

ANALYSIS ON CAPACITY OF GALILEO, EGNOS AND COPERNICUS TO CONTRIBUTE TO THE OPERATIONS AND IDENTIFICATION OF GAPS

AVIS

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1. INTRODUCTION

1.1. PURPOSE

The present document is the “Analysis on Capacity Of Galileo, EGNOS and Copernicus to Contribute to the Operations and Identification of Gaps” document for the AVIS project. The main purpose of this document is, starting from the previous identified user needs, to identify how EGNSS and Copernicus can support for the fulfilment of these needs .

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. describes the methodology used for this document.
- Chapter 5. assesses the capability of EGNSS and Copernicus to meet the user needs
- Chapter 0 will identify gaps on the capacity of EGNSS and Copernicus to meet user requirements

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]	SERVICE CONTRACT CONTRACT NUMBER – MOVE/D3/2022-501 – MOVE/2022/OP/0029 for “Study with pilot projects on EU Space Data for automated vessels on European inland waterways”	Contract number: MOVE/D3/2022-501 – MOVE/2022/OP/0029	-	10 May 2023
[AD.2]	Study with pilot projects on EU Space Data for automated vessels on European inland waterways Tender Specifications	Call for tenders MOVE/OP/2022/0029 MOVE/D3/FV-2022-501	-	10 May 2023
[AD.3]	AVIS Technical Proposal	GMV 11852/23 V1/23	1.0	13 July 2023

2.2. REFERENCE DOCUMENTS

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
[RD.1.]	River and Lake Ice Extent 2016-present (raster 20 m), Europe, daily — Copernicus Land Monitoring Service (https://land.copernicus.eu/en/products/water-bodies/high-resolution-river-and-lake-ice-extent)	-	-	September 2024
[RD.2.]	Christopher B. Obida, George A. Blackburn, James D. Whyatt, Kirk T. Semple, River network delineation from Sentinel-1 SAR data, International Journal of Applied Earth Observation and Geoinformation, Volume 83, 2019, 101910, https://doi.org/10.1016/j.jag.2019.101910	-	-	November 2019
[RD.3.]	Galileo Open Service - Service Definition Document	GALILEO OS SDD	1.3	Nov 2023
[RD.4.]	Galileo High Accuracy Service - Service Definition Document	HAS SDD	1.0	Jan 2023
[RD.5.]	Galileo OSNMA SIS ICD	OSNMA SIS ICD	1.1	Oct 2023
[RD.6.]	EGNOS - Open Service - Service Definition Document	EGNOS OS SDD	3.0	Nov 2024
[RD.7.]	Su, Z.; Xiang, L.; Steffen, H.; Jia, L.; Deng, F.; Wang, W.; Hu, K.; Guo, J.; Nong, A.; Cui, H.; et al. A New and Robust Index for Water Body Extraction from Sentinel-2 Imagery. <i>Remote Sens.</i> 2024 , <i>16</i> , 2749. https://doi.org/10.3390/rs16152749	-	-	Dec 2024
[RD.8.]	Kansara, P.; Lakshmi, V. Water Levels in the Major Reservoirs of the Nile River Basin—A Comparison of SENTINEL with	-	-	Dec 2024

Ref.	Title	Code	Version	Date
	Satellite Altimetry Data. <i>Remote Sens.</i> 2022 , <i>14</i> , 4667. https://doi.org/10.3390/rs14184667			
[RD.9]	M. Niroumand-Jadidi, C. J. Legleiter and F. Bovolo, "River Bathymetry Retrieval From Landsat-9 Images Based on Neural Networks and Comparison to SuperDove and Sentinel-2," in <i>IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing</i> , vol. 15, pp. 5250-5260, 2022, doi: 10.1109/JSTARS.2022.3187179.	-	-	Dec 2024
[RD.10]	Ruciński, M.; Woźniak, E.; Kulczyk, S.; Derek, M. Small Recreational Boat Detection Using Sentinel-1 Data for the Monitoring of Recreational Ecosystem Services. <i>Remote Sens.</i> 2023 , <i>15</i> , 1807. https://doi.org/10.3390/rs15071807	-	-	Dec 2024
[RD.11]	Algorithm theoretical basis document – High Resolution Ice products Europe (SENTINEL-1 and SENTINEL-2) , https://land.copernicus.eu/en/products/water-bodies/high-resolution-river-and-lake-ice-extent	-	-	Dec 2024
[RD.12]	Maritime navigation and radiocommunication equipment and systems – Global navigation satellite systems (GNSS) – Part 3 Galileo receiver equipment. Performance requirements, methods of testing and required test results.	IEC 61108-3	1.0	May 2010

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
Accuracy (Copernicus)	<p>Accuracy is a measure of how often the binary classification model correctly predicts the classes. It is the ratio of the number of correct predictions (both true positives and true negatives) to the total number of predictions made.</p> $\text{Accuracy} = \frac{\text{True Positives} + \text{True Negatives}}{\text{Total Instances}}$ <ul style="list-style-type: none"> • True Positives (TP): Instances where the model correctly predicts the positive class. • True Negatives (TN): Instances where the model correctly predicts the negative class. • Total Instances: The total number of instances in the dataset, which is the sum of true positives, true negatives, false positives, and false negatives.
Commission Error (Copernicus)	<p>Commission Error, also known as Type I Error or False Positive Rate, occurs when the model incorrectly predicts the positive class for an instance that is actually negative. It measures the proportion of negative instances that are incorrectly classified as positive.</p> $\text{Commission Error} = \frac{\text{False Positives}}{\text{False Positives} + \text{True Negatives}}$ <ul style="list-style-type: none"> • False Positives (FP): Instances where the model incorrectly predicts the positive class. • True Negatives (TN): Instances where the model correctly predicts the negative class.
Omission Error (Copernicus)	<p>Omission Error, also known as Type II Error or False Negative Rate, occurs when the model incorrectly predicts the negative class for an instance that is actually positive. It measures the proportion of positive instances that are incorrectly classified as negative.</p> $\text{Omission Error} = \frac{\text{False Negatives}}{\text{False Negatives} + \text{True Positives}}$ <ul style="list-style-type: none"> • False Negatives (FN): Instances where the model incorrectly predicts the negative class.

Concept / Term	Definition
	<ul style="list-style-type: none"> • True Positives (TP): Instances where the model correctly predicts the positive class.
Positional Accuracy (Copernicus)	Positional Accuracy measures how close the estimated boundaries are to the actual boundaries (for river extent). For river depth, this measures the deviation between the actual depth and the estimated depth.

3.2. ACRONYMS

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

Table 3-2 Acronyms

Acronym	Definition
AVIS	Automated Vessels on European Inland Waterways
CAS	Commercial Authentication Service
CCNR	Central Commission for the Navigation of the Rhine
COG	Course Over Ground
CPA	Closest Point of Approach
DEM	Digital Elevation Models
EFAS	European Foot & Ankle Society
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European GNSS
ENC	Electronic Navigational Charts
GLOFAS	Global Flood Awareness System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HAS	High Accuracy Service
HDT	Heading
ICD	Interface Control Document
IEC	International Electrotechnical Commission
IWW	Inland Waterways
NWIO	Navigational Warning Information Overlay
OSNMA	Open Service Navigation Message Authentication
PDOP	Position Dilution of Precision
PPP	Precise Point Positioning
ROT	Rate Of Turn
SAR	Search and Rescue
SBAS	Satellite-Based Augmentation System
SDD	Service Definition Document
SPP	Single Point Positioning
SIS	Signal in Space
SOG	Speed Over Ground

Acronym	Definition
SPP	Standard Point Positioning
TBA	Time Between Authentication
WUL	Worst User Location
XTE	Cross-Track Error

4. CONTEXT AND METHODOLOGY

In this document produced in AVIS WPx2100 "User Requirements"

The high-level methodology for the work performed is:

- Step 1: From the previous identified user needs in D2.1, identify **how EGNSS and Copernicus can support** for the fulfilment of these needs (Section 5.).
- Step 2: analyze the outcomes of WP2100 to understand the user needs to perform the different automated operations for the selected IWW navigation operation scenarios. This analysis will be complemented with a study of the capability of EU Space Data to fulfill the user requirements identified for GNSS and Copernicus, together with the gaps to meet such compliance (Section 0)

5. ASSESSMENT ON THE CAPABILITY OF EGNSS AND COPERNICUS TO SUPPORT TO FULLFIL THE IWW USER NEEDS

5.1. EGNSS ASSESSMENT

This section discusses how the services provided by EGNSS help meet the needs for autonomous/automated navigation identified in D2.1. "User Requirements for Automated Navigation". In this document, a list of user needs has been identified in order to achieve autonomous navigation in inland waterways with an automation level 3, according to the CCNR scale.

The needs analysis has shown that there are different types of needs. This variety implies that, although many of the needs identified can be met (totally or partially) by EGNSS services, not all of them can be met.

EGNSS services are an essential in the operation of autonomous vessels by addressing a variety of navigational needs. Particularly, the European EGNSS services provider, Galileo, broadcasts several types of GNSS services. Among of them, Galileo Open Service (OS). The Galileo OS service provides position, velocity and time information with sufficient accuracy to cover many of the most basic positioning needs. The performance that can be obtained depends on the environmental conditions, both in terms of satellite visibility and atmospheric conditions. In nominal conditions with good visibility, we can expect that the accuracy obtained using Galileo OS can be in the order of 3 m. In addition, from the position and velocity information, it is possible to derive other navigation parameters such as course, rate of turn, and heading.

Then, it should be noted that even if other Galileo services are used, the Galileo OS service can always be used, so it is considered a fundamental service and helps to satisfy, totally or partially, all the needs that can be covered by the EGNSS services.

Regarding accuracy requirements, if more accuracy is needed, the data provided by the Galileo High Accuracy Service (HAS) can be used in the computation of position and velocity, maintaining the Single Point Positioning (SPP) algorithm. With this service, accuracy performance can be improved to the order of about 1 meter. Thus, those needs for higher accuracy can begin to be met using HAS SPP.

For a very accurate positioning (vertical and horizontal), the Galileo HAS data can be combined with a Precise Point Positioning (PPP) algorithm, improving the accuracy performances. For example, incrementing the vertical positioning accuracy which is particularly beneficial in areas with varying water levels or height constraints, such as passing under bridges. The high precision of this data ensures that the vessel can operate safely and effectively in challenging environments.

Furthermore, Galileo supports the calculation of integrity confidence levels. This capability enhances navigation safety by providing data and metrics that gauge the reliability of the navigation solution. Furthermore EGNSS services provide their own integrity service, called EGNOS, which is Europe's regional Satellite-based Augmentation System (SBAS). SBASs are used to augment the signals of GNSS so that they can be used for Safety-of-Life precision applications.

Related to the integrity concept, both EGNOS service and user integrity algorithms provide integrity alerts and supports quick action. This functionality is critical for dynamic decision-making, as it enables the vessel to respond quickly to positioning and navigation alerts during its operation.

EGNSS also plays also a role in maintaining resilience to external factors that might otherwise degrade navigation performance. By using a multi-frequency approach, it mitigates the impact of potential disruptions like signal interference, thus preserving navigational accuracy. However, in the case of a spoofing attack, Galileo's Open Service Navigation Message Authentication (OSNMA) offers an additional security layer by providing authentication data (similar to a digital signature) for each satellite navigation message. This authentication data can be verified to ensure that the data is originated from the original source and not by a malicious attacker.

Continuous navigation support is another key feature of EGNSS services, ensuring that the vessel's position is consistently tracked throughout its operation. According to the Galileo OS Service Definition

Document (SDD), the availability of the constellation is of a 99.5%. This uninterrupted tracking is vital for maintaining positioning information for autonomous control over the vessel.

Overall, Galileo EGNSS services support autonomous vessels by providing accurate, safe, and secure navigation data, ensuring continuous operation, and enabling timely responses to navigational challenges.

However, there are also certain limitations in the case of GNSS services. In some areas of the river, especially in areas with constructions where the visibility of the satellites can be compromised and local effects such as multipath appear. In addition, the characteristics of GNSS services make them very vulnerable to interference and there is a risk of denial of service due to interference. Therefore, it is very important that there are services and techniques that improve the safety and security of navigation.

5.1.1. EGNSS SUMMARY

The following table shows a relationship between the EGNSS services and the user needs. It is indicated which services could help to satisfy, totally or partially, the different user needs.

Table 5-1 Relationship between EGNSS services and user needs

User need	OS	OSNM A/CAS	HAS SPP	HAS PPP	EGNOS /User integrity
Know own vessel position, course, speed, RoT and heading parameters	X		X		
Info about other vessels					
Dynamic real time ENC					
Fairway info parameters (NtS, berth occupancy, lock&bridge operating times, etc)					
Safe fairway indication parameters					
Route planning parameters					
Path generation parameters					
steering code parameters (e.g. XTE)					
engine (propulsion) code parameters					
extra remote control parameters					
to be able to provide a confidence level in the solution	X				X
to be resilient to external factors that degrade the navigation performance	X	X			
to provide a solution during the whole operation	X				
to provide alerts within a specific time and react accordingly	X	X			X
To Authenticate positioning data to be able to have spoofing alarms	X	X			
vertical info under water					
water current parameters					

distance & CPA info to other targets					
vertical info above water	X			X	
high accuracy horizontal info	X			X	

5.2. COPERNICUS ASSESSMENT

5.2.1. RIVER EDGE

Copernicus Land Monitoring Service provides pan-European information about surface open water extent using Sentinel 1 and 2 satellites with a common spatial resolution of 20m from the year 2016 onwards. The data is available within 6-12 hours after the measurements taken by the satellites. A primary check around the rivers of interest found that the average revisit time is around 2-3 days. In the literature, errors for surface water extent are given in terms of confusion matrix and related performance indices¹ (not in terms of errors in distance). For open water bodies the quality of the results are given in [RD.1.]. In another study [RD.2.] involving Sentinel 1 satellites found that 75% of the detected river edges have an error of 10m (pixel size).

This denotes that Copernicus services already have the capability to deliver RIVER EDGE information in **Pan-EUROPEAN** level two to three times weekly within 6-12 hours of the measurements with a spatial resolution of 20m².

5.2.2. RIVER DEPTH/BATHYMETRY

Both Sentinel-1 and Sentinel-2 data can indirectly provide river water depth information under specific conditions or in certain regions. Sentinel-1 data is used to extract wavelength and wave direction information of water surface waves, which allows for direct estimation of water depth. On the other hand, optical signals captured by Sentinel-2 can penetrate through the water column, providing information on water depth. The blue and green bands are recommended for bathymetry estimation due to their superior penetration ability.

However, there are several errors associated with this method. The performance of satellite-derived bathymetry deteriorates with increasing water depth and the presence of constituents in the water. Optical bathymetry can estimate water depth up to 20 meters in clear water and 1 to 3 meters in turbid water. Whereas Sentinel 1 can have potential to measure water depths up to 80 meters with 10% relative error.

5.2.3. RIVER DISCHARGE/WATER SPEED

River discharge is the volume of water flowing through a river channel at any given point in time. It is typically measured in cubic meters per second (m³/s). The river discharge is measured in-situ through gauges placed in river. Speed of water in the surface of river at a point of interest has a complex dependency on river discharge and the cross-section and topography of the river around the point of interest. As a result, it cannot be measured directly. Therefore, the quantity measured through gauges placed in river is river discharge (quantity of water flowing per unit of time). Though an approximation can be made on the dependence of velocity on river depth, which can in principle arrive at the measurement of water speed. Consequently, we concentrate on the rest of this part on monitoring of river discharge. river outflow data. Copernicus Marine Environment Monitoring Service(<https://marineinsitu.eu/dashboard/>)

¹ Please consult the quality assessment report [RD.1.]

² Here we are talking about effective resolution from the Sentinel 1 and 2 satellites which are different from the pixel size.

Have placed measuring gauges along the European coastline and some of which are situated in inland rivers (see the figure below)

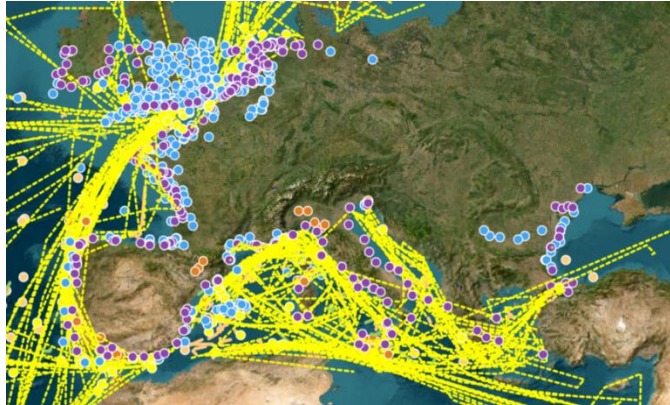


Figure 5-1 Distribution of gauges along Europe. As can be seen by blue circles, some of them are in inland rivers

Due to their sparseness, there may not be sufficient to use as an input data for inland navigation and machine learning algorithm. Moreover, relation between spectral data of the Sentinel 1 and Sentinel 2 satellites and rate of volume of water flowing is open to investigation. At present moment, there is need for further investigation of this point. In other hand, expansion of Copernicus database with data provided by gauge stations on European waterways could be sufficient for machine learning.

5.2.4.OBJECT DETECTION

Sentinel 1 and 2 along with Copernicus Land Monitoring Service can be used to Map presence of ice and other foreign bodies in an inland waterbody. In Ref 1 it is found that ice extent has an omission error rate of **30.0% (Sentinel 1) and 37% (Sentinel 2)** for snow-covered or snow-free ice. One should comment that, the process of finding river edge in Section 5.2.1 also includes detection of foreign objects (such as other boats). Moreover, due to the global nature of the satellites, it is possible to detect such objects through the length of a river. Also as mentioned in Section 5.2.1, such global detections are available every 2-3 days in Europe.

5.2.5.FLOOD FORECASTING (EFAS/GLOFAS)

EFAS (European Flood Awareness System) and GLOFAS (Global Flood Awareness System) are tools for flood monitoring and early warning. EFAS provides flood forecasts up to 15 days in advance, focusing on Europe. It offers detailed forecasts at specific locations and includes flash flood risk assessments. However, its accuracy depends on the quality of data from national services. GLOFAS, on the other hand, offers global flood forecasts up to 30 days in advance. Its spatial resolution is approximately 5.57 km at the Equator, although the flood hazard maps are generated at about 90 meters. These flood forecasting services are only available to the EFAS and GLOFAS partners.

5.2.6. COPERNICUS SUMMARY

The following table shows a relationship between the Copernicus services and the user needs. It is indicated which services could help to satisfy, totally or partially, the different user needs.

Table 5-2 Relationship between Copernicus services and user needs

User need	River edge	River depth/ bathymetry	Water speed	Object detection	Floods forecasting
Know own vessel position, course, speed, RoT and heading parameters					
Info about other vessels					
Dynamic real time ENC	X	X	X		
Fairway info parameters (NtS, berth occupancy, lock&bridge operating times, etc)					
Safe fairway indication parameters	X	X		X	
Route planning parameters	X	X			X
Path generation parameters					
steering code parameters (e.g. XTE)					
engine (propulsion) code parameters					
extra remote control parameters					
to be able to provide a confidence level in the solution					
to be resilient to external factors that degrade the navigation performance					
to provide a solution during the whole operation					
to provide alerts within a specific time and react accordingly					
vertical info under water		X			
water current parameters			X		
distance & CPA info to other targets					
vertical info above water					
high accuracy horizontal info					

5.3. EU SPACE DATA SUMMARY

The following table shows a relationship between the EU Space data services and the user needs. It is indicated which services could help to satisfy, totally or partially, the different user needs.

Table 5-3 Relationship between EU Space data and user needs

User need	OS	OSNM A/CAS	HAS SPP	HAS PPP	EGNOS /User integrity	River edge	River depth/ bathymetry	Water speed	Object detection	Floods forecasting
Know own vessel position, course, speed, RoT and heading parameters	X		X							
Info about other vessels										
Dynamic real time ENC						X	X	X		
Fairway info parameters (NtS, berth occupancy, lock&bridge operating times, etc)										
Safe fairway indication parameters						X	X		X	
Route planning parameters						X	X			X
Path generation parameters										
steering code parameters (e.g. XTE)										
engine (propulsion) code parameters										
extra remote control parameters										
to be able to provide a confidence level in the solution	X				X					
to be resilient to external factors that degrade the navigation performance	X	X								

to provide a solution during the whole operation	X									
to provide alerts within a specific time and react accordingly	X	X			X					
vertical info under water	X	X					X			
water current parameters								X		
distance & CPA info to other targets										
vertical info above water										
high accuracy horizontal info	X			X						

6. IDENTIFICATION OF POTENTIAL GAPS ON THE CAPACITY OF E-GNSS AND COPERNICUS

The objective of this section is to Identify potential gaps on the capacity of EGNSS (Galileo, EGNOS, etc.) and Copernicus to contribute to the operations and support the user requirements. Also, it will be assessed an identification of gaps between the available Inland ENCs and the reality observed with other sources of information e.g. Copernicus-derived bathymetry.

The logic followed is that first an analysis is made of the performance that can be expected, under nominal conditions, for the different parameters. Then, once the expected performances have been identified, they are compared with the requirements defined in AVIS, to assess which ones are achievable today using the current EU Space services. Finally, a gap analysis is made of those requirements that are not currently achievable.

6.1. EGNSS REQUIREMENTS ASSESSMENT

In order to analyze the potential gaps in EGNSS capabilities to meet the requirements, we shall first understand the performance that would be expected for each of the EGNSS services. For this purpose, the official service documentation is consulted, specifically the Service Definition Document (SDD).

After analysis, the following benefits are obtained for each of the services:

- **Galileo OS** ([RD.3.]):

Table 6-1 Galileo OS expected performance according SDD

Galileo OS		
Positioning accuracy		
Single frequency	Horizontal	≤ 5 meters (95%) at average user location, ≤ 10 meters (95%) at worst user location
	Vertical	≤ 8 meters (95%) at average user location, ≤ 16 meters (95%) at worst user location
Dual frequency	Horizontal	≤ 5 meters (95%) at average user location, ≤ 10 meters (95%) at worst user location
	Vertical	≤ 8 meters (95%) at average user location, ≤ 16 meters (95%) at worst user location
Continuity		
Not specified. Designed to provide continuous service.		
Availability		
PDOP	Average User Location (AUL)	≥ 90% of the time, PDOP ≤ 6
	Worst User Location (WUL)	≥ 87% of the time, PDOP ≤ 6
Single frequency	Average User Location (AUL)	Horizontal accuracy ≤ 7.5 m (95%) and vertical accuracy ≤ 15 m (95%) for ≥ 90% of the time
	Worst User Location (WUL)	Horizontal accuracy ≤ 7.5 m (95%) and vertical accuracy ≤ 15 m (95%) for ≥ 87% of the time
Dual frequency	Average User Location (AUL)	Horizontal accuracy ≤ 7.5 m (95%) and vertical accuracy ≤ 15 m (95%) for ≥ 90% of the time
	Worst User Location (WUL)	Horizontal accuracy ≤ 7.5 m (95%) and vertical accuracy ≤ 15 m (95%) for ≥ 87% of the time
Integrity		

Prob. SIS fault	Psat	$\leq 3 \times 10^{-5}$
Prob Const fault	Pconst	$\leq 2 \times 10^{-4}$

- Galileo HAS ([RD.4.]):

Table 6-2 Galileo HAS expected performance according SDD

Galileo HAS		
Positioning accuracy		
Galileo only	Horizontal	≤ 25 cm (68th percentile)
	Vertical	≤ 30 cm (68th percentile)
Galileo + GPS	Horizontal	≤ 15 cm (68th percentile)
	Vertical	≤ 20 cm (68th percentile)
Continuity		
Not specified. Designed to provide continuous service.		
Availability		
Galileo only		At least 87% availability, with at least 5 HAS-corrected and valid satellites in view
Galileo + GPS		At least 95% availability, with at least 8 HAS-corrected and valid satellites in view.

- Galileo OSNMA ([RD.5.]):

Table 6-3 Galileo OSNMA expected performance according to ICD

Galileo OSNMA		
TBA	Time between authentication	30 seconds

- EGNOS ([RD.6.]):

Table 6-4 EGNOS expected performance according SDD

EGNOS		
Positioning accuracy		
Horizontal		3 meters (95% confidence level)
Vertical		4 meters (95% confidence level)
Continuity		
Not specified. Designed to provide continuous service.		
Availability		
At least 99% of the time within the defined compliance area		

Requirements are dependent on the performance of the GNSS services and receiver. Therefore, in order to analyze the gaps, it is necessary to take into account the expected performance according to

the services provided, but also the performance of the receiver who uses the services as expected. In fact, some requirements depend directly on the performance of the GNSS receiver.

For those requirements that are more dependent on the receiver, we shall review the state-of-the-art receivers available on the market.

Regarding SOG and COG performance, it is possible to rely on the performance required for a maritime Galileo receiver. According to [RD.12] the minimum expected performance for a GNSS receiver is:

- COG: [1° - 3°], depending on the speed range.
- SOG: 2% of actual speed or 0,37 km/h, whichever is greater.

Regarding the expected performance for heading, no official documentation has been found to indicate the expected performance. In this case, it is decided to use as expected value the performance indicated by the manufacturer of a typical inland navigation equipment. In this case, it was decided to use a common commercial GNSS COMPASS receiver unit as a reference. According to the product specifications, the accuracy it can be expected in heading is 0.25°.

As for the performance of the ROT parameter, it can be derived from the heading accuracy. This parameter can be calculated, making use of GNSS services, by means of the variation of the heading with time. Therefore, looking at the expected heading accuracy, assuming that measurements can be obtained every second, we would have that the expected ROT accuracy would be twice the heading accuracy, 0.5°/s. Since performance is usually expressed in degrees per minute, changing the units would give an accuracy of 30°/min.

Having analyzed the expected performance, it is possible to analyze which requirements are currently achievable or not with the current GNSS services. Table 6-5 summarizes the status of GNSS requirements with respect to whether they are currently achievable.

The status of all requirements is detailed below.

6.1.1. CONTINUITY

The commitment of the system is to provide continuous service without interruption; therefore, this requirement can be met. In any case, during navigation it is possible that, due to environmental conditions, signal reception may be lost due to obstruction or interference. These conditions could affect any of the GNSS parameters, so this consideration applies to all of the following parameters. In any case, the requirements are considered to be achievable for all groups and Automation Levels (AL).

6.1.2. AVAILABILITY

The availability achievable depends on the area in which the receiver is located. Therefore, the availability performance can vary significantly depending on whether it is in an area and at a time with a lot of satellite visibility or not.

The performance established by the service for the worst possible area would not be sufficient to meet the requirements. The performance of an average zone would also fall short of the established performance levels. However, this does not mean that in some areas and at some appropriate times it cannot be achieved. Therefore, in this case, it is considered that the requirements would be achievable depending on the conditions in which the GNSS antenna is located.

6.1.3. HORIZONTAL POSITION

6.1.3.1. ACCURACY

Horizontal position accuracy requirements vary considerably by group and Automation Level. With Galileo OS performance, it is already possible to meet the requirements for Group 1 operations. As for

group 2, for automation levels 0 to 2 it is also possible to meet the requirements with Galileo OS. However, the accuracy performance varies depending on the location. Therefore, for those cases where the location does not allow the required accuracy to be achieved, it may be possible to achieve it with the EGNOS augmentation service.

Group 2 requirements for an AL3 and Group 3 requirements for AL0-2 require higher accuracy than is achievable with Galileo OS or EGNOS. For these cases, it can be seen that the accuracy that can be achieved with Galileo HAS does meet the requirements. The only case where the requirement cannot be met with available GNSS services is the requirement for group 3 operations with an automation level 3. For this case, it would be necessary to have the support of other sensors to increase the accuracy in the short range.

6.1.3.2. INTEGRITY RISK

The integrity risk can be configured at the receiver by adjusting the integrity algorithms. However, there is a direct relationship between integrity risk and continuity and availability. Therefore, in order to meet integrity risk integrity requirements, it is important to ensure that this is done without compromising continuity and availability requirements. Therefore, this requirement is considered achievable if the balance with the other requirements is also achievable.

6.1.3.3. TIME TO ALERT AND ALERT LIMIT

As a general rule, the GNSS receiver is capable of alerting the user the instant it detects the alert. Generally, this information is usually provided every second, so the warning time requirements would be achievable.

Regarding the alert limit, this is usually a configurable parameter, therefore, it is only necessary that the receiver design allows the required alert levels to be selected.

6.1.3.4. UPDATE FREQUENCY

This parameter is also usually a configurable parameter. As long as the receiver has the capability to adjust the data update rate the requirement is achievable. There are already receivers on the market today that work at the required frequencies in all cases.

6.1.3.5. TIME BETWEEN AUTHENTICATIONS (TBA)

Currently the time between successive authentications provided by the OSNMA service is 30 seconds. Therefore, the requirement between successive authentications would not be achievable for the time being.

6.1.4. VERTICAL POSITION

The accuracy required for vertical position is not achievable with current GNSS services. In this case, only the requirements of Group 3 are applicable since, as explained in D2.1, the vertical position is only relevant for requirement group 3.

All other requirements for the vertical position have the same characteristics as for the horizontal position, so refer to the details of the horizontal position for more information.

6.1.5. SOG REQUIREMENTS

With the level of accuracy achievable today, it is possible to meet the requirements for all groups of operations, but only for the lowest automation levels. For an AL3 it is seen that the accuracies that can be obtained, derived from information from GNSS services would not be sufficient to meet the requirements.

The update frequency requirements are analogous to those of the horizontal position, so they would also be achievable.

6.1.6. COG REQUIREMENTS

COG accuracy requirements depend on the speed at which the vessel is moving. Therefore, the requirements for all groups at a lower automation level could be achieved if the ship travels at sufficient speed.

For the case of the accuracy requirements of all groups for an AL3 we see that they would not be achievable using current GNSS services.

The update frequency requirements are analogous to those of the horizontal position, so they would also be achievable.

6.1.7. HEADING (HDT) REQUIREMENTS

The performance that can be obtained with the heading can really vary a lot depending on the set up arrangement used. Factors such as the distance and location of the antennas used can significantly vary the result.

However, looking at the reference values that would be achievable, we can see that the heading accuracy requirements could be met for all groups of operations for a low automation level. For an AL3 we see that the requirements of Group 1 could only be met by making use of the current GNSS services.

6.1.8. RATE OF TURN (ROT) REQUIREMENTS

It can be seen that the accuracy performance of ROT cannot be achieved by using current GNSS services. It is seen that the difference with respect to user requirements is very large. Therefore, in order to obtain this parameter accurately, it is identified that it would be necessary to use equipment including IMUs or gyroscopes that would allow obtaining this parameter more accurately.

6.1.9. SUMMARY OF EGNSS REQUIREMENTS ASSESSMENT

Following there is a table that summarizes the requirements assessment performed.

Table 6-5 GNSS requirements feasibility assessment

		Continuity	Availability	Horizontal Position						Vertical Position					SOG		COG		HDT		ROT	
				Accuracy	Integrity Risk	Time to Alert	Alert Limit	Update rate	TBA	Accuracy	Integrity Risk	Time to Alert	Alert Limit	Update rate	Accuracy	Update rate	Accuracy	Update rate	Accuracy	Update rate	Accuracy	Update rate
Group 1	AL0-AL2	OS	OS	OS	Rx	Rx	Rx	Rx						Rx	Rx	Rx	Rx	Rx	Rx		Rx	
	AL3	OS	OS	OS/EGNOS	Rx	Rx	Rx	Rx							Rx	Rx		Rx	Rx		Rx	
Group 2	AL0-AL2	OS	OS	OS/EGNOS	Rx	Rx	Rx	Rx						Rx	Rx	Rx	Rx	Rx	Rx		Rx	
	AL3	OS	OS	HAS	Rx	Rx	Rx	Rx							Rx	Rx		Rx			Rx	
Group 3	AL0-AL2	OS	OS	HAS	Rx	Rx	Rx	Rx			Rx	Rx	Rx	Rx	Rx	Rx	Rx	Rx	Rx		Rx	
	AL3	OS	OS		Rx	Rx	Rx	Rx			Rx	Rx	Rx		Rx		Rx				Rx	

Note: This feasibility matrix considers nominal conditions, the feasibility might change when having obstructions as for example passing under a bridge.

Legend

	Achievable with the use of current GNSS services.
	Achievable depending on conditions.
	Not achievable with the use of the current services.
	Not applicable.
OS	Galileo Open Service
EGNOS	EGNOS Services
HAS	Galileo High Accuracy Service
Rx	GNSS Receiver dependant

6.2. COPERNICUS REQUIREMENTS ASSESSMENT

For AVIS, Copernicus will be used to create ad-hoc services mentioned in Section **iError! No se encuentra el origen de la referencia.**. As the ad-hoc services will be created by processing the products available through Copernicus, first we give an evaluation of accuracy of such ad-hoc services from literature (if available) or through qualitative estimations.

6.2.1. RIVER EDGE

Within Copernicus services, the performance for extracting water bodies (the boundaries of water bodies represent the edge) are given in the table below,

Table 6-6 Metrics for water body detection from [RD.2.](S1) and [RD.7](S2)

Metric	S1-based measurement	S2-based measurement
Accuracy	76%	82%
Commission Error	11%	8%
Omission Error	39%	10%
Positional Accuracy	30 m.	20 m.

By comparing with the user requirements given in D2.1, it is seen that it is only possible to meet the temporal resolution and alert refresh rate requirements for the lowest automation levels (AL0-AL2).

6.2.2. RIVER DEPTH

From [RD.8] (for S1) and [RD.9] (for S2), the performance error for estimating river depth/bathymetry is

Found to be varying from 0.72m to 2m for S1-based measurements and from 0.35m – 2.21m for S2-based measurements. The horizontal resolution for these estimations is 30m, same as that of the freely available Digital Elevation Model from Copernicus. These estimation as a result involves an additional assumption which says that the riverbed remains unchanged over the horizontal resolution of the Digital Elevation Model. By comparing with the user requirements given in D2.1, it is seen that it is only possible to meet the temporal resolution and alert refresh rate requirements for the lowest automation levels (AL0-AL2) for Group 1.

6.2.3. RIVER DISCHARGE/WATER SPEED

At D2.1, the user requirement is given in terms of water speed. On the other hand, the Copernicus in situ services provide river discharge. The average water speed at water surface can be calculated by a gauge station taking into account the water level, river discharge, river cross section area, and an approx. logarithmic vertical speed distribution. Determination of average water speed on a river stretch between gauge stations is difficult, due to the unknown in-and outflowing river discharge between the gauges, and lack of cross section information (area, water level). An approximation of water speed can be given for river sections between gauges, based on the slope of the water surface, which can be calculated from water levels at gauges. Change and forecast of river discharge over time is also important for water speed, due to the effect on water surface slope. E.g. decreasing river discharge above a gauge station cause slower water speed by the same water level, than an increasing river discharge.

Accuracy of average water speed measurement depends on the applied technology.

- At gauge stations the water level accuracy is about 3-10mm,
- the river discharge accuracy is about 2-5% (lower accuracy belongs to the water level-based discharge estimation and older measurement technologies),
- and the river cross section must be estimated, e.g. based on (electronic) navigation chart bathymetry data. The cross-section accuracy in constructed and regulated waterways is about 1-2%. On free-flowing rivers the cross-section accuracy depends very much on age of the survey. Older cross section data can have 5% difference to the actual cross section area.

However, most discharge measurement technologies for gauge stations are based on average water velocity, so cross-section and water level errors are compensated in determining the average water flow velocity based on discharge, and the accuracy of the velocity is determined by the accuracy of the measuring instrument. The accuracy of an average flow meter for water speed measurement is 0.005-0.3 m/s.

A qualitative estimation gives an uncertainty of order of 0.2 m/s for rivers with width of approximately 500m and depth of 5m.

By comparing with the user requirements given in D2.1, the only requirements that could not be met with the current service would be the time resolution and alert update frequency for AL3.

6.2.4.OBJECT DETECTION

Copernicus satellites have been studied in literature to detect small objects (mainly recreational and fishing boats) in inland rivers. In [RD.10] it is found that it is possible to detect smaller boats of dimension of approximately 10m. By comparing with the user requirements given in D2.1, it is assessed that it is not possible to meet the requirements with the current performance of the Copernicus service.

6.2.5.FLOOD FORECASTING

The flood forecasting service provided by Copernicus fulfils the user requirement and as a result the assessment table is that the requirements can be fulfilled.

6.2.6.LIMITATIONS

- **Interference from Shoreline Vegetation and Urban Structures:** Dense vegetation and urban areas can interfere with Sentinel-1 radar signals and Sentinel-2 optical signals, complicating the accurate mapping of water bodies. Narrow streams and small water bodies are intensively affected by pixels in their neighborhood and, consequently, they are often falsely identified. It is thus recommended to only take into account water bodies whose characteristic length/width is greater than 150 m ([RD.11]).
- **Additional Data Requirements:** Accurate depth estimation requires supplementary data sources, such as Digital Elevation Models (DEMs). As a result, the accuracy and spatial resolution of DEM will determine further the accuracy of depth estimation. As an example, using open source Copernicus DEM with 30m spatial resolution will mean that the calculated river depth accuracy is only valid for rivers with extent much larger than 30 meters.
- **Cloud Obstruction:** Optical imagery from Sentinel-2 can be obstructed by clouds, making it difficult to obtain clear images during cloudy weather or rainy seasons.
- **High Turbidity Levels:** Turbid water can lead to misclassification of river extent due to mixed pixels at the river banks.
- **Sun-Glint:** Sun-glint can impact the accuracy of water body extent mapping.

6.2.7. SUMMARY OF COPERNICUS REQUIREMENTS ASSESSMENT

Following there is a table that summarizes the requirements assessment performed.

Table 6-7 Earth Observation requirements feasibility assessment

		River edge			River depth			Water speed			Object detection			Flood forecasting
		Update Nautical charts		Provide alerts	Update Nautical charts		Provide alerts	Update Nautical charts		Provide alerts	Update Nautical charts		Provide alerts	Provide alerts
		Temporal resolution	Service error	alert update frequency	Temporal resolution	Service error	alert update frequency	Temporal resolution	Service error	alert update frequency	Temporal resolution	Service error	alert update frequency	forecasting time
Group 1	AL0-AL2													
	AL3													
Group 2	AL0-AL2													
	AL3													

Note:

Legend

	Achievable with the use of current Copernicus services.
	Achievable depending on conditions.
	Not achievable with the use of the current services.
	Not applicable.

6.3. COLLECTION OF POTENTIAL GAPS

Once the feasibility analysis of the requirements has been done, it is possible to identify what gaps currently exist between what the users require and what the services provide.

Below Table 6-8 compiles all the identified gaps in the requirements. This table identifies the value of the requirements that are not met, the value of performance that is currently achievable and the gap, as a relative measure of the difference between the requirement and the current performance. In this way, the magnitude of the size of the current gap to meet the requirements can be seen. It should be taken into account that the values provided in the current performances refer to the best values to be expected under nominal conditions.

Table 6-8 Requirements gaps collection

Parameter	Requirement	Current performance	Gap
Availability	99,80%	90%	9,82%
Horizontal Position Accuracy Group 3 AL3	0,1 m.	0,5 m.	400,00%
Time Between authentications (TBA) AL0 - AL2	10 s.	30 s.	200,00%
Time Between authentications (TBA) AL3	6 s.	30 s.	400,00%
Vertical Position Accuracy Group 3 AL0 - AL2	0,1 m.	0,6 m.	500,00%
Vertical Position Accuracy Group 3 AL3	0,1 m.	0,6 m.	500,00%
SOG Accuracy Group 1 AL3	1%	2%	100,00%
SOG Accuracy Group 2 AL3	0,2 km/h.	0,37 km/h.	85,00%
SOG Accuracy Group 3 AL3	0,2 km/h.	0,37 km/h.	85,00%
COG Accuracy Group 1 AL3	0,3°	1°	233,33%
COG Accuracy Group 2 AL3	0,17°	1°	488,24%
COG Accuracy Group 3 AL3	0,07°	1°	1328,57%
HDT Accuracy Group 2 AL3	0,17°	0,25°	47,06%
HDT Accuracy Group 3 AL3	0,07°	0,25°	257,14%
ROT Accuracy All Groups AL0 - AL2	1°/min.	30°/min.	2900,00%
ROT Accuracy Group 1 AL3	1°/min.	30°/min.	2900,00%
ROT Accuracy Group 2 AL3	0,5°/min.	30°/min.	5900,00%
ROT Accuracy Group 3 AL3	0,3°/min.	30°/min.	9900,00%
River Edge Service Error AL0 - AL2	0,1 m.	20 m.	19900,00%
River Edge Service Error AL3	0,05 m.	20 m.	39900,00%
River depth Service Error Group 1 AL0 - AL2	0,1 m.	0,35 m.	250,00%
River depth Service Error Group 1 AL3	0,05 m.	0,35 m.	600,00%
River depth Service Error Group 2 AL0 - AL2	0,05 m.	0,35 m.	600,00%
River depth Service Error Group 2 AL3	0,05 m.	0,35 m.	600,00%
Object detection Service Error AL0 - AL3	2 m.	10 m.	400,00%
Object detection Service Error AL3	2 m.	10 m.	400,00%

Regarding the EGNSS gaps, it can be seen that the smallest gaps are for availability and SOG. The farthest requirement currently from being achieved is the ROT accuracy requirement for Group 3 in AL3. In general, the ROT requirements are those identified as being furthest from being achievable

with GNSS services. We also see that COG and vertical position are currently far from achievable with current services. In cases where the gap is larger, it is more necessary to use other sensors to help achieve the performance required by users. For example, in the cases of operations where vertical position is required (Group 3 operations), it is seen that it will be necessary to have other methods that can provide the vertical position.

Figure 6-1 shows graphically the magnitude of all EGNSS-related gaps.

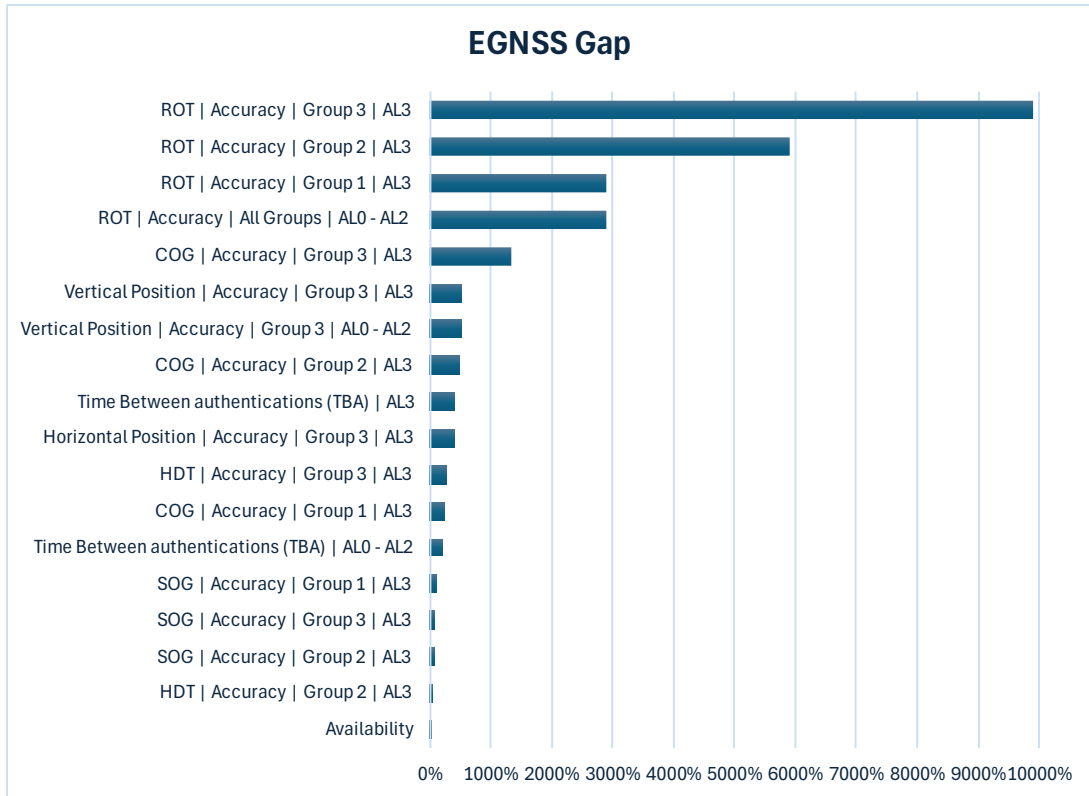


Figure 6-1 EGNSS requirements gap graphical representation

Regarding the Copernicus gaps we see that all the service errors have quite a large gap, however, the error in the river edge measurement is noteworthy, which is several orders of magnitude larger than the rest of the gaps. This is because the current pixel size provided by Copernicus is too large. This is one of the reasons why the use of Copernicus to update nautical charts is identified in the longer term, as the current gap is too large. The temporal resolution could be useful, the higher it is, the more useful the service would be, but with the current one it could be useful. However, with the service error that we usually find, it might make it more difficult to use Copernicus for automated navigation.

Figure 6-2 shows graphically the magnitude of all Copernicus-related gaps.

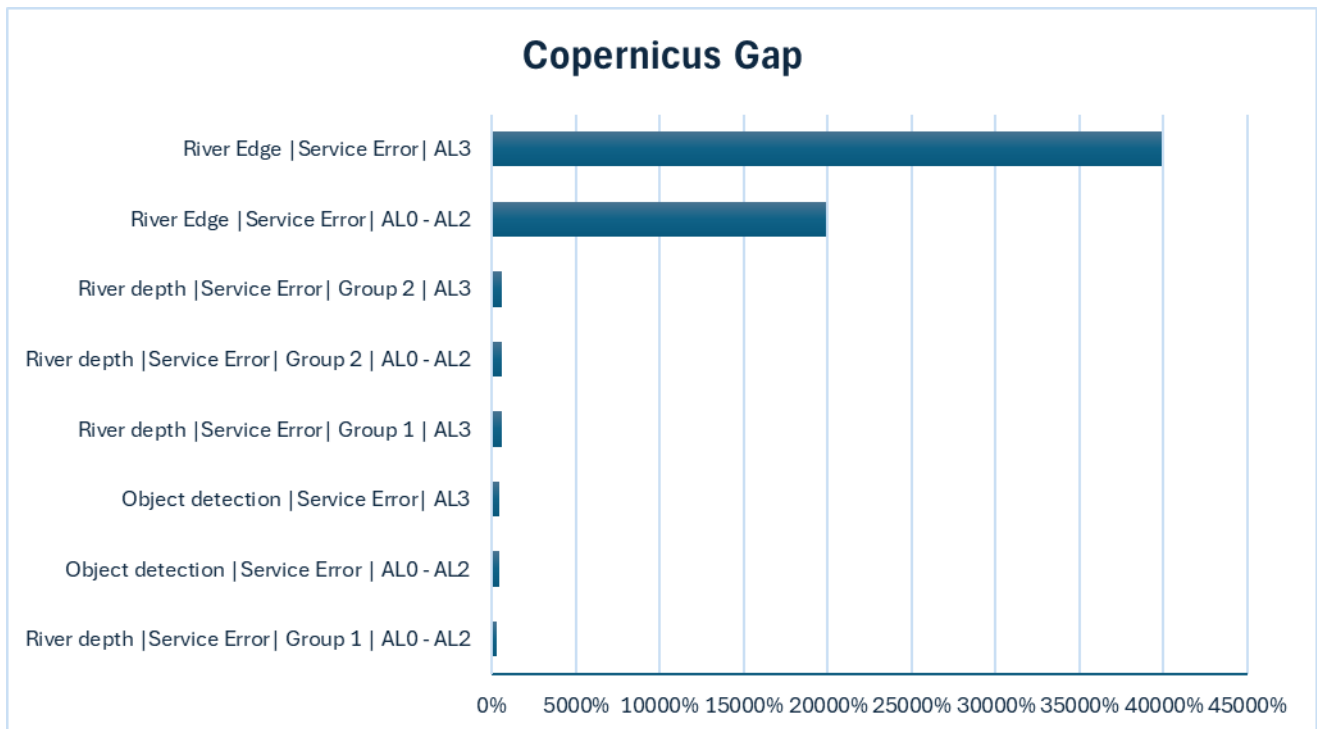


Figure 6-2 Copernicus requirements gap graphical representation

This gap analysis approach is considered very interesting, since it allows different strategies for improving services to be proposed. With this structuring, several different strategies for planning service improvements can be identified. For example:

- A strategy of trying to improve on those parameters that are closest to being achievable. The parameters that have a smaller relative gap are supposed to be closer to being achievable, so that, devoting efforts to improve them would imply reducing the number of requirements that are not achievable today. On the other hand, services may already be providing very demanding performance and the cost of a marginal improvement in performance is very high.
- A strategy of trying to improve those parameters that have a greater gap. While these parameters may be more difficult to achieve at the required level, working on improving them would provide a greater relative advance, having a much greater relative effect in terms of their potential usefulness in navigation.
- A strategy that involves trying to achieve at least the requirements of AL3 for Group 1 of operations. This would imply that at least the most basic inland navigation operations could be performed with greater autonomy using mainly EU Space data.
- A strategy that attempts to prioritize meeting the requirements of all groups of operations at a lower automation level. Thus, although it would not yet be possible to have a completely automated navigation, a partially autonomous navigation could be considered for the whole range of inland operations that can be encountered.

On the other hand, speaking of gaps, there is another type of gap that generally affects any parameter or requirement. All performance assumes certain nominal expected conditions. However, these nominal conditions are not always achievable. As developed in this document, there are several situations of degraded or constrained environments. In the case of EGNSS, this would be situations where satellite visibility is lost when passing over a bridge, or where interference is experienced that degrades or denies service. In the case of Copernicus, it can also be seen that there are many

boundary conditions that can affect the expected performance, such as, for example, the presence of clouds, turbidity or sun glint. Therefore, the fact that performance cannot always be guaranteed is considered a generic gap in meeting user requirements.

Also, it can be found gaps between the available inland ENC and the reality observed with other sources of information. In general – although it varies between producing authorities - inland ENCs have decimeter accuracy. This is about two orders of magnitude better than what can be obtained from current Sentinel 1 and 2 satellite-based imagery. On the other hand, current inland ENCs only contain static encoded chart data.

Copernicus data has lower accuracies but can provide dynamical changing images of the same region over time. It is this dynamic feature that is lacking in current inland charts. It is the temporal aspect which is the advantage of Copernicus service.

The challenge will be to try to combine low accurate, dynamic satellite data with the high accuracy static ENCs.

The temporal aspect – which is not present in current ENCs – can also be used to detect trends from the image data. The result can be up front indications, warnings or alarms to end users when certain thresholds are exceeded.

In fact, it is this temporal effect that can boost all observations (environment degradation, river edges, river depths or water speed). It can be seen as the main gap between dynamic Copernicus Satellite data and static published chart data.

Another gap is how this extra dynamical data can be provided to end users. ENCs are already commonly used by boat masters. So, the dissemination of new dynamical data through existing ENCs could be a solution because (commercial) ENC update-mechanisms to get chart changes to end users are already in place. The enhancement to get this new information in ENCs could be provided by the new S-100 transfer standard. E.g. S-124 already describes a Navigational Warning Information Overlay (NWIO).