ARAIMTOO FINAL REPORT

ARAIMTOO

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DOCUMENT STATUS SHEET

Version	Date	Pages	Changes
1.0	18/07/2022	27	First version delivered for Final Review
1.1	20/09/2022	52	Version delivered implementing FR RIDS
1.2	03/10/2022	51	Version delivered implementing FR CO RIDS

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1. INTRODUCTION

1.1. PURPOSE

The purpose of this document is to provide the Final Report of ARAIMTOO project, including the status at the end of the project and a technical Executive Summary. This document serves as input for ARAIMTOO FR meeting.

Thus, this Final Report includes the Technical, Management and Contractual status of the project.

1.2. SCOPE

The present document has been organized as follows:

- Chapter 1. Gives an introduction to the document, including purpose and scope of the plan.
- Chapter 2. Provides the list of project applicable and reference documents.
- Chapter 3. Provides the list of terms, definitions and acronyms used throughout the plan.
- Chapter 4. Provides a technical Executive Summary of the project
- Chapter 5. Is devoted to the technical project status
- Chapter 6. Is devoted to the management status
- Chapter 7. Is related with contractual aspects
- Chapter 8. Provides the risks status of the project
- Chapter 9. Gives the updated travel plan

1.3. DOCUMENT CONTRIBUTIONS

Next table provides the details concerning the contributions to this document.

Section	Company
All sections	GMV with contributions from partners

Table 1-1: Document Contributions

2. REFERENCES

2.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X]:

Table 2-1: Applicable documents.

Ref.	Title	Code	Version	Date
[AD.1]	ARAIMTOO Contract	DEFIS/2020/OP/0009	N/A	22/06/2021
[AD.2]	Advanced Receiver Autonomous Integrity Monitoring for applications beyond Aviation sector Tender Specifications	Call For Tender No DEFIS/2020/OP/0009	N/A	15/12/2020
[AD.3]	ARAIMTOO Proposal	GMV 10058/21 V1/21	N/A	26/02/2021

The following documents, although not part of this document, amplify or clarify its contents. Reference documents are those not applicable and referenced within this document. They are referenced in this document in the form [RD.X]:

Table 2-2: Reference documents.

Ref.	Title	Code	Version	Date

3. TERMS, DEFINITIONS AND ABBREVIATED TERMS

3.1. DEFINITIONS

Concepts and terms used in this document and needing a definition are included in the following table:

Table 3-1 Definitions

Concept / Term	Definition

3.2. ACRONYMS

Acronyms used in this document and needing a definition are included in the following table:

Table 3-2 Acronyms

Acronym	Definition
AD	Autonomous Driving
ADAS	Advanced Driver Assistance Systems
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
ARAIMTOO	ARAIM for Applications Beyond Aviation
CFI	Customer Furnished Items
DFMC	Dual Frequency and Multi-Constellation
EC	European Commission
EGNOS	European Geostationary Navigation Overlay Service
ESA	European Space Agency
EUROCAE	European Organisation for Civil Aviation Equipment
FR	Final Review
GBAS	Ground Based Augmentation System
GEO	Geostationary
GIS	Geographic Information System
GIVE	Grid Ionospheric Vertical Error
GNSS	Global Navigation Satellite System
GSA	European GNSS Agency
IMO	International Maritime Organization
IMU	Inertial Measurement Unit
ISM	Integrity Support Message
ITT	Invitation To Tender
KOM	Kick-Off Meeting
KPI	Key Performance Indicator
LBS	Location Based Service
MEO	Medium Earth Orbit
MSC	Maritime Safety Committee
NLOS	Non Line Of Sight
PM	Progress Meeting
PNT	Position Navigation and Timing
PPP	Precise Point Positioning
RAIM	Receiver Autonomous Integrity Monitoring
RTCA	Radio Technical Commission for Aeronautics

Acronym	Definition
RTK	Real Time Kinematics
SBAS	Space Based Augmentation System
SDD	Service Definition Document
SoL	Safety of Life
SOLAS	Safety Of Life At Sea
SPS	Standard Positioning Service
TN	Technical Note
TTA	Time To Alert
UAV	Unmanned Aerial Vehicle
UDRE	User Differential Range Error
WP	Work Package

4. TECHNICAL EXECUTIVE SUMMARY

The Advanced Receiver Autonomous Integrity Monitoring (ARAIM) is an evolution of the Receiver Autonomous Integrity Monitoring (RAIM) integrity technique recently developed to protect multi-constellation users by means of robust user algorithms. ARAIM includes an offline ground monitoring architecture, which provides updates on the nominal performance and fault rates of multiple constellations. This integrity data is contained in the Integrity Support Message (ISM) that is generated by an offline ground monitoring network and is provided to the airborne fleet through the GNSS signals.

The ARAIM concept was designed initially to serve the Aviation sector. Nevertheless, the concept can be used by other user sectors, in particular, the markets comprising critical applications with a need of Global Navigation Satellite System (GNSS) integrity capability. A wide range of applications, and specially safety critical applications, can in principle take advantage of this service, or a modified version of it, since they have similar and even more demanding requirements than aviation users. Rail, Maritime, Road, Unmanned Aerial Vehicles (UAVs), Location Based Services (LBS) and Space User Sectors are analysed as potential target sectors in this work.

In ARAIMTOO Project, non-aviation sectors, applications and the use of other GNSS integrity technologies are analysed exploring the user needs in order to identify potential applications for the penetration of ARAIM. Then, a gap analysis on current ARAIM concept is conducted in order to identify potential areas of improvements which allows to define suitable ARAIM Evolutions for non-aviation applications. Finally, a dedicated experimentation is conducted in order to proof the concept of the ARAIM evolutions and assess whether they could comply with the user requirements of non-aviation applications.

4.1. STAKEHOLDERS CONSULTATION

The consultation with relevant stakeholders conducted was intended to validate the desk research on user needs, guide the prioritization of the sectors and discuss technical details on the use of ARAIM in non-aviation sectors. The following interviews with experts were conducted: Telespazio and NTT Data for UAVs, Hitachi Rail STS and Université Gustave Eiffel for Rail, Thales Alenia Space for Space, EUSPA for LBS, UK's General Lighthouse Authorities for Maritime, Université Gustave Eiffel for Road.

In terms of the general acceptance and interest in the concept and its use in sectors beyond the aviation, all stakeholders acknowledged the potential added value of ARAIM, especially due to the additional layer of integrity that it can provide to the PNT information, as well as the possibility to deal with errors due to local effects.

Requirements and use of ARAIM

The stakeholders from all sectors agreed that ARAIM can be beneficial for several safety- and liability-critical applications, including when in dealing with local effects, due to the additional integrity layer that ARAIM can provide and the corresponding enhancement of the performance of GNSS information.

In rail sector, the introduction of ARAIM can be useful for any safety-related application, as well as the virtual balise. In addition, the following were identified as the most promising applications for the introduction of the concept (mainly based on the evolution of the rail signalling system):

- Safe train position function
- Safe odometry function
- Track surveys
- Innovative maintenance processes
- Virtual balise (also considered a priority from the market perspective)

Similar considerations can be applied to the road sector, where the stakeholders expressed their interest for the concept and its introduction in particular in safety-critical and automated applications.

Regarding the maritime sector, the stakeholders underlined that the use of ARAIM could be useful in general navigation (AIS, VDES, etc.), especially now as DGPS beacons are being turned off by some countries and vessels are starting to have few source of integrity to navigate. However, the stakeholders underlined that, as Aids to Navigation ARAIM, not GNSS, is expected to bring significant added value, since the navigation is done mainly using visual aids, as well as radars. The future autonomous vessels were pointed out as likely the most important application to benefit from ARAIM, since the vessels will rely purely on electronic AtoN.

For the UAV sector, the stakeholders indicated in particular eVTOL (electric vertical take-off and landing) applications, vertiport operation and all operations in the controlled airspace as the most promising for the introduction of ARAIM.

Specifically for the Space Users sector, the stakeholders underlined as the most promising applications the Rendez-vous, Formation Flying, Debris collision avoidance, and GEO station keeping applications.

Finally, for LBS the stakeholders agreed that the introduction of ARAIM can be beneficial in the following applications:

- Geo-marketing and advertising
- Enterprise applications
- Social networking
- Geotagging photo application within CAP
- Mobile payments and e-commerce
- mHealth
- Personal tracking
- Games and Augmented Reality
- Sports and Navigation

Despite of the above, the stakeholders highlighted tracking of valuable goods, commercial fraud management and commercial billing as the most promising applications for the penetration of ARAIM.

Limitations of GNSS to cover specific applications requirements

As underlined during the discussions with stakeholders in the different sectors, as well as with the ARAIM expert, the main limitations of GNSS are experienced across all sectors in urban and other obstructed environments, where local effects could result in incorrect positioning information.

More specifically, in the rail sector, the stakeholders underlined that, as it stands, GNSS alone does not meet the integrity requirements of rail applications, given the highly obstructed operating environment in this sector. Several applications cannot be done by using GNSS code measurement only, as the guaranteed accuracy does not meet the requirement. Consequently, the use of other technologies and sensors is required to address the requirements in the sector.

The use of GNSS can be limited also in the maritime sector, where the vessel itself often is a source of multipath. In addition, for several applications the stakeholders underlined that the use of GNSS to navigate or to perform manouvres could be dangerous, as the mariners prefer to use relative positioning (e.g. short-wave radar) and visual aids to navigation.

Similar considerations with regard to obstructed environments were also made for road, UAV, and LBS sectors, where stakeholders explained that the use of GNSS can be problematic given th often obstructed operating environments (e.g. tunnels or underground parking, urban canyons), as well as for in-door applications in the case of LBS.

Modifications required to ARAIM to address the requirements

The possible modification for ARAIM to address the requirements for specific applications derives from the fact that, as underlined by the stakeholders, it is nearly impossible to experience the open sky conditions beyond the aviation sector, due to multiple local noise sources and disturbances that the other sectors feature.

The stakeholders argued that for most sectors/applications modifications to the baseline ARAIM algorithm could be beneficial to meeting the defined requirements if certain conditions are met (e.g. any additional errors are accounted for, etc.), while for the UAV sector, given that the operations often take place in open sky conditions, the stakeholders explained that the baseline ARAIM algorithm will be sufficient.

Costs & benefits

In terms of costs, the stakeholders agreed that they will be mainly the same across the sectors. These will involve:

- Cost of update of the receivers (for the users)
- Cost of development of new receivers (for the receiver manufacturers)
- Certification costs (with the exception of LBS, where such costs are not expected)

Some stakeholders also considered the possibility for the existence of operating costs of the system.

In terms of benefits, the introduction of ARAIM across the sectors was considered beneficial to guarantee a more reliable positioning information by providing an integrity layer. In addition, some stakeholders stated that the introduction of the concept in non-aviation sectors could also potentially enable the development of new applications in the future.

Regarding specific benefits in the rail sector, the stakeholders stated that a high-performance train position, as well as an odometry function or a train integrity function (or combination of both) would result in an enhanced railway line capacity (e.g. higher number of trains per line). Furthermore, when applied to virtual balise, the savings in terms of infrastructure maintenance and replacement would be very high.

In the maritime domain safety is the most expected benefit that can be facilitated by ARAIM. Although GNSS-based solutions are not by far the exclusive aids to navigation used in this domain, when a mariner does rely on GNSS for navigation, it is important that the information provided is trustworthy and correct. According to the stakeholders interviewed, the expected safety benefits from ARAIM in maritime navigation would happen in traffic separation schemes or port entries.

In addition, while on the one hand the stakeholders from the UAV sector underlined the main benefits as experiencing increased accuracy and integrity overall, especially in specific high-performance applications, on the other hand maritime stakeholders noted that the use of ARAIM could support in particular the development of autonomous shipping (which will require genuine integrity and safety in its electronic systems), potentially saving operational costs for the industry.

Status of standardisation

In terms of standardisation, in most sectors this is still an ongoing process. An exception is represented by the UAV sector, where, according to the stakeholders, the needed standardisation has already been developed and implemented. In some specific sectors, such as LBS or road, it was pointed out that standardisation is a difficult process and that it should happen at the application level rather than at the sector level. In railway sector, it was highlighted that the standadisation is a complex process and the existing change processes (e.g. TSI) could be leveraged to introduce new modifications.

4.2. SELECTION OF MOST PROMISING USER SECTORS

Six **non-aviation user sectors** have been considered for the penetration of ARAIM concept, namely: Rail, Road, Maritime, UAVs, LBS and Space. The user requirements of the different non-aviation applications have been investigated based on literature review including GNSS standards and EUSPA User Consultation Platform Reports and based on interviews with relevant experts. The goal is to quantify the user requirements in order to assess the compliance of such non-aviation requirements by the performances achievable with the evolutions of the ARAIM concept. The focus has been placed in applications demanding GNSS integrity capability as ARAIM is basically an integrity technique at user level. Other typical performance parameters of GNSS have been considered for the requirements definition as Accuracy, Availability and Continuity. The specificities of each sector/applications have been taken into account, such as e.g. constrained movement of the vehicle to 1 dimension (e.g. Rail) or in the horizontal dimension (most maritime applications).

Rail

GNSS is already widely used in Rail non-safety related applications such as passenger information system and rolling stock fleet management and is well positioned for being a key technology in SoL applications in the near future. The use of GNSS in Rail faces difficulties coming from local effects at signal reception as typical rail applications can be operated in harsh environments, novel error models need to be considered and the integrity information needs to reach the user with safe and reliable methods, without suffering masking and low visibility problems as it would be the case of disseminating integrity information through GEO satellites in typical SBAS solutions. A key advantage of ARAIM with respect to SBAS or GBAS is the worldwide coverage of the service disseminated through MEO GNSS satellites.

GNSS Rail SoL applications clearly have a need of GNSS integrity capability, possibly combined with additional sensors. The fact that the use of GNSS for Rail SoL applications is still in research phase, without even having a consolidated integrity technique tuned for these applications – SBAS and RAIM integrity techniques are well positioned – opens a window opportunity for ARAIM penetration in this market.

In the Rail sector the particularity of the movement in one dimension can be exploited to define the Key Performance Indicators in the horizontal dimension distinguishing between the Along Track and the Cross Track dimension and distribute the integrity budget accordingly.

In terms of User Needs, two kind of applications with different Service Levels can be identified:

- Applications without High-Accuracy Needs such as Virtual Balise, Level crossing protection, Fleet Management, Hazardous cargo monitoring, etc. These applications show moderate accuracy needs of the order of at least several meters. These applications also have moderate to high integrity requirements for the GNSS sensor, of the order 10-4 / hour to 10-6 / hour and TTA of order seconds.
- Applications with High-Accuracy Needs such as Cold movement detection, Track identification, Infrastructure surveying, etc. These applications present high accuracy needs at the sub-meter level and moderate to high integrity requirements for the GNSS sensor, of the order 10-5 / hour to 10-6 per hour and TTA of order seconds.

Road

Road sector is one of the most important GNSS sectors in terms of cumulative revenues. GNSS technology is already widely used in road transportation and its growth is driven by both commercial and regulated applications. GNSS is expected to be widely used for ADAS, due to the added value in terms of availability in a multi-constellation context, thus being able to provide absolute position in a wide range of environments and complementing perception sensors in featureless areas. Besides, its integration with inertial sensors also helps providing navigation in difficult environments such as urban canyons. Autonomous Driving is in R&D phase, with all major car groups worldwide and tech giants working on AD technology. A positioning system using sensor data fusion is a key enabler for AD. A GNSS engine will be an essential element of this positioning system. Absolute positioning provided by GNSS is the only way to reference the vehicle within a high-resolution digital map, which also mandatory for AD as a support for perception-based navigation techniques based on cameras. Besides, A-GNSS is able to provide navigation in featureless roads, thus complementing the perception-based navigation. The use of GNSS in Road faces difficulties coming from local effects at signal reception as typical rail applications can be operated in harsh environments. In the Road sector the particularity of the movement in two dimensions can be exploited to define the Key Performance Indicators in the horizontal dimension and allocate the integrity budget accordingly.

Most Road applications have high accuracy needs at the sub-meter level and stringent integrity requirements with very low TTA (below one second) and demanding alarm limits and integrity risk of the order 10-7 / hour.

Maritime

GNSS is already widely used by the maritime industry. SOLAS (Safety Of Life At Sea) vessels and in general large vessels are equipped with more than one device for redundancy reasons, as well as to serve multiple applications. The widespread uptake of GNSS for commercial shipping has raised the need for common standards for performance, reliability and resilience across and within constellations. Standardisation of use of GNSS is on-going. Developing international regulations followed by all shipping nations has always been recognized as the best way of improving safety at sea. The International Maritime Organization (IMO) has always paid great attention to the improvement of maritime navigation safety, developing and adopting a whole series of measures being the most important the International Convention for the Safety of Life at Sea (SOLAS). As part of SOLAS regulation, IMO has issued a series of resolutions, guidelines on navigation and performance standards for shipborne navigational and radio-communications equipment such as IMO resolution

A.915(22) or A.1046(27). Under IMO Maritime Safety Committee (MSC) is included the scope of GNSS systems recognition. GPS, GLONASS, BeiDou and Galileo have been so far recognized by IMO as components of the WWRNS. IMO set out the performance requirements for different maritime radio navigation receivers (e.g. IMO MSC.112(73) for GPS or MSC.233(82) for Galileo.

The use of GNSS in Maritime faces difficulties coming from local effects at signal reception for applications near to the coast and determination of a suitable multipath model for maritime. In the Maritime sector the particularity of the movement in two dimensions can be exploited to define the Key Performance Indicators in the horizontal dimension and allocate the integrity budget accordingly.

Apart from some niche applications demanding high accuracy, typical navigation applications require accuracies of several meters, moderate integrity requirements in terms of Alarm Limits of the order of tens of meters, integrity risk of the order 10-5 / hour and TTA of the order 6 to 10 seconds.

UAVs

UAVs is a highly innovative GNSS User Sector very fast growing in the last years. GNSS technology is penetrating UAVs sector faster than standardization and regulation. As shown in the GSA GNSS market report, it is expected that drone services will rise more and more in a wide range of markets. At the moment, the largest number of specialized drone operators are mainly in surveillance and agriculture applications. However, it is also foreseen that from 2021 onwards, drone operations will be taking place more and more in urban environments (e.g., drone delivery). Taking account of the role that UAVs will be playing in urban environments in the next future, the key GNSS requirements for their use will include a high level of accuracy, availability, continuity, robustness and integrity. In this context, it will be necessary to have constant and reliable positioning information while navigating between urban infrastructures and buildings.

Standardisation in drone segment market is at an incipient stage, with many different work streams concurrently progressing in the frame of different bodies such as RTCA, EUROCAE, etc. UAVs sector has different similarities with manned Aviation sector for which ARAIM concept has been developed and thence, ARAIM penetration in UAVs seems promising.

It is important to highlight that UAVs Market Segment is still not fully mature for GNSS and the User Needs in terms of GNSS KPIs are under definition in other contexts, still not fully quantified and not standardised. The requirements depend on the UAVs categories (Open, Specific and Certified categories), environmental conditions in which they operate (e.g. open sky, urban) and applications (e.g. drone operations under U-Space, Operations in the proximity of critical infrastructure, Seach and Rescue Operations, Geofencing, etc). Basically, the integrity requirements are likely of the same order as for manned aviation, with integrity risk of the order 10-7 / hour, TTA around 6 seconds and Alarm limits of the order tens of meters. In Urban environments, high-accuracy requirements below one meter could be necessary while in open sky operations, accuracies of the order several meters would be enough.

LBS

The criticality of LBS applications Is in general much lower than for Aviation applications which are Safety-Of-Life. Only a sub-set of LBS applications have a certain degree of criticality, which could be rather defined as Liability Critical. This implies that only a reduced number of LBS applications present a need of GNSS Integrity capability and thence are attractive for ARAIM penetration. This includes applications such as Mapping & Geographic Information System (GIS), tracking and commercial applications, etc. The Integrity needs are not completely clear and quantified in the literature but in principle they are more relaxed than in Aviation applications, which implies that the Integrity concept could be also relaxed compared to the integrity concept of Aviation applications.

Space

The introduction of GNSS in Space sector is in an incipient stage. Space applications are usually not safety of life critical but rather liability critical. The GNSS user needs are not clear, not quantified and even if a GNSS integrity capability would be likely welcome by several Space applications, the space market is still not mature to have quantified integrity requirements.

Technologies for non-Aviation applications

Different PNT technologies could compete with ARAIM for the penetration in non-aviation sectors but also show interesting synergies which could be exploited for the combination with ARAIM:

- GBAS: taking into account its local coverage area (40km radius) this technology could be unpractical for sectors demanding a wide coverage area such as Rail or Road. It is a well consolidated technology providing GNSS integrity, standardized for its use in civil aviation, the receivers GBAS-enabled are expensive, a large investment at system level would be needed to provide coverage in a wide area. Being an integrity technique at system level, no protection against local effects is provided and a higher TTA of the order seconds can be achieved than ARAIM.
- SBAS provides a regional service within a wide area, it is a well consolidated GNSS integrity technique which is standardized for civil aviation applications, the receivers SBAS-enabled are expensive when certified against the MOPS. Being an integrity technique at system level, no protection against local effects is provided. A drawback for its applications to non-aviation applications is that GEO visibility in harsh environments is compromised. A higher TTA than ARAIM of the order seconds is achievable.
- RAIM is an integrity technique at user level with the main drawback of not being able to deal with multi-failures and thence, not suitable in a DFMC environment. ARAIM can be considered as the extension of RAIM concepts towards multi-failure capabilities.
- Hybridization: hybridization of GNSS with other sensors such as IMU is convenient to cope with the limitations that GNSS has in harsh environments typical of non-aviation applications such as GNSS outages due to e.g. tunnels, low satellite visibility due to obstructions or a strong multipath and NLOS environment.

In particular, the following technologies are relevant for the different non-aviation sectors:

- Rail:
    - There are activities on-going analysing the use of different GNSS technologies for Rail,
    - There is a need of hybridization with other sensors such as Odometer or IMU to cope with harsh environments,
    - In the EU Technical Specification for Interoperability to be issued in 2023, SBAS is the GNSS technology considered for Rail,
- Road:
    - SBAS is a potential GNSS integrity technique for Liability Critical Applications with moderate accuracy and integrity requirements (e.g. payment applications),
    - PPP with Integrity capability is needed for applications with high accuracy needs,
    - Hybridization with other sensors is needed to cope with harsh environments,
- Maritime:
    - SBAS is a promising GNSS Integrity technique for maritime, in Europe an EGNOS V3 dedicated Maritime Service will be deployed,
    - RAIM is requested in IEC 61108-3 Standard "Maritime navigation and radio-communication equipment and systems –GNSS" and could be substituted in the future by ARAIM,
- UAVs:
    - SBAS and GBAS could be applied to applications operated in open sky environment,
    - There is a need of hybridization for applications operating in harsh environments,
    - PPP with integrity would be needed for applications demanding high-accuracy,

Taking into account the previous arguments, ARAIM concept adequately evolved towards its use in non-aviation applications seems a promising integrity technique to cope with local effects typical of non-aviation applications and to satisfy the non-aviation user needs.

For the selection of the most promising User Sectors a trade-off was conducted taking into account different criteria such as the criticality of the applications within each user sector and the need of a GNSS integrity capability, the market maturity in terms of GNSS integrity user needs, the innovation associated to each user sector, the urgency to have available suitable GNSS integrity solutions, the a-priori feasibility to comply with the User Needs with ARAIM concepts and costs and benefits aspects.

Next figure depicts the prioritization analysis of the user sectors beyond Aviation for the penetration of ARAIM.

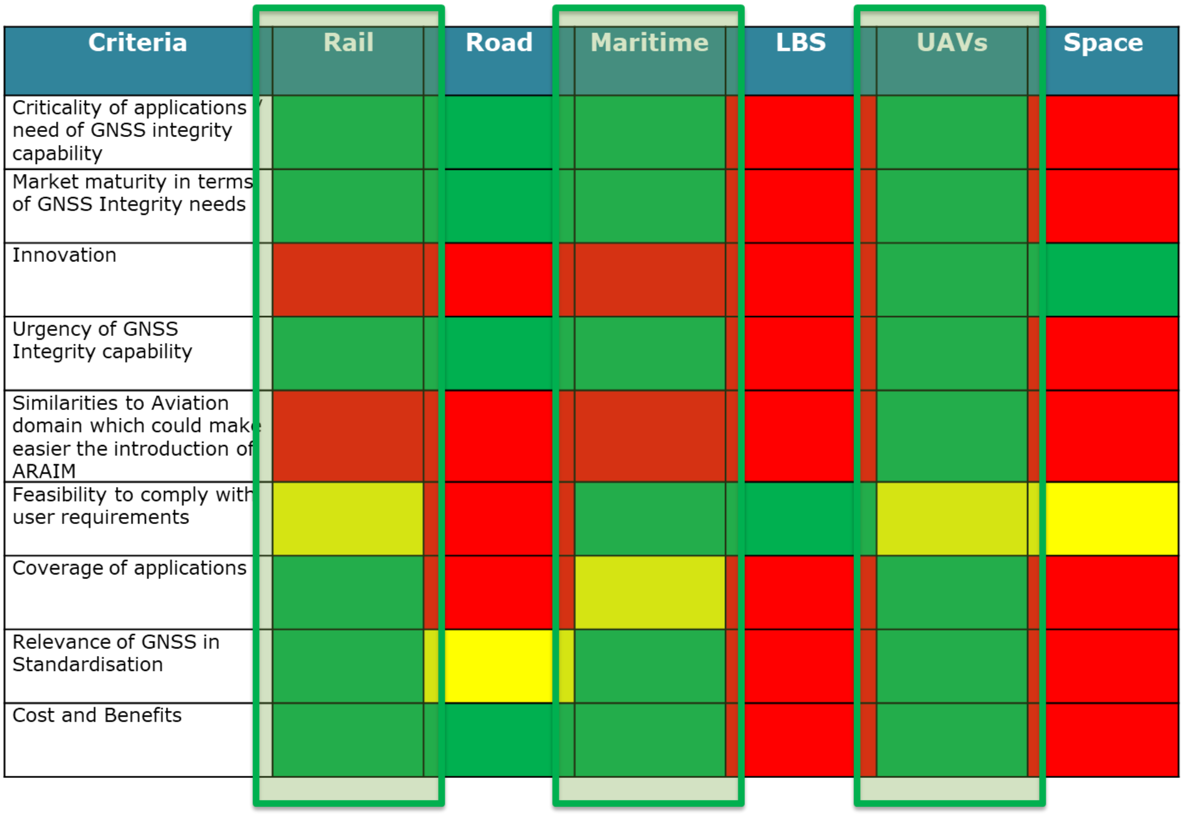

Figure 4-1: Prioritization of User Sectors for ARAIM Penetration

Rail, Maritime and UAVs sectors were prioritized while discarding to further analyse LBS, Space and Road Sectors due to the following main reasons:

-LBS Sector was discarded basically due to the fact that the criticality of LBS applications is usually low and only few niche applications demand a GNSS integrity capability,

-Space Sector was discarded basically because GNSS penetration is in an incipient stage, the market is not mature in terms of GNSS Integrity needs and the penetration of ARAIM would be in a longer timeframe than in other sectors,

-Fulfilling the very demanding requirements of Road SoL critical applications would be challenging for ARAIM. In any case, the studies for Rail and UAVs sectors could be partially extrapolable for the Road User Sector.

-Addressing Rail, UAVs and Maritime allows to conduct the study in the context of three very relevant non-aviation User Sectors with applications demanding a GNSS Integrity capability. Those sectors present a high degree of innovation and are promising for the penetration of ARAIM.

Nevertheless, it is important to remark that the ARAIM evolutions studied for Rail, Maritime and UAVs could be also applicable or partially re-used to adapt the concepts for the Road, Space and LBS sectors.

4.3. DESIGN OF ARAIM EVOLUTIONS

4.3.1. APPLICATIONS ALREADY FULFILLED BY ORIGINAL ARAIM CONCEPT FOR AVIATION

The original ARAIM concept for Aviation with minor adaptations (if needed) is able to fulfil the less demanding non-aviation applications in terms of operational environment and User Requirements, as confirmed by the Service Volume Simulations conducted, in particular:

- Rail applications operated in Open Sky conditions and low integrity needs such as: Fleet Management, Cargo Monitoring or Energy Charging,
- Maritime Ocean Navigation and Autonomous Vessels – Ocean Navigation,
- UAVs: RNP0.1 in Open Sky.

A short Timeframe for the penetration of ARAIM in these applications can be expected, around two years, once the ARAIM Standards are finalized.

For the most demanding non-aviation applications in terms of User Needs and Operational Environments, a Gap Analysis is conducted to identify areas of improvement, as presented in the following section.

4.3.2. MORE DEMANDING APPLICATIONS

A **Gap analysis** of the applicability to non-aviation applications of current ARAIM Aviation concept has been conducted in order to identify areas of improvement to support the definition of ARAIM Evolutions. The following areas have been addressed:

- ARAIM User Algorithm,
- Architecture and ARAIM Configuration,
- Error Models,
- ISM Parameters,
- ISM Parameter Values,
- ISM Parameters Characterisation,
- Safety Analysis.

The Gap catalogue then is used to select the most relevant gaps identified to build Evolutions of the ARAIM concept to non-aviation applications.

ARAIM User Algorithm

The algorithm at receiver level has to be carefully analysed in order to verify that it is suitable for the intended operations. Among many other factors, the key element to check is the alignment with the algorithm hypothesis, which could imply a safety risk. The ARAIM algorithm was designed for manned aviation and its extrapolation to other GNSS domains could imply a change in its foundations such as the protection levels computation. Several concrete gaps were identified, please refer to D211.

Architecture and ARAIM Configuration

Concerning the Architecture and basic ARAIM Configuration, the following areas could be improved:

- Extension towards more than two constellations. The original ARAIM concept currently being defined at standardization level relies on the augmentation of two constellations: GPS and Galileo. The extension towards three or four constellations would provide several benefits as improved number of satellites in view, Protection Levels and Availability performances, especially in harsh environments typical of non-aviation applications such as deep urban, additional resilience to jamming and spoofing (e.g. with cross-checks which could be implemented at receiver level).
- Extension towards the processing of more than two frequencies. ARAIM concept currently considered at standardisation level foresees the augmentation of two GNSS frequencies. The

extension of ARAIM concept towards the processing of three GNSS frequencies could provide the following advantages.

  - Improvement in the determination of ionospheric uncertainty,
  - Additional resilience to jamming and spoofing threats with the possibility of additional back-up modes upon jamming/spoofing in one or two frequencies,
  - Benefits in the context of RTK and PPP techniques: improved ambiguity resolution, extra-widelane based RTK, augmented RTK service, shortened PPP convergence, improved availability and reliability.

- Extension of H-ARAIM Architecture towards On-Line Architecture. The ARAIM architecture currently considered at Standardisation level is the H-ARAIM architecture which would provide horizontal guidance. For non-aviation sectors such as UAVs and Space applications, the vertical component is at least as relevant as the horizontal and thence, and extension of the ARAIM architecture towards the On-Line architecture with a frequent update of the ISM could be needed in order to provide GNSS improved performances, in particular for the vertical component.
- ARAIM combined with PPP. ARAIM concept could be extended in combination with PPP to improve the accuracy and the protection levels for non-aviation applications demanding high accuracy solutions.
- ARAIM combined with SBAS to exploit the synergies between the SBAS monitoring of threats at system level and the orbit and clock corrections with the ARAIM monitoring power of local effects.
- ARAIM combined with hybridization with additional sensors such as IMU. ARAIM concept could be extended to be combined with additional sensors in order to deal with local effects and GNSS outages

Error Models

The Error Models assumed for the ARAIM concept for Aviation, which operates in typical environments which can be considered Open Sky, should be modified when extending the ARAIM concept to non-Aviation applications as typical Road or Rail environments usually comprise - in addition to Open Sky - Urban, sub-urban or Mountain environments. This implies the need of an adaptation of the ARAIM concept to non-aviation environments to model larger multipath, Noise and NLOS effects.

The following potential Gaps have been identified:

- There is a clear need of developing a multipath and NLOS model to model the different non-aviation environments. An extensive experimentation campaign to model multipath and NLOS effects is needed as was done to model open-sky aviation environment in the GNSS Aviation Standards (RTCA DO-229).
- For non-aviation applications demanding high-accuracy solutions with integrity, there is a need to consider PPP + ARAIM. Then, additional ISM parameters could be needed in this context as for e.g. covering second order ionospheric effects, probability of cycle slips, etc.
- There is also the possibility for the user to monitor in real-time the level of local effects errors and use the corresponding parameters value in the ARAIM algorithm. For example, the use of Digital Maps could help the user to identify the surrounding environment and consider different local effect error models depending on the environment in which he is located.
- Another possibility could be to define a higher masking angle than the 5º usually assumed in Open Sky to further mitigate local effects at the price of discarding satellites with low elevation.

ISM Parameters

Additional ISM parameters specifically defined for non-aviation users could be also proposed such as:

- Dissemination of ISM parameters for Glonass and Beidou (in the case of extending the ARAIM concept towards more than 2 constellations);
- Dissemination of parameters for Galileo E6 (in case of extending the ARAIM concept to use Galileo E6 signal, and if E6 ISM parameters, after a detailed characterization of the signal,

would be different from the ISM parameters for Galileo E1/E5. This could be needed in the case of proposing a combination of ARAIM with PPP and/or Signal Authentication);

- Additional ISM parameters could be needed in case of combination of ARAIM with high-accuracy techniques:
  - Orbit and clock correction errors (sigma URA);
  - Ionospheric errors (second-order);
  - Probability of cycle slips;
- Another possibility could be to increase the ISM parameters update rate, towards an ARAIM online architecture;
- Another potential area of improvement is to split URE / URA in different components: a clock component and an orbit component, allowing also the possibility to define different update rates for the different components in order to better adapt to the temporal variations of each component. Similar ideas are applied for example in SBAS, separating UDREs from GIVEs, which implies to separate clock and orbit uncertainties from ionospheric uncertainties.

ISM Parameter Values

More ambitious values of the ISM parameters such as Psat and Pconst could allow to comply with stringer performance requirements. This could imply discussing the constellation commitments and recommendations for the modifications of these commitments in the Galileo SDD and GPS SPS.

ISM Parameters characterization

ARAIM concept for aviation has been built considering GPS L1/L5 and Galileo E1/E5 signals, which are the ones used in aviation concept. For combination of ARAIM with Galileo E6 signal to take into account Galileo Signal Authentication and Galileo High Accuracy Service, this Galileo E6 signal would have to be characterized in terms of fault probabilities for the ARAIM concept definition. A set of new default ISM parameters for Galileo is assessed. For the details, please refer to D211.

Safety Analysis

Concerning the applicability of ARAIM to non-aviation applications, there may be some gaps regarding the integrity and continuity risk tree considering the whole system. Applications may have different requirements and safety allocations than in aviation and therefore the integrity and continuity requirements and allocations could be modified. For details of such analyses, please refer to D211.

In order to analyse different potential ARAIM Evolutions, the **three most promising User Sectors for ARAIM penetration have been selected** and three high-level ARAIM evolutions have been proposed, one for each User Sector, namely:

- Rail User Sector with an ARAIM Evolutions based on the combination with SBAS and hybridization with IMU/Odometer,
- Maritime User Sector with an ARAIM Evolution based on the combination with SBAS and multi-antenna processing,
- UAVs User Sector with and ARAIM Evolutions based on the combination with PPP and hybridization with IMU.

ARAIM Evolutions

Next sections describe from a high-level perspective the three proposed ARAIM Evolutions.

ARAIM Evolution for Rail

With the previous catalogue of Gaps, some of them have been considered to build an ARAIM Evolution suitable for Rail applications.

The main ingredients for the ARAIM Evolution proposed for Rail are listed in the following:

- Combination of ARAIM with SBAS, taking advantage of the synergies between both technologies. On the one hand, SBAS would be used to monitor System Level threats and the orbit and clock corrections provided by SBAS could also improve the accuracy of the PNT solution. On the other hand, ARAIM would be exploited to monitor the local effects,
- Hybridization with IMU or Odometer to improve Availability especially in Urban environments, cope with GNSS outages, better deal with local effects, improve the FDE capabilities, etc,
- Implementation of Local Effects models for Multipath, NLOS considering typical Rail environments,
- Allocation of Integrity Budget to Horizontal component and discrimination between Along Track and Cross Track components.

The following figure depicts the high-level architecture for the proposed ARAIM Evolution for Rail.

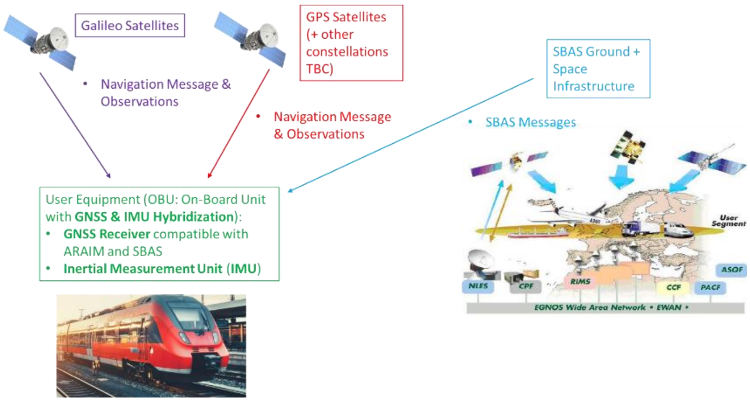

Figure 4-2: High-level architecture of ARAIM Evolution for Rail

The Receiver Architecture is depicted in the following figure.

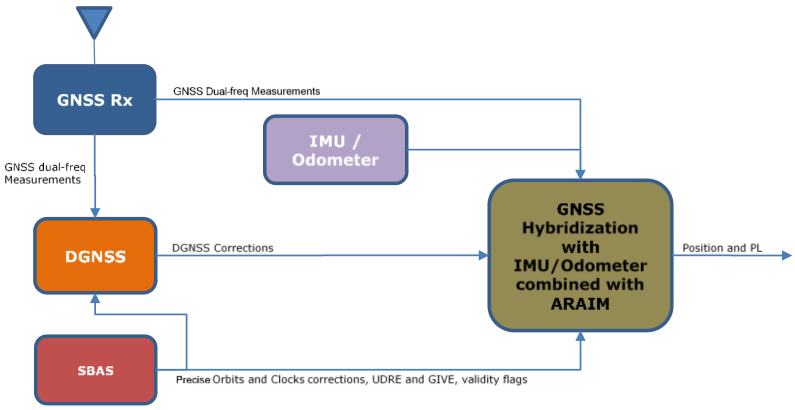

Figure 4-3: Receiver Architecture for the ARAIM Evolution for Rail

It is important to remark that the processing of the ISM when ARAIM is combined with SBAS is in principle not needed if the SBAS integrity risk is aligned with the user needs of non-aviation applications. Then, Psat and Pconst would be either 0 or re-interpreted only for local effects. Prior probability of satellite faults can be neglected or set to significantly lower values. Faulted satellites can be excluded by SBAS prior to the ARAIM algorithm. Similarly, constellation wide fault can be neglected. These two assumptions reduce the computational load of the algorithm.

In addition, it is also important to remark that poor availability of GEO Signals in typical Rail environment due to obstruction by obstacles implies the need to define alternative dissemination channels such as GSM-R or EDAS.

A suitable multipath model overbounding the multipath error for typical Rail harsh environments is assumed. A specific and extensive data campaign would be needed for such purpose.

In addition, NLOS local effects should be monitored. A potential strategy could be the use of Digital Maps to identify the environment in which the receiver is operating and then apply a model for the Probability of NLOS dependent on the environment.

The Hybridization of GNSS with IMU has been extensively studied in ARAIMTOO and relies on the following principles:

- Propagation of ARAIM Solution:
    - Propagate the ARAIM solution with the inertial sensors (or any other relative positioning sensor),
    - The PLs would be degraded according to the sensor quality,
    - The propagated solution can be used to cope with the lack of satellites in view when the propagated solution is better than the current one,
- Improvement of FDE:
    - An FDE based on a filter hybridizing GNSS and other sensors provides improved performances, especially in harsh environments,
- Measurements from previous epochs:
    - In harsh environments phase-smoothing is not possible. Doppler-smoothing can be used instead,
    - Smoothing could be aided by IMU/Odometer and a clock with good short-term stability,
- Improvement of measurement error monitoring
    - Environmental conditions change due to local effects so they need to be monitored,
    - Hybridization can help to better monitor the level of error in the measurements.

The ARAIM Error model needs to be adapted to harsh/urban environments. Higher multipath errors implies an increase on the sigma bounding multipath with respect to Aviation. Concerning NLOS, if the error model includes the NLOS biases in the multipath sigma we would obtain high Protection Levels while if the NLOS biases are out of the error model we would need to include a Probability of NLOS, called P_{NLOS} in ARAIM.

Thence, the hybridization allows to:

- Improve the FDE: the FDE of the Hybrid solution provides a better detection and excludes most NLOS so take it into account and use a smaller PNLOS in ARAIM,
- Propagate previous ARAIM PL and use it when it is better than the PL computed at current epoch. The previous PL would be increased based on the sensors and propagation quality.

The proposed Architecture of GNSS Hybridization with IMU/Odometer combined with ARAIM is shown in the following figure and comprises the following modules:

- Hybrid Filter (GNSS hybridization with IMU/Odometer):
- Smoothing of GNSS Pseudoranges:
- Environment Error Level Monitoring:
- Satellite Multipath Sigma Estimator & FDE:
- ARAIM Algorithm:
- ARAIM Solution Propagation:
- ARAIM Solution Selection:

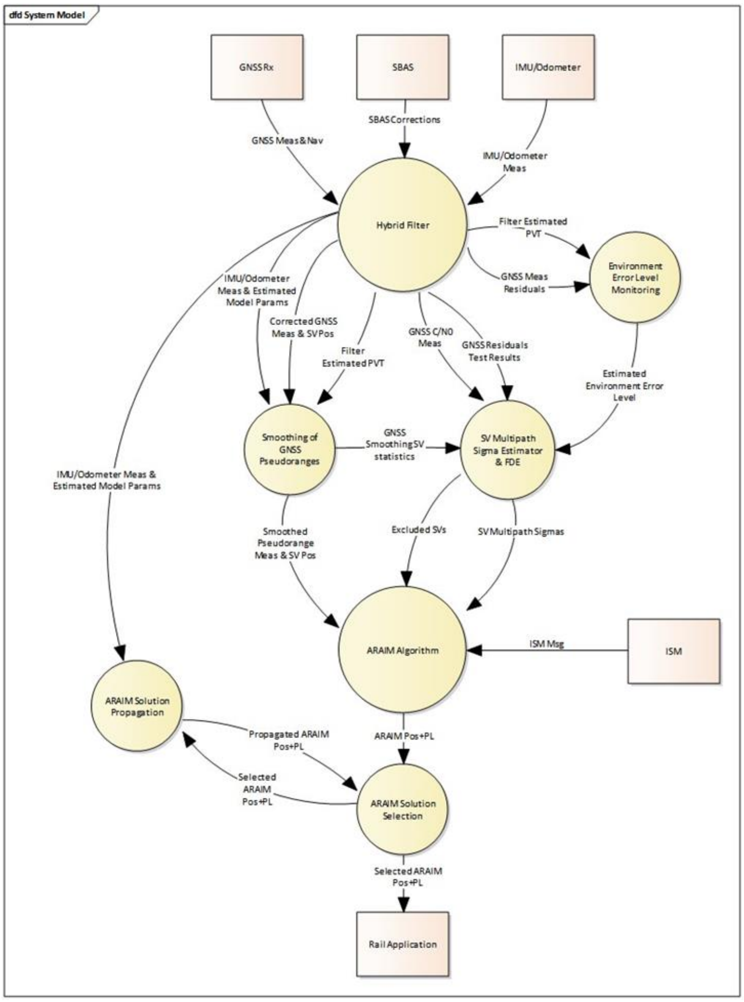

Figure 4-4: Proposed Architecture for GNSS Hybridization with IMU/Odometer combined with ARAIM

ARAIM Evolution for Maritime

Taking into account the Gaps catalogue, some of them have been considered to build an ARAIM Evolution suitable for Maritime applications.

The main ingredients for the ARAIM Evolution proposed for Maritime are listed in the following:

- Combination of ARAIM with SBAS, taking advantage of the synergies between both technologies. On the one hand, SBAS would be used to monitor System Level threats and the orbit and clock corrections provided by SBAS could also improve the accuracy of the PNT solution. On the other hand, ARAIM would be exploited to monitor the local effects,
- Implementation of Local Effects models for Multipath, NLOS considering typical Maritime environments,
- Recommendations for the best antenna location on the top of the mast to mitigate multipath effects as much as possible and Multi-Antenna processing to improve the FDE.
- Allocation of Integrity Budget to Horizontal component.

The following figure depicts the high-level architecture for the proposed ARAIM Evolution for Maritime.

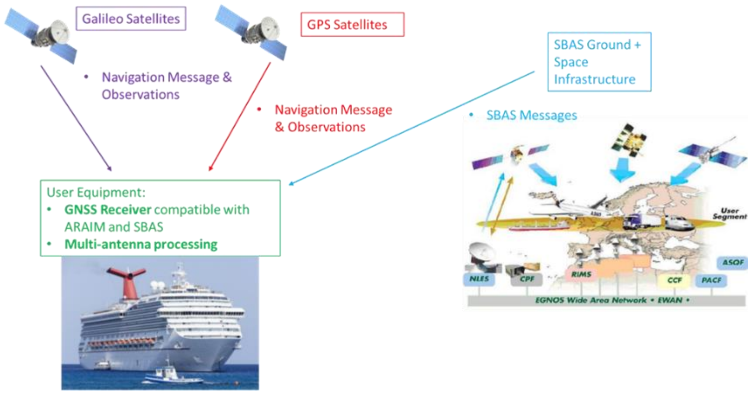

Figure 4-5: High-level architecture of ARAIM Evolution for Maritime

The Receiver Architecture is depicted in the following figure.

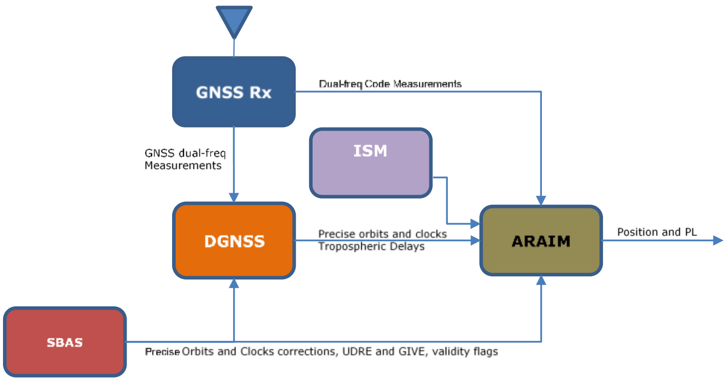

Figure 4-6: Receiver Architecture for the ARAIM Evolution for Maritime

It is important to remark that the processing of the ISM when ARAIM is combined with SBAS is in principle not needed if the SBAS integrity risk is aligned with the user needs of non-aviation applications. Then, Psat and Pconst would be either 0 or re-interpreted only for local effects. Prior probability of satellite faults can be neglected or set to significantly lower values. Faulted satellites can be excluded by SBAS prior to the ARAIM algorithm. Similarly, constellation wide fault can be neglected. These two assumptions reduce the computational load of the algorithm.

A suitable multipath model overbounding the multipath error for typical Maritime harsh environments is assumed. A specific and extensive data campaign would be needed for such purpose.

In addition, NLOS local effects should be monitored. A potential strategy could be the use of Digital Maps to identify the environment in which the receiver is operating and then apply a model for the Probability of NLOS dependent on the environment.

The selected approach for the multiple antennas in the ARAIM Evolution for Maritime is to exploit the multi-antenna power for the FDE process. In particular, it is proposed as a redundancy technique to double differencing the pseudoranges in order to discard faulty satellites. Only quality measurements and coherent and consistent measurements between the two antennas would be retained while inconsistent measurements would be discarded. In this way the reliability of the PNT solution would be maximized with the multiple antenna approach instead of increasing the availability of measurements as we believe that it is the most promising approach to exploit multi-antenna capabilities.

ARAIMTOO project is funded by the European Commission. The results are the property of the European Commission.

ARAIM Evolution for UAVs

Considering the identified Gaps, some of them have been considered to build an ARAIM Evolution suitable for UAVs applications.

The main ingredients for the ARAIM Evolution proposed for UAVs are listed in the following:

- Combination of ARAIM with PPP, in order to cope with demanding accuracy requirements in Urban environment,
- Hybridization with IMU to improve Availability especially in Urban environments, cope with GNSS outages, better deal with local effects, improve the FDE capabilities, etc,
- Implementation of Local Effects models for Multipath, NLOS considering typical Rail environments,

The following figure depicts the high-level architecture for the proposed ARAIM Evolution for UAVs.

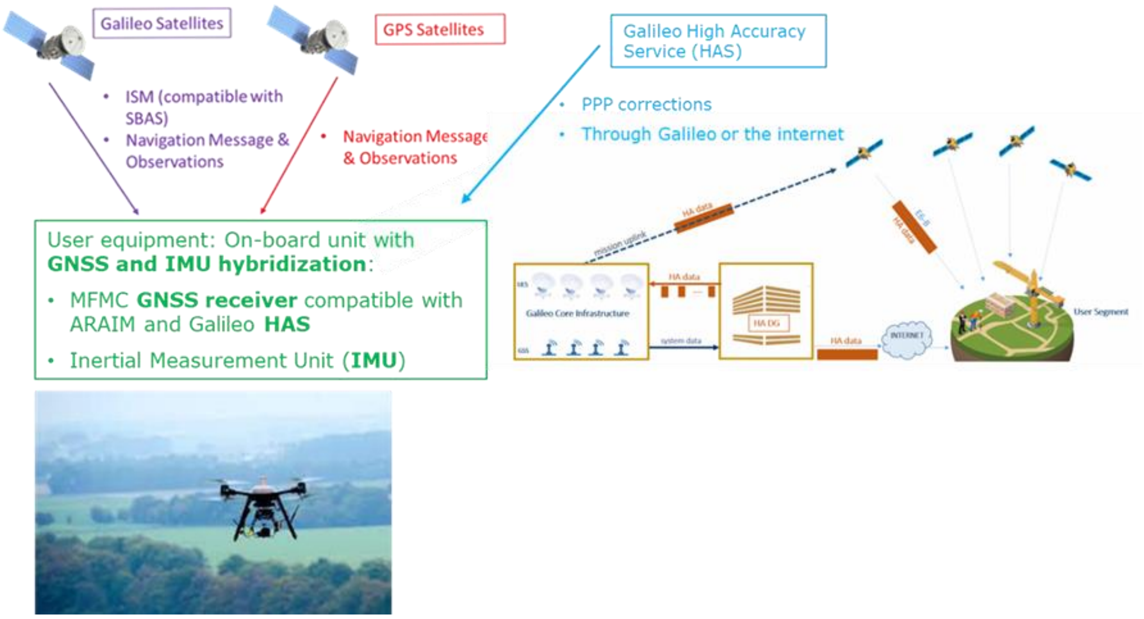

Figure 4-7: High-level architecture of ARAIM Evolution for UAVs

The Receiver Architecture is depicted in the following figure.

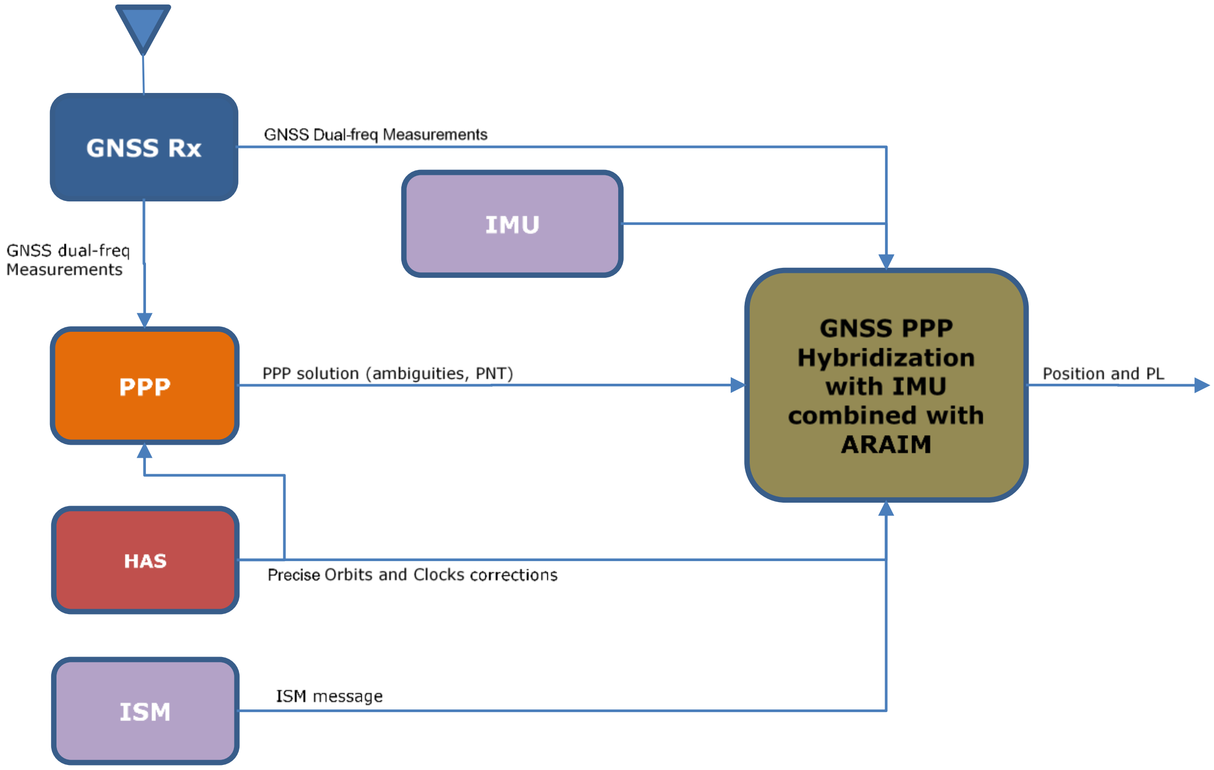

Figure 4-8: Receiver Architecture for the ARAIM Evolution for UAVs

For further details, please refer to D223.

4.4. EXPERIMENTATION

Proof-Of-Concept

An experimentation to proof the concept of the proposed ARAIM Evolutions has been conducted in order to evaluate the performances achievable and to assess the compliance with the User Requirements of non-Aviation applications.

For that, the following tools has been used:

- A Service Volume Simulator (SVS) with ARAIM algorithms implemented – version 4.0 of ARAIM Algorithm Description Document (ADD) – and with the capability to configure and simulate different local environmental parameters and providing as output Protection Levels and Availability Performances.
- ARAIM C-platform with ARAIM algorithms implemented processing GNSS observation measurements and GNSS Navigation, and using as input, the outcomes of a Signal Simulator simulating relevant GNSS threats.

Next table summarises the different Test Cases executed:

Table 4-1: Test Plan Overview

Test Case Id	Title	Purpose
TC-01	Simulations with the ARAIM Concept for	-To demonstrate that the original ARAIM Concept for Aviation cannot in general be applied to non-aviation applications. For

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	Aviation without specific evolutions for non-aviation applications	that, Service Volume Simulations are conducted with a typical configuration in both open sky and harsh environments typical of non-aviation applications. -To identify the non-aviation applications which could be fulfilled with the original ARAIM concept for Aviation
TC-02	Open Sky Environment Characterization	To characterize Open-Sky environment in terms of satellite visibility, multipath and NLOS by means of analysing Real GNSS data gathered in a representative open-sky environment. Statistics from the ARAIM behaviour in terms of signal quality checks and satellite rejection are also extracted to characterise the open sky environment.
TC-03	Urban Environment Characterization	To characterize urban environment in terms of satellite visibility, multipath and NLOS by means of analysing Real GNSS data gathered in a representative open-sky environment. Statistics from the ARAIM behaviour in terms of signal quality checks and satellite rejection are also extracted to characterise the open sky environment.
TC-04	Sensitivity Analysis to Key ARAIM parameter values	To test the sensitivity of the ARAIM performances varying key ARAIM parameters values: P_{sat}, P_{const}, URA, bnom, P_{NLOS}, P_{FDE}, Smoothing time, etc
TC-05	Sensitivity Analysis to the number of constellations	To test the sensitivity of the ARAIM performances varying the number of constellations augmented in both open sky and urban environments
TC-06	Protection Levels and Availability Performances of ARAIM Evolution for Rail	To assess the protection levels and availability performances of ARAIM Evolution for Rail with Service Volume Simulations
TC-07	Protection Levels and Availability Performances of ARAIM Evolution for Maritime	To assess the protection levels and availability performances of ARAIM Evolution for Maritime with Service Volume Simulations
TC-08	Protection Levels and Availability Performances of ARAIM Evolution for UAVs	To assess the protection levels and availability performances of ARAIM Evolution for UAVs with Service Volume Simulations
TC-09	FDE Test and assessment of integrity for ARAIM Evolution for Rail	To assess the FDE capabilities and the integrity of ARAIM Evolution for Rail
TC-10	FDE Test and assessment of integrity for ARAIM Evolution for Maritime	To assess the FDE capabilities and the integrity of ARAIM Evolution for Maritime
TC-11	FDE Test and assessment of integrity for ARAIM Evolution for UAVs	To assess the FDE capabilities and the integrity of ARAIM Evolution for UAVs

The details of the tools' configuration and the complete results are provided in ARAIMTOO D313 and will be described and analysed in depth in a future publication specifically dedicated to the experimentation conducted in ARAIMTOO. In the following, just a summary of the main conclusions and a sample of the most relevant results obtained in the experimentation are provided.

TC-01: Simulations with the ARAIM Concept for Aviation

Simulations have been conducted to assess the performances of the original ARAIM concept for Aviation in both Open Sky and Urban environment. The main conclusion that can be extracted is that evolutions on the ARAIM concept are needed to be able to deal with local effects typical of non-aviation environments and to fulfil the User Requirements of non-aviation applications. Only the Requirements of a few applications such as Ocean Navigation for Autonomous Vessels, RNP0.1 for UAVs and Rail Applications with low integrity needs such as Fleet Management, Cargo Monitoring or Energy Charging can be met with the original ARAIM concept for Aviation.

TC-02: Open Sky environment characterization and TC-03: Urban Environment characterization

An experimentation analyzing a limited amount of real GNSS data has allowed to validate local effects models typical of open sky and urban environments for parameters such as the multipath and NLOS. This characterization is then injected in the Service Volume Test Cases configuration to simulate typical non-aviation environments.

TC-04: Sensitivity Analysis to Key ARAIM parameter values

Simulations for assessing the sensitivity of PLs performances in both open sky and urban environments to key ARAIM design parameters have been conducted. The parameters varied are Rsat, Rconst, URA, bnom, Probability of NLOS (PNLOS), Probability of Fault Detection and Exclusion (PFDE) and Smoothing approach.

The GPS configuration usually presents a higher influence on the results than Galileo in terms of PLs in the sensitivity tests performed since current Rsat, Rconst, URA and bnom parameters are better for GPS than for Galileo, implying that GPS is the constellation mainly driving the performances. The PLs results show a relevant influence of Rsat, Rconst and URA parameters.

TC-05: Sensitivity Analysis to the number of constellations

Simulations for assessing the sensitivity of PL performances in both open sky and urban environments to the number of constellations processed have been conducted. When processing 4 and 3 constellations, the PLs significantly improve with respect to the case of processing only two constellations. This is especially important in Urban environments in which the number of visible satellites is a very relevant factor for the performances as the obstructions of such environments decreases the number of satellites in view with respect to the case of Open Sky.

TC-06: Protection Levels and Availability Performances of ARAIM Evolution for Rail

Different scenarios have been run with the ARAIM Service Volume to assess PL and Availability performances with different Integrity Risks and Alarm Limits corresponding to the Requirements of Rail applications. The proposed ARAIM Evolution for Rail based on the combination with SBAS and IMU was considered in the Simulations. In particular, the combination with SBAS implied an improvement of Psat, Pconst, URA and bnom values since we can safely assume that SBAS can cope with System Level events for applications with an integrity risk requirements equivalent or lower than the one for SBAS for Aviation. Hybridization with IMU was considered assuming a configuration corresponding to the specifications of a medium-grade IMU.

Both Open Sky and Urban environments were also taken into account in the simulations.

Next Figure shows an example of the Availability performances, in this case, obtained for the Urban Scenario with IR of $7.5x10^{-6}$ hour, with an HAL of 20 meters once IMU is activated in the simulations.

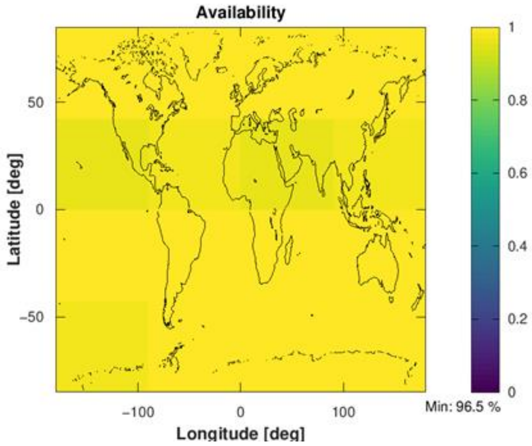

Figure 4-9: Availability performances obtained in Service Volume Simulations for ARAIM Evolution for Rail in Urban Environment for IR of 7.5x10-6 hour, HAL of 20 meters and hybridization with IMU activated

The following main conclusions were obtained from Simulations:

- With the proposed ARAIM Evolution, both under Open Sky and Urban environments, the Requirements are fulfilled for all Rail Applications not demanding High Accuracy. The covered applications comprise:
    - Level Crossing Protection,
    - Train integrity and train length monitoring,
    - Door control supervision,
    - Trackside personnel protection,
    - Management of emergencies,
    - Location of GSM Reports,
    - Fleet Management,
    - Cargo Monitoring,
    - Energy charging,
    - Infrastructure charging,
    - Hazardous cargo monitoring,
    - Virtual Balise
- Hybridization with IMU is key to comply with the Requirements in Urban environments. Without hybridization, Rail requirements in Urban would not feasible.
- Combination of ARAIM with SBAS is also key to comply with the Rail Requirements. Comparing the performances in Open Sky scenarios between the original ARAIM Concept for Aviation and the ARAIM Evolution, the combination with SBAS helps to improve the PLs and availability performances due to the improvement on the Psat, Pconst, URA and bnom configuration parameters.
- The proposed ARAIM Evolution provides a clear added value with respect to the original ARAIM concept for Aviation. ARAIM without evolutions could only met the less stringent requirements (IR of 10-4 / hour) in Open Sky while with the ARAIM Evolution based on the combination with SBAS and hybridization with IMU, also the more stringent Rail Requirements are met even in Urban environment.

TC-07: Protection Levels and Availability Performances of ARAIM Evolution for Maritime

Different scenarios have been run with the ARAIM Service Volume to assess PL and Availability performances with different Integrity Risks and Alarm Limits corresponding to the Requirements of Maritime applications. The proposed ARAIM Evolution for Maritime based on the combination with SBAS and Dual-Antenna processing was considered in the Simulations. In particular, the combination with SBAS implied an improvement of Psat, Pconst, URA and bnom values since we can safely assume that SBAS can cope with System Level events for applications with an integrity risk requirements equivalent or lower than the one for SBAS for Aviation. Dual-antenna was simulated in the configuration by introducing a probability of rejecting satellite measurements and a reduction of the probability of FDE miss-detection.

Both Open Sky and Urban environments were also taken into account in the simulations.

The main conclusions extracted from this Test Case are summarized below:

- Modifications proposed for maritime, SBAS and the dual antenna, improved the PL's when compared to the results obtained from the original ARAIM Concept for aviation. It could also be concluded that this solution is much more robust against outliers and other local failures.
- Because of that, availability improves a lot with modifications for maritime (from former 30% to 99.9% for an Integrity Risk of 10-5 / 15 min).
- Several applications which were not covered by the original ARAIM concept can be covered by the proposed ARAIM Evolution for Maritime, in particular: General Navigation: Coastal, Port Approach, Inland Waterways, General Navigation (SOLAS); Inland waterways, Oceanography and Station-keeping / anchor-watch alarms. DP systems.

TC-08: Protection Levels and Availability Performances of ARAIM Evolution for UAVs

Different scenarios have been run with the ARAIM Service Volume to assess PL and Availability performances with different Integrity Risks and Alarm Limits corresponding to the Requirements of UAVs applications. The proposed ARAIM Evolution for UAVs based on the combination with PPP and hybridization with IMU was considered in the Simulations.

The combination of GNSS dual frequency dual constellation measurements, with PPP processing based on the High Accuracy Service and hybridized with IMU measurements, results in ARAIM availability for the open sky UAV user sector. The significant reduction in amongst others URA and improvement in available satellites with respect to the legacy ARAIM implementation for aviation, results in reduced protection levels over the globe. Without PPP, the accuracy required for open sky applications cannot be met, and other means of accuracy improvement have to be applied.

For UAV operations in the urban environment, the baseline settings considered do not result in acceptable availability. When considering lower fault probabilities of both satellite and constellation, the results are on the border of providing adequate availability. In the European service area, the requirements can be met with such settings. Although HAS does not commit on integrity, there is room for discussion on implementing such values, especially considering the extra fault detection capabilities that the Kalman Filter offers.

Next table shows the compliance with the user requirements of the non-aviation of Rail, Maritime and UAVs for both, the original ARAIM concept for Aviation and the three ARAIM Evolutions.

Table 4-2: Coverage of applications with original ARAIM Concept and proposed ARAIM Evolutions

User Sector and applications assessed	Applications covered with Original ARAIM Concept for Aviation	Applications covered with ARAIM Evolution
Rail -Cold Movement Detection -Level Crossing Protection -Train integrity and train length monitoring -Track Identification -Cross-talk protection -Door control supervision -Door control supervision in ATO (autonomous train operations)	-Fleet Management (in open sky) -Cargo Monitoring (in open sky) -Energy Charging (in open sky)	-Level Crossing Protection, -Train integrity and train length monitoring, -Door control supervision, -Trackside personnel protection, -Management of emergencies, -Location of GSM Reports, -Fleet Management, -Cargo Monitoring,

User Sector and applications assessed	Applications covered with Original ARAIM Concept for Aviation	Applications covered with ARAIM Evolution
-Trackside personnel protection -Management of emergencies -Infrastructure surveying -Location of GSM Reports -Gauging Surveys -Structural Monitoring -Fleet Management -Cargo Monitoring -Energy Charging -Infrastructure Charging - Hazardous Cargo Monitoring -Virtual Balise		-Energy charging, -Infrastructure charging, -Hazardous cargo monitoring, -Virtual Balise
Maritime -Autonomous vessels – ocean navigation -Autonomous vessels – coastal navigation -General Navigation: Ocean, Coastal, Port Approach, Inland Waterways -General Navigation (SOLAS); Inland waterways -Oceanography -Marine Engineering, construction, maintenance and management: cable and pipe laying -Ports operations: Container/Cargo management & Law enforcement -Hydrography -Bridges operation (IWW) -Marine Engineering: Dredging and construction works -Inland Waterways: bridge collision warning systems -Operations: Docking -Port Operations: Cargo Handling -Port Navigation -Station-keeping / anchor-watch alarms. DP systems -Buoyage / AtoN placement	-General Navigation: Ocean -Autonomous vessels – ocean navigation	-Autonomous Vessels: Ocean Navigation -General Navigation: Ocean, Coastal, Port Approach, Inland Waterways -General Navigation (SOLAS); Inland waterways -Oceanography -Station-keeping / anchor-watch alarms. DP systems
UAVs	-RNP0.1	-RNP0.1

User Sector and applications assessed	Applications covered with Original ARAIM Concept for Aviation	Applications covered with ARAIM Evolution
-RNP0.1 -Drone Operations under U-Space -Operations in proximity of critical infrastructures -Search & Rescue applications -Geofencing		-Drone Operations under U-Space -Operations in proximity of critical infrastructures -Search & Rescue applications -Geofencing

Finally, three different Test Cases, TC-09 to TC-11 have analysed the FDE capabilities to deal with relevant GNSS threats:

- In Rail:
  - Regarding the FDE simulations, results show the benefits of the integrity provided by ARAIM algorithm, including FDE checks, ensuring that in nominal conditions the protection level overbounds the error with the expected level of integrity;
  - The number of integrity events present in section founded proves that when multipath error is misconfigured, ARAIM is not able to overbound the real error and the safety of the positioning is not guaranteed. The greater the difference between the model and the real error, the greater the risk.
- In Maritime:
  - Regarding the FDE simulations, results show the benefits of the integrity provided by ARAIM algorithm, including FDE checks, ensuring that in nominal conditions the protection level overbounds the error with the expected level of integrity;
  - The number of integrity events present in section founded proves that when multipath error is misconfigured, ARAIM is not able to overbound the real error and the safety of the positioning is not guaranteed. The greater the difference between the model and the real error, the greater the risk. However, NLOS could have a relevant impact in ARAIM integrity since marging of safety has been reduced by an NLOS, despite no integrity event has been observed. In addition, some NLOS are big enough to be detected by the ARAIM FDE and then discarded from the solution or rejected due to a too low C/N0, increasing the PL values but not jeopardizing the safety
- In UAVs:
  - an FDE test case was used to analyse a software implementation of the proposed solution using real data. This test was divided into two parts, the first part applying the real data in open sky environment, the second part using the real data adjusted to mimic feared events.
  - It was found that for the open sky environment the protection levels stay far below the alert limit resulting in full availability of the system.
  - For the feared events five different events were simulated; a slowly accumulating fault, multipath, blanking, non-line-of-sight and multipath combined with blanking. For the event applied, the slowly accumulating fault, the FDE is capable of excluding this faulty satellites. The position output does not suffer from the event.
  - For the multipath event it is seen that some observable errors are detected by the FDE. Not all multipath effected satellites are being excluded which resulted in small errors in the position solution. The protection level increases slightly, which is a valid effect in case the accuracy is deteriorated.

- For the blanking event it can be seen that the ARAIM protection level suffer from the lower satellite availability. The same behavior was already observed from TC-08. Due to the integration with IMU measurements however the system can stay longer available (PL<AL) than if no integration with IMU would have been proposed. Due to the uncertainty of solution on the last GNSS epoch and the uncertainty of the IMU the protection level will inflate (slowly). This will result in an unavailability over time.
- For the non-line-of-sight events the same behavior as for the multipath event was seen. The FDE was not able to detect or correct all non-line-of-sight resulting in a slightly lower accuracy of the solution. In this event it also seen that the protection level is increased as expected.
- As shown for the blanking event, the multipath combined with banking event shows that the solution has a better availability than only the pure ARAIM solution. The inflation of the PL will result in unavailability over time. The influence of user dynamics was also visible during this event.

4.5. DISSEMINATION

The Project was presented in different fora, in particular:

- WG-C
- EUROCAE WG5 SG6
- Workshop with HELMET Project

In addition, an Abstract for presenting the outcomes of ARAIMTOO in ION GNSS 2022 was accepted. The corresponding paper and presentation was developed in close coordination with EC.

An Abstract for presenting more technical outcomes in ION ITM 2023 will be submitted.

An Abstract for presenting the outcomes of ARAIMTOO focused on UAVs will be submitted for the European Navigation Conference (ENC).

5. TECHNICAL PROJECT STATUS

5.1. WORK PACKAGES

The figure below shows the work breakdown structure, and indicates the company leading each WP/task and the companies of the consortium supporting the leader as contributors to the corresponding tasks:

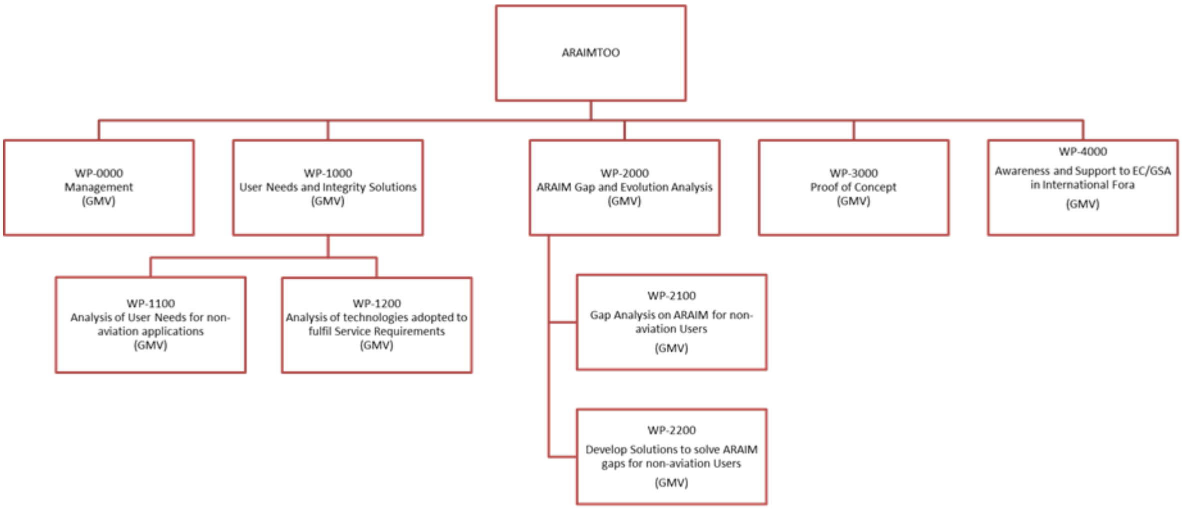

Figure 5-1: Work Breakdown Structure

All Work Packages (WP) activities have been launched and finalized at the time of preparation of the current report:

- WP0000: Management
- WP1000: User Needs and Integrity Solutions
  - WP1100: Analysis on User Needs for non-aviation applications
  - WP1200: Analysis of Technologies adopted to fulfil the Service Requirements
- WP2000: ARAIM Gap and Evolutions Analysis
  - WP2100: ARAIM Gap Analysis
  - WP2200: ARAIM Evolutions Analysis
- WP3000: Proof-Of-Concept
- WP4000: Awareness and Support to EC/GSA in International Fora
  - WP4100: Awareness Actions
  - WP4200: Support EC/GSA in International Fora

A high level view of the status of each started WP is included hereafter. It is important to remark that the effort for implementing potential comments gathered in the ARAIMTOO Final Review, has not been taken into account in the advanced status estimations. This is, we consider the Work Packages closed with the delivery of the KO+12m data-package even if additional comments could be received in the ARAIMTOO Final Review. The same holds for the improvement of the Dissemination material.

It is also important to remark that the progress of WP4000 has been estimated to be 100% even if at the time of this writing, not all the dissemination meetings have been attended.

WP No	WP Description	Responsible	Status	Advanced Status
0000	Management	GMV	Open	100%
1000	User Needs and Integrity Solutions	GMV	Open	100%
2000	ARAIM Gap and Evolutions Analysis	GMV	Open	100%
3000	Proof-Of-Concept	GMV	Open	100%
4000	Awareness and Support EC/GSA in International Fora	GMV	Open	100%

5.2. PROBLEMS, LIMITATIONS AND UNEXPECTED POINTS

No significant problems appeared during the reporting period.

The identified risks in ARAIMTOO Project Management Plan (see the status in section 8.) have been closed.

5.3. WP0000: MANAGEMENT

Objective: Overall management of the project, coordination and interface with the customer.

Activities done during this period (T0+10 to T0+12):

- Maintenance of the Travel Plan
- Delivery of the Final Report
- Project Management
- Quality Assurance
- Configuration Management
- Consortium Management

Progress: 100%

Status: Closed

5.4. WP1000: USER NEEDS AND INTEGRITY SOLUTIONS

5.4.1. WP1100: ANALYSIS OF USER NEEDS FOR NON-AVIATION APPLICATIONS

Objective: The objective of this work package is to analyse the user needs of non-aviation applications

Activities done during this period (T0+10 to T0+12):

- None

Progress: 100%

Status: Closed

5.4.2. WP1200: ANALYSIS OF TECHNOLOGIES ADOPTED TO FULFILL SERVICE REQUIREMENTS

Objective: The objective is to analyse the competing technologies with ARAIM which are used to fulfill the service requirements.

Activities done during this period (T0+10 to T0+12):

- None

Progress: 100%

Status: Closed

5.5. WP2000: ARAIM GAP AND EVOLUTIONS ANALYSIS

5.5.1. WP2100: GAP ANALYSIS ON ARAIM FOR NON-AVIATION USERS

Objective: conduct a gap analysis on ARAIM for non-aviation applications.

Activities done during this period (T0+10 to T0+12):

- None

Progress: 100%

Status: Closed

5.5.2. WP2200: DEVELOP SOLUTIONS TO SOLVE ARAIM GAPS FOR NON-AVIATION USERS

Objective: Develop solutions to solve the identified gaps on ARAIM for non-aviation applications.

Activities done during this period:

- Third version of D223 describing ARAIM Evolutions
- Delivery of D223 v3.0

Progress: 100%

Status: Closed

5.6. WP3000: PROOF-OF-CONCEPT

Objective: conduct proof-of-concept of the ARAIM concepts proposed for non-aviation users.

Activities done during this period:

- Execution and analysis of third batch of Test Cases
- Delivery of D313 v3.0

Progress: 100%

Status: Closed

5.7. WP4000: AWARENESS AND SUPPORT EC/GSA IN INTERNATIONAL FORA

Objective: raise awareness of the results of the project and support EC/GSA in International Fora.

Activities done during this period:

- Maintenance of Dissemination Plan
- Continuation of support activities
- Preparation of all Dissemination material, including Abstracts, draft papers and draft presentations for 4 conferences
- Delivery of D410

Progress: 100%

Status: Closed

6. MANAGEMENT STATUS

6.1. SCHEDULE STATUS

The detailed project schedule is presented in the Gantt charts reproduced below. In order to generate the Gantt charts, a T0 (15 days after signature of the contract by the last party) of July 23rd, 2021 has been reflected.

It has been accomplished to submit the Final Report within 1 year to the start of the project.

The following Gantt charts are reproduced and explained below:

- Milestones and External Inputs
- WP0000: Management
- WP1000: User Needs and Integrity Solutions
- WP2000: ARAIM Gap and Evolutions Analysis
- WP3000: Proof-Of-Concept
- WP4000: Awareness and Support EC/GSA in International Fora

Complete Gantt Chart (support WPs not shown)

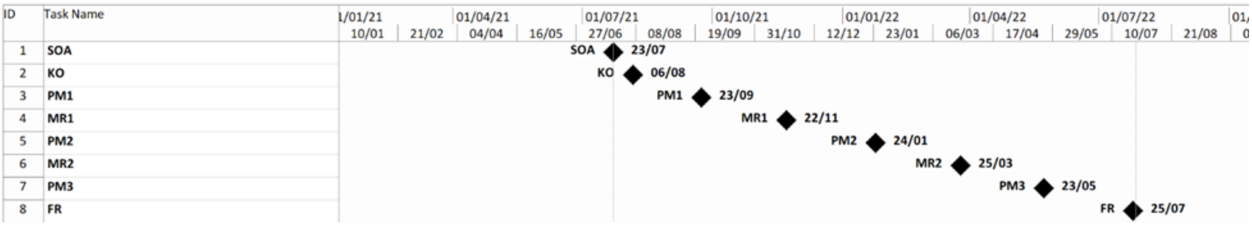

Figure 6-1: Proposed Milestones schedule

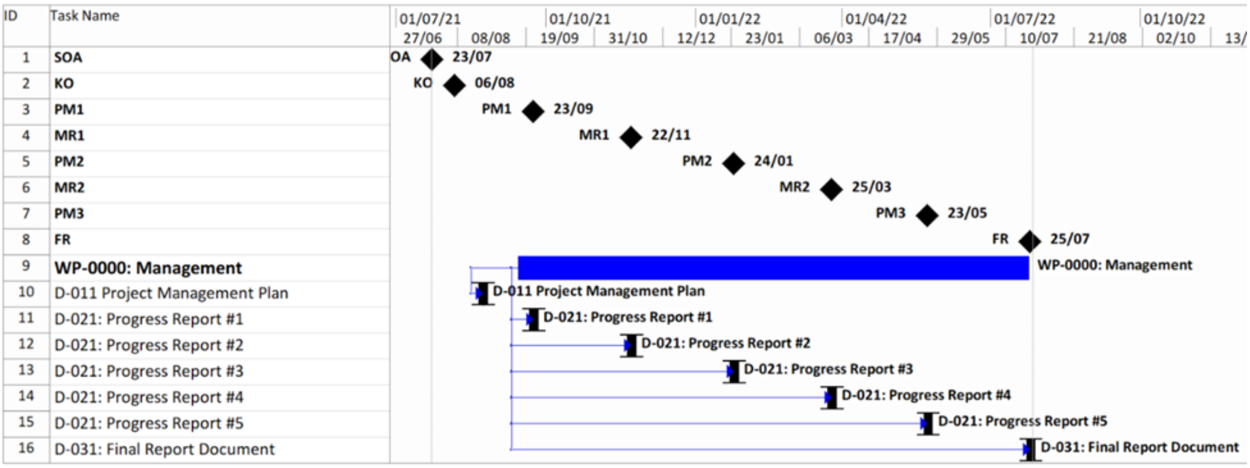

Figure 6-2: WP0000 proposed schedule

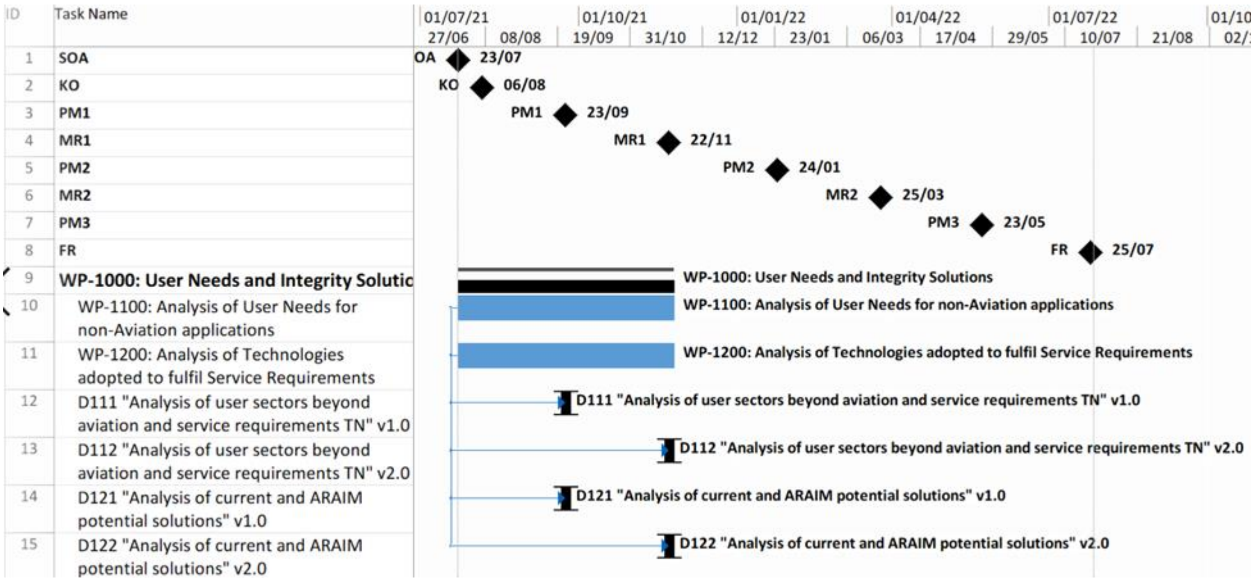

Figure 6-3: WP1000 Proposed schedule

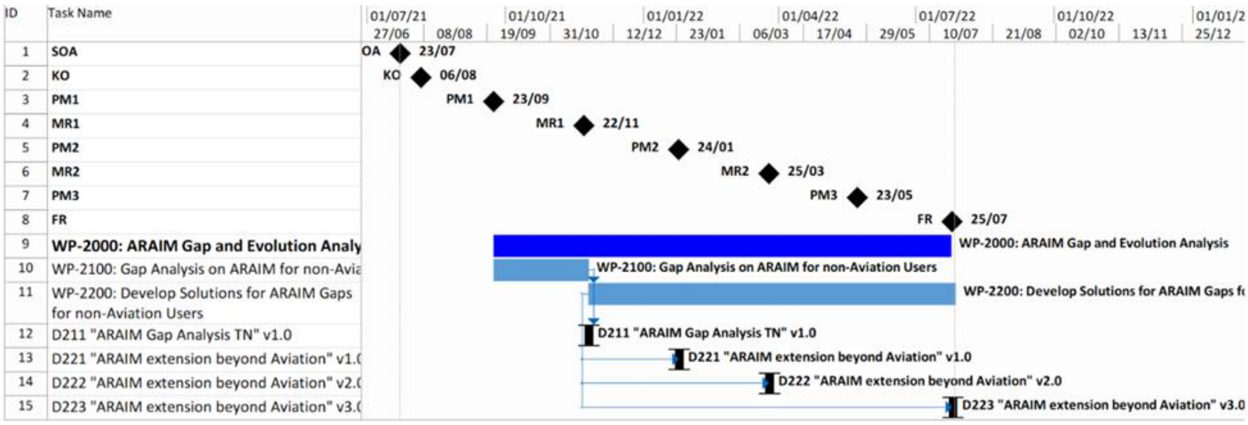

Figure 6-4: WP2000 Proposed schedule

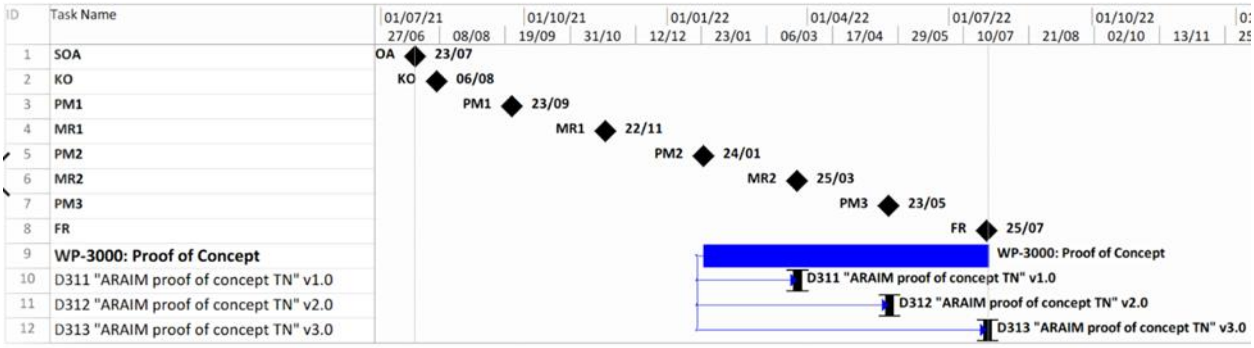

Figure 6-5: WP3000 Proposed schedule

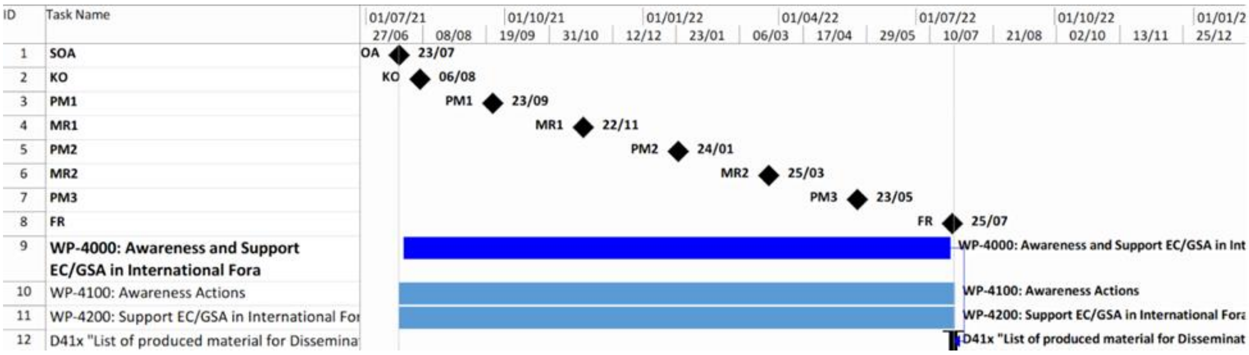

Figure 6-6: WP4000 Proposed schedule

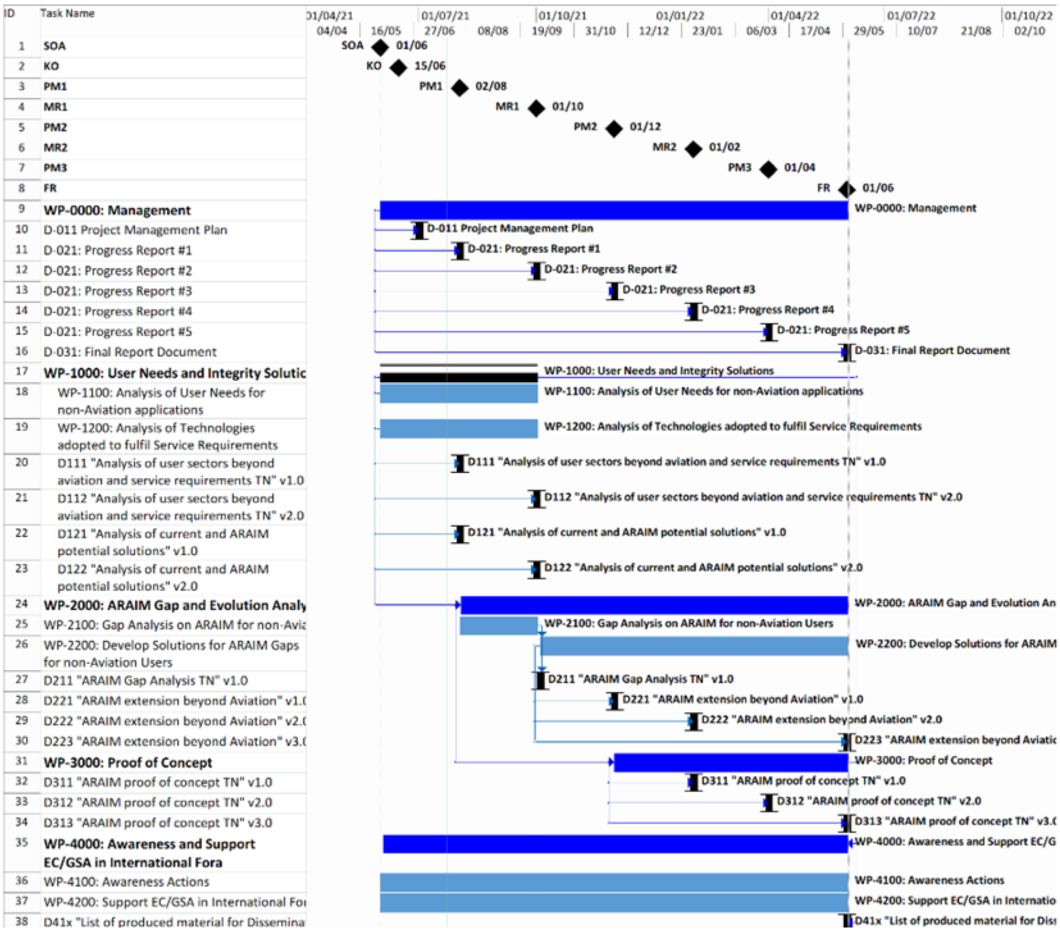

Figure 6-7: Complete Gantt Chart

6.2. MEETINGS

Next table includes ARAIMTOO project meetings status in the context of the project.

Section 9. provides the Travel Plan for meetings with stakeholders and conferences.

Name	Acronym	Date	Status	Remarks
Kick-Off Meeting	KOM	T0+15d	Closed	
Progress Meeting 1	PM1	T0+2m	Closed	
Milestone Review 1	MR1	T0+4m	Closed	
Progress Meeting 2	PM2	T0+6m	Closed	
Milestone Review 2	MR2	T0+8m	Closed	
Progress Meeting 3	PM3	T0+10m	Closed	
Final Review	FR	T0+12m	Pending	

Table 6-1: Project meetings

6.3. DOCUMENT DELIVERY STATUS

The following table includes the documents delivered as part of the ARAIMTOO deliverables:

ID	Document Title	WP	Status	Version-Date	Remarks
D011	Project Management Plan (PMP, including Travel Plan and Risk Management Plan))	0000	Closed	1.0 at Proposal 2.0 at 23/08/21 2.1 at 13/09/21	
D021	Progress Report x	0000	Closed	D021_T0+2 at 15/09/2021 D021_T0+4 at 10/11/2021 D021_T0+6 at 19/01/2022 D021_T0+8 at 21/03/2022 D021_T0+10 at 24/05/2022	
D031	Final Report Document	0000	Closed	1.0 at 18/07/2022 1.1 at 20/09/2022	
D111	Analysis of user sectors beyond aviation and service requirements TN (v1.0)	1000	Closed	V1.0 at 15/09/2021 V1.1 at 05/10/2021	
D112	Analysis of user sectors beyond aviation and service requirements TN (v2.0)	1000	Closed	V2.0 at 10/11/2021 V2.1 at 12/2021	
D121	Analysis of current and ARAIM potential solutions (v1.0)	1000	Closed	V1.0 at 10/11/2021 V1.1 at 05/10/2021	
D122	Analysis of current and ARAIM potential solutions (v2.0)	1000	Closed	V2.0 at 10/11/2021 V2.1 at 12/2021	
D211	ARAIM gap analysis TN (v1.0)	2000	Closed	V1.0 at 10/11/2021 V1.1 at 12/2021	
D221	ARAIM extension beyond Aviation (v1.0)	2000	Closed	V1.0 at 19/01/2022 V1.1 at 16/02/2022	
D222	ARAIM extension beyond Aviation (v2.0)	2000	Closed	V2.0 at 21/03/2022 V2.1 at 29/04/2022	

ID	Document Title	WP	Status	Version-Date	Remarks
D223	ARAIM extension beyond Aviation (v3.0)	2000	Closed	V3.0 at 18/07/2022 V3.1 at 20/09/2022	
D311	ARAIM proof of concept TN (v1.0)	3000	Closed	V1.0 at 21/03/2022 V1.1 at 29/04/2022	
D312	ARAIM proof of concept TN (v2.0)	3000	Closed	V2.0 at 24/05/3033	
D313	ARAIM proof of concept TN (v3.0)	3000	Closed	V3.0 at 18/07/2022 V3.1 at 20/09/2022	
D41x	List of produced material for dissemination For each dissemination event, a description of the feedback received will be included. -Intermediate versions: After each event, an intermediate version containing the material and the feedback received will be issued within 1 month from the event. -Final Version: T0+12 months Full list of material	4000	Closed	V1.0 at 18/07/2022	
SW Delivery	SW Delivery	3000	Closed		SW Delivery provided for ARAIMTOO FR Close-out
Data eliver y	Data Delivery	3000	Closed		Data Delivery provided for ARAIMTOO FR Close-out

Table 6-2: ARAIMTOO Deliverables status

6.4. ACTION STATUS

All the ARAIMTOO actions have been implemented. See Section 10. in which the Excel sheet managing the Actions along the project is attached.

6.5. RIDS IMPLEMENTED DURING THE PROJECT REVIEWS

Next table provides the RIDS shared with the consortium. All the RIDS resolutions were agreed between the consortium and EC and were implemented in the deliverables.

Table 6-3: RIDS implemented during the project reviews

Review	RIDS Excel File
T0+1	ARAIMTOO-RIDS_PMPv2_IM_GMV.xlsx
T0+2	ARAIMTOO-RIDS_D111_D121_IM_GMV.xls ARAIMTOO-RIDS_D111_D121_MP_GMV.xl
T0+4	ARAIMTOO-RIDS_MR1_Final.xlsx
T0+6	ARAIMTOO-RIDS_T0+6_GMV_for_2.0.xlsx
T0+8	ARAIMTOO-RIDS_T0+8_GMV.xlsx
T0+10	ARAIMTOO-RIDS_T0+10_EC_Impl_Final.xl
T0+12	ARAIMTOO-RIDS_T0+12_EC_GMV_EC.xlsx

7. CONTRACTUAL ASPECTS

- Status of Specific contract EC signature:
  - Already signed EC+GMV (08/07/2021)
- Status of Specific Sub-contracts with NLR & VVA:
  - NLR: Already signed GMV+NLR
  - VVA: Already signed GMV+NLR

8. IDENTIFIED RISKS

The following table includes the risks identified in the project:

Risk Id	Probability	Severity	Risk / Mitigation Actions	Status
ARAIMTOO-RISK-001	Medium	Medium	**Impact on the outcomes of the project due to potential difficulties in the market penetration of ARAIM for non-Aviation applications** For the outcomes of the project being relevant, if a potential ARAIM concept for non-aviation applications is developed, the market penetration should be significant. The ARAIM concept has been developed for civil aviation applications and it could be perceived by the non-aviation community as not suitable for the needs of non-aviation applications. Non-aviation users could be unfamiliar with ARAIM concepts. It is of extreme importance to gather carefully the user needs and the technology competitors to find niche applications for the penetration of ARAIM. As a mitigation measure at proposal level it is proposed to to conduct validation interviews with relevant experts for the outcomes of the desk research to be performed in Task 1 in order to count with the point of view of non-aviation users, ARAIM experts and other relevant stakeholders. The consortium plans to work in close coordination with experts by means of dedicated interviews in order to take into account the users point of view.	Closed
ARAIMTOO-RISK-002	High	High	**Technology competitors** Again, as for the previous risk, the outcomes of the project will be more valuable as the potential ARAIM service for non-aviation applications achieves high penetration in the different sectors. Different technology competitors exist for the market penetration of ARAIM in non-aviation applications such as SBAS, GBAS, RAIM, etc. In addition, technologies are evolving to cover the evolving user needs (for example, EC has recently launched a study for the definition on an EGNOS Service for road payment critical applications). The relevance of the technology competitors of ARAIM and the evolving context are a clear risk for the outcomes of the project. As a mitigation action, the consortium proposes to carefully evaluate the user needs and technology competitors within Task 1. In particular, we find very important to have not only the static view but also to analyse and foresee the evolutions of both the non-aviation applications user needs and the possible evolutions of the competitor technologies with the purpose of identifying the most suitable Cases of Interest for the ARAIM penetration.	Closed
ARAIMTOO-RISK-003	High	Medium	**Wide and open scope for the project activities** The consortium after analysing carefully the Tender, thinks that the topics to be addressed are quite open and ambitious which could make the scope of the activities to be performed very wide and which could imply a risk of dispersion of the project outcomes. Integrity/safety topics, ARAIM techniques, different and varied markets (Road, Maritime, Rail, UAVs, etc) with many applications therein, each of them having a significant complexity, many technology competitors, standardisation, multi-sensor fusion, PPP, authentication… all these topics are to be taken into account in the project.	Closed

Risk Id	Probability	Severity	Risk / Mitigation Actions	Status
			As a mitigation action the key personnel to work in the project has been carefully selected, with a high degree of seniority and with transversal knowledge within the different topics among the GNSS field in order to count with a deep expertise for all the different topics to be addressed in the project. In addition, during the project execution, the consortium proposes to use a straightforward methodology, trying to focus the effort on the most relevant aspect to be addressed by means of dedicated trade-offs, in close coordination with the customer.	
ARAIMTOO-RISK-004	Medium	High	**Technical risk on the adaptation of integrity concepts developed for aviation to other segments** This project has a high degree of innovation associated from a technical perspective since the main goal is to adapt the ARAIM concept, originally designed for civil aviation applications, to other GNSS sectors such as Road, Rail or Maritime, with different environments (usually harsh environments where local effects are relevant, as opposed to aviation in which a clean environment is present), different user needs and requirements, different operational concepts, etc. This complexity implies a technical risk of not being able to find suitable non-aviation applications for ARAIM or not finding suitable evolutions of the ARAIM concept, or which could imply too stringent commitments to the GNSS core constellations, or which could demand complex and expensive evolutions of the ARAIM architecture. As a mitigation actions the consortium and the project team has been carefully selected to provide technical excellence to the project technical tasks. In particular, the Technical Manager selected has +17 years of experience in GNSS and has participated in many different activities on ARAIM and GNSS integrity aspects in non-aviation domain. The Technical Manager will lead all the technical tasks and will periodically monitor the technical work of the project team	Closed
ARAIMTOO-RISK-005	Medium	Medium	**Covid Impact on meetings** The Covid situation could impact the physical meetings foreseen and potentially the schedule of the project. As a mitigation action we propose to monitor the Covid situation, being in contact with EC in advance to decide on the meetings, have teleconference systems available as a back-up and plan with time enough the meetings.	Closed

9. TRAVEL PLAN

Table 9-1 below provides the list of foreseen meetings and attendance of the different companies.

This list of meetings includes all meetings and reviews requested in the Tender Specifications.

For each meeting, the following information is provided:

- Meeting name
- Meeting acronym
- Foreseen date
- Proposed meeting location: Note that the ITT prescribes that certain reviews are held by teleconference.
- Estimated duration in days
- Number of participants per company

Name	Acronym	Date	Venue	Duration (days)
Kick-Off Meeting	KOM	T0+15d	Telco	1
Progress Meeting 1	PM1	T0+2m	Telco	1
Milestone Review 1	MR1	T0+4m	Telco	1
Progress Meeting 2	PM2	T0+6m	Telco	1
Milestone Review 2	MR2	T0+8m	Telco	1
Progress Meeting 3	PM3	T0+10m	Telco	1
Final Review	FR	T0+12m	EC (Brussels)	1

Table 9-1: Project Meetings[1]

In addition to project milestone meetings, a number of travels are foreseen during the project for meeting stakeholders or participating in relevant fora or congresses, see the following table, in which one participant of the corresponding company has been assumed.

Name	Acronym	Date	Venue	Duration (days)
4 Meetings in EU	-	TBD	TBD	2
2 International Conferences (outside EU)	-	TBD	TBD	3

Table 9-2: Other meetings

Next table provides potential Conferences which could be attended in the context of WP4 Dissemination Activities.

Conference	Link with project	Date	Location	Deadline for submission	Comments
ION GNSS+	Renowned GNSS conference, presentation of technical papers for a wide audience	September 2022	Denver Colorado, USA	Abstracts: March 2022 Paper: End September 2022	
ION ITM	Renowned GNSS conference, presentation of technical papers for a wide audience	End January 2023	Long Beach, California, USA	Abstract: 7/10/22 Paper: 1/12/22	
European Navigation Conference	Renowned GNSS conference, presentation of technical papers for a wide audience	November 2022	UK (TBC)	Abstract: Autumn 2022 (TBD) Full paper: TBD	Call for papers for 2021 Conference closed
IALA	Technical association in field of Maritime	2 meetings per year	Depends on WG meeting: ENG or ENAV are the relevant WG for ARAIMTOO activity	Deadline for submission: 1 month before meeting Two meetings per year, in October and March	
Conference on Marine Navigation and Safety of Sea Transportation (transnav)	Maritime conference	June 2023	TBD	Deadline for Abstract submission: End December 2022 Full paper: April 2023	
Journal Of Marine Science and Engineering	Journal	N/A	N/A	N/A	As not many maritime conferences with GNSS topic being relevant have been identified, a possibility is to publish a paper in this Journal
RailTech Europe	Tech conference in field of Rail	8/03/2022	Online event	No information found (participation may be difficult since it's a very general conference while GNSS/ARAIM may not be of interest for general audience)	

Conference	Link with project	Date	Location	Deadline for submission	Comments
Innorail	Tech conference in field of Rail	November 2022		No information found in the webpage (https://innorail2021.hu/en/program/) it seems that there are panel discussions on different topics rather than presentation	
Innotrans	Tech conference on transport and mobility	20 - 23 Septembe r 2022	Berlin, Germany	N/A	Rather than a presentation, the disseminatio n material would consist on producing a project leaflet to be distributed in EC stand
International conference on Unmanned aircraft systems	Tech conference in field of UAVs, incl. call for papers	June 2022	Croatia	February 1, 2022: Full Papers/ Invited Papers/Tutorial Proposals Due April 15, 2022: Acceptance/Rejection Notification May 10, 2022: Upload Final, Camera Ready Papers; Early Author Registration Deadline June 21-24, 2022: Conference dates	
Galileo User Assembly (European Space Week)	Conference for Galileo Users	December 2021 or 2022	TBD	Participation to be coordinated by EC/EUSPA	2021 edition too soon for presenting consolidated material
Navitech (ESA)	General PNT conference	4-8 April 2022	ESTEC (Netherlands)	Abstract submission deadline is 31th of October 2021	
International navigation conference (Royal Institute of Navigation)	General PNT conference	November 2022	TBD	Based on 2021 dates: Stage 1: submit your abstract before 31 May 2022, and Stage 2: if you are successful in your abstract submission you will be invited to submit your full paper before 20 August 2022.	
International Conference on Localization and GNSS (AESS-IEEE-sensors)	General PNT conference	June 2022	Tampere, Finland	Based on 2021 dates: Submission deadlines IEEE-copyrighted papers: March 5, 2022 (extended) Work-in-Progress/industrial papers: April 1 (abstract) / April 15 (full paper) Notification schedule IEEE-copyrighted papers: April 12, 2022 (extended) Work-in-Progress/industrial papers: May 4, 2022 (extended)	

Conference	Link with project	Date	Location	Deadline for submission	Comments
International Technical Symposium on Navigation and Timing (CNES, ENAC)	General PNT conference	June 2022	Toulouse, France	Abstract submission mid May	
Enhanced Safety of Vehicles ESV (Giappone)	Tech conference on automotive	April 3-6, 2023	Yokohama, Japan,	N/A	Bi-annual conference, next is on 2023, too late for ARAIMTOO
ITS world congress	Tech conference on automotive	October 2022	Los Angeles (US)	Based on 2021 dates: Submission deadline for all types of Papers, Business Presentations and Proposed Sessions – 12 February 2022 The platform remains open for the completion of submissions – 22 February 2022 Notification of status to paper, business presentations authors and Session proposals – April 2022	
IEEE intelligent vehicle symposium	Tech conference on automotive	July 2022	Aachen, Germany	Based on 2021 dates: Feb. 1, 2022 → February 15th, 2022 Submission Deadline April 5, 2022 → April 19th, 2022 → April 26th, 2022 Notification Deadline May 10, 2022 → May 24th, 2022 → May 31st, 2022 → June 4, 2022 Camera-ready Deadline June 11th, 2022 → June 16th, 2022 Video Presentation Submission Deadline	
IEEE international conference on intelligent transportation systems	Tech conference on automotive	Septembe r 2022	TBD	February, 2022 – Proposal due for special sessions March, 2022 – Proposal due for workshops/tutorials/industrial sessions March April, 2022 – Initial submission deadline for regular, special session, and workshop papers June, 2022 – Notification of paper acceptance July, 2022 – Final paper submission deadline	

Table 9-3: Proposed Meeting Plan

The Conferences to be attended have been discussed with EC at T0+5 once the 3 more promising User Sectors have been selected.

As discussed with EC, Abstracts will be prepared for the following Conferences:

- **ION GNSS 2022 with a general presentation of the project including technical elements.**
- **ION ITM 2023 with a more technical presentation focused on ARAIMTOO Experimentation and ARAIM Evolutions**
- **European Navigation Conference 2022 with a presentation more focused on a specific User Sector (Rail or UAVs).**

10. ANNEX 1: ARAIMTOO CLOSED ACTIONS

The ARAIMTOO Excel with Actions including all the closed actions is attached in the following.

Actions_ARAIMTOO.xlsx

END OF DOCUMENT