutions. There is significant potential to further expand this benefit by providing integrity at greater levels of accuracy performance – delivered through ongoing development of the technical solutions.

INSPIRe has shown how integrity can be achieved, but realising the benefits requires ongoing collaboration and development

Overall, INSPIRe has investigated and validated a number of technical solutions for monitoring the integrity of a mariner's GNSS solution. These solutions can be integrated to provide an integrity monitoring architecture, and represent part of the ongoing technical development required to achieve a resilient PNT architecture that is fit for a future maritime sector.

Immediate benefits can be realised for users, especially when considering the potential of the non-regulated maritime sector to validate and mature use cases, and to foster development of the technical solutions themselves.

Over the longer-term, integrity needs to be adopted through international standards to ensure a widespread and international adoption of the technologies, and hence enable improvements in safety and enable mission critical use cases which have a high dependence on trustworthy navigation. The results of INSPIRe provide an initial framework for this, however continued and coordinated development of technical solutions, standards and system-level components will be required to achieve the required level of capability to support a resilient PNT capability.

To progress towards a widespread implementation of integrity both nationally and internationally in maritime navigation, three key future recommendations are identified:

- The maritime RF environment needs to be characterised to understand the effects of local errors for user receivers. This will enable user-level solutions to be configured, further developed, and validated in a representative maritime environment to establish integrity risk requirements, and hence representative assurance of the user-level solutions. This activity will require long-term data collection on a variety of vessels in various environments.
- International standards need to be drafted and developed to align how integrity is considered and adopted in maritime standards. This will require education of the need for integrity to mariners, extensive use case analysis with maritime users to

identify the necessary requirements in detail, a systems approach for integration with a wider resilient PNT architecture, and adoption within the IMO and IEC.

- Continued technical development of both the user-level and system-level solutions is required, both to mature the solutions and to improve their integrity monitoring capabilities to expand the applicable use cases. Several key opportunities for development are identified within this project; for example, through ongoing validation using extended data, by utilising crowdsourcing concepts and by integrating adaptive error characterisation techniques within the algorithms.

However, to maximise the benefits of GNSS integrity, solutions need to be developed with cross sector collaboration. This will enable solutions to be developed which consider the needs of all users and enable areas of commonality to be identified in both the development and assurance of solutions - ensuring the solutions can provide benefits to all GNSS users.

REFERENCES

Ref No.	Description
[1]	Centre for Economics and Business Research (2022). 'The economic contribution of the UK Maritime Sector'. Accessible at: *Cebr-UK-Maritime-Sector-2022_06.pdf (safety4sea.com)*
[2]	The economic impact on the UK of a disruption to GNSS – Executive Summary. Published 18 October 2023. Accessible at *www.gov.uk*.
[3]	UK Government National Risk Register 2023. Published 3 August 2023. Accessible at *www.gov.uk*.
[4]	The Space Based Positioning, Navigation and Timing Programme (SBPP). Accessible at *www.gov.uk*
[5]	Maritime Integrity and Resilience for Navigation project. Published 2020. Accessible at *www.marrinav.com*.
[6]	European Space Agency definition of TRL. Accessible at *www.esa.int*.

LIST OF PROJECT DOCUMENTS

Ref No.	Description
[7]	D1.1 Systems Engineering support report
[8]	Data 1.2 Test and validation data for systems engineering report
[9]	D2.1 Algorithm documentation (GPSM(S)RAIM) report
[10]	Alg2.1 Algorithm documentation (GPS M(G)RAIM)
[11]	Data2.1 Test and validation data for Alg 2.1
[12]	Spec2.1 Functional and software design and test specifications (GPS M(G)RAIM)
[13]	D3.1 Algorithm development (DFMC M(G)RAIM) report
[14]	Alg3.1 Algorithm documentation (DFMC M(G)RAIM) including design for DFMC MRAIM and MGRAIM algorithms
[15]	Data 3.1 Test and validation data for Alg3.1
[16]	Spec3.1 Functional and software design and test specifications (DFMC M(G)RAIM)
[17]	D4.1 Algorithm documentation (DFMC & DR VAIM) report
[18]	Alg4.1 Algorithm documentation (DFMC & DR VAIM)
[19]	Data4.1 Test and validation data for Alg4.1
[20]	Spec4.1 Functional and software design and test specifications (DFMC & DR VAIM)
[21]	D5.1 EGNOS Prototype Monitoring station report
[22]	D6.1 RAIM Prototype report
[23]	D7.1 DFMC Integrity Monitoring Report
[24]	D8.1 Crowd-sourced inputs into DFMC integrity report
[25]	Spec 8.1 Functional software design and test specification
[26]	D9.1 Infrastructure & CBA Review (ICR) Documentation
[27]	D10.1 Outline integrity system design, development & exploitation plan
[28]	D11.1 Stakeholder engagement package
[29]	D0.2 Mid Term Review (MTR) documentation
[30]	D0.3 Technical Data Package
[31]	D0.4 Contract Closure Documentation
[32]	D0.5 Final Report
[33]	D0.6 Executive Summary Report
[34]	D0.7 Final Presentation