ANALYSIS ON THE MINIMUM REQUIREMENTS TO PROVIDE GNSS (GALILEO, EGNOS) ALARMS AND COPERNICUS-BASED ALARMS

AVIS

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1.1	31/10/2025	24	Second version prepared for IRM2 closeout

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1. INTRODUCTION

1.1. PURPOSE

The present document is the "Analysis on the Minimum Requirements to Provide GNSS (Galileo, EGNOS) Alarms and Copernicus-Based Alarms" document for the AVIS project. The main purpose of this document is to analyse which alerts or alarms can be provided from Copernicus data. Additionally, even if the ITT does not consider it, it has been included also alerts derived from GNSS data to have a wider picture of the EU Space data possibilities.

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. provides a state of the art of GNSS and Copernicus alerts
- Chapter 6. provides an analysis on potential alerts that could be provided in the context of AVIS

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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
[AD.4]	User Requirements for Automated Navigation. AVIS.	AVIS-D2.1	1.1	15 January 2025

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.]	EGNOS - Safety of Life assisted service for Maritime users - Service Definition Document	ESMAS SDD	1.0	March 2024
[RD.2.]	Bye RJ, Aalberg AL, Maritime navigation accidents and risk indicators: an exploratory statistical analysis using AIS data and accident reports. *Reliab Eng Syst Saf.,* 2018;176:174, 86.			2018
[RD.3.]	https://land.copernicus.eu/en/products/eu-hydro			April 2025
[RD.4.]	EUROPEAN AGREEMENT ON MAIN INLAND WATERWAYS OF INTERNATIONAL IMPORTANCE (AGN), https://treaties.un.org/Pages/showDetails.aspx?objid=080000028004ca9a&clang=_en			April 2025
[RD.5.]	Report on the state of the art including EU funded projects. AVIS.	AVIS-D1.1	1.1	May 2024
[RD.6.]	Track Guidance Assistant for Inland Navigation. Aspects of Safe Use. CESNI		1.0	April 2025

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3. TERMS, DEFINITIONS AND ABBREVIATED TERMS

3.1. DEFINITIONS

There are no definitions that apply to this document.

3.2. ACRONYMS

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

Table 3-1 Acronyms

Acronym	Definition
AGN	European Agreement on Main Inland Waterways of International Importance
AIS	Automatic Identification System
AVIS	Automated Vessels on European Inland Waterways
CAMS	Copernicus Atmosphere Monitoring Service
CESNI	European committee for drawing up standards in the field of inland navigation
DEM	Digital Elevation Model
DOP	Dilution of Precision
ECDIS	Electronic Chart Display and Information Systems
EFAS	European Flood Awareness System
EFFIS	European Forest Fire Information System
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European GNSS
ENC	Electronic Navigational Charts
EPL	Envelope Protection Level
ESMAS	EGNOS Safety of Life Assisted Service for Maritime users
FIRMS	Fire Information for Resource Management System
GEO	Geostationary
GIVE	Grid Ionospheric Vertical Error
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
ITT	Invitation to Tender
MMU	Minimum Mapping Unit
MODIS	Moderate Resolution Imaging Spectroradiometer
MSC	Maritime Safety Committee
OSNMA	Open Service Navigation Message Authentication
RADAR	Radio Detection and Ranging
SAR	Synthetic Aperture Radar
SDD	Service Definition Document

Acronym	Definition
TGAIN	Track Guidance Assistants for Inland Navigation
TROPOMI	TROPOspheric Monitoring Instrument
UDRE	User Differential Range Error
UDREI	UDRE Indicator
VIIRS	Visible Infrared Imaging Radiometer Suite

4. CONTEXT AND METHODOLOGY

In this document produced in AVIS WP2200 “EU Space Interfaces requirements”, the high-level methodology for the work performed in it is:

- Step 1: review the state of the art on the use of GNSS and Copernicus-derived data to provide alerts. (Section 5.)
- Step 2: analyse what information available from Copernicus images may be relevant for safety of navigation and for the provision of alarms (Section 6.2.1)
- Step 3: analyse the alerts that can be provided from GNSS and Copernicus for detection of degradations that can result in a decrease of safety (Section 6.1 and Section 6.2.2)
- Step 4: analyse potential alerts combining the use of GNSS or Copernicus with other tools (Section 6.3)

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5. STATE-OF-THE-ART REVIEW OF GNSS AND COPERNICUS ALERTS

It has already been mentioned in document D2.1 that, according to the IMO resolution MSC.302(87), there is a difference between the concept of alarm and alert. Alerts are announcing abnormal situations and conditions requiring attention. Alerts are divided into four priorities: emergency alarms, alarms, warnings and cautions, listed in descending order of priority.

Table 5-1 Priority categorization of alerts.

Alerts	emergency alarms	Alarms which indicate immediate danger to human life or to the ship and its machinery exits and require immediate action.
	alarms	Condition requiring immediate attention and action by the bridge team, to maintain the safe navigation of the ship.
	warnings	Condition requiring immediate attention, but no immediate action by the bridge team.
	cautions	Awareness of a condition which does not warrant an alarm or warning condition but still requires attention out of the ordinary consideration of the situation or of given information.

From the perspective of the AVIS project, the priority that the different alerts should have is not discussed in depth, so in general it is preferred to use the term alert, in a general way, without specifying priorities. In ITT [AD.2] the name of "alarms" was specified for this document, however, to keep the consistency with previous deliverables we continue to use the term alert.

Alerts are considered an essential navigation aid at all automated levels. For the lower levels it helps the pilot to make better decisions. For the higher levels they would be used as inputs to the automated control system (i.e. TGAIN and others) to make decisions or adjust some decision autonomously.

5.1. REQUIREMENTS DERIVED IN AVIS PROJECT

During the first year of project development, work was done in particular on requirements for the EGNSS and Copernicus services. As a result, document D2.1 "User requirements for automated navigation" was produced. Different types of requirements were developed in this document, including some alert requirements.

Regarding GNSS alerting requirements, an alert time of 6 to 10 seconds was established as integrity parameters. Likewise, similar requirements were established for the time between authentications, which is directly related to the time to provide alerts.

Regarding Copernicus, one of its main functionalities is to provide alerts, so the Copernicus requirements derived in document D2.1 are closely linked to alert requirements. Mainly it is possible to see requirements that establish the acceptable time to produce a new alert.

In this document, the focus is on the alerts proposed as part of the AVIS solution, to better detail their functionality and what is required of them.

5.2. STATE-OF-THE-ART OF GNSS ALERTS

5.2.1. EGNOS ALERTS

In the context of GNSS alerts we can distinguish several types of alerts. Currently, one of the services that monitor and provide GNSS-related alarms is the EGNOS system. The EGNOS system is designed to improve GPS performance in Europe. This system provides corrections and integrity information to users.

EGNOS is made up of different services, among which, for the context of this document, we can highlight the safety of life service. In particular, the analysis of the EGNOS Safety of Life assisted service for Maritime users (ESMAS) service is considered interesting. This service is provided freely without any direct charge. It is tailored to maritime applications, however it is found interesting to be used also for inland waterways operations. In particular, it is interesting to review the alerts provided by the ESMAS service. According to [RD.1.] the alerts provided are:

- **System Alerts**: This alert is used to indicate that the information provided by GEO satellites is not suitable for safety applications. In the event of receiving such an alert, it implies to stop using the EGNOS service for any operation.
- **Satellite Alerts**: These are alerts provided through the monitoring of each of the satellites. EGNOS provides position corrections for each satellite with an accuracy defined by the User Differential Range Error (UDRE) and broadcast through the UDREI (UDRE Indicator). An alert of this type indicates that it has been found an inconsistency or the estimated fast correction is out of the expected range. Receiving this alert implies not using the specific satellite related with the alert.
- **Ionosphere Alerts**: The ionospheric corrections are defined by the Grid Ionospheric Vertical Error (GIVE). EGNOS broadcast the GIVE indicator through a message. If the alert is received it implies that the Ionospheric Grid Point shall not be used.

In relation to satellite or ionosphere alerts, the EGNOS system is designed to inform the user within a maximum of 5.2 seconds from the occurrence of the alert conditions. Each alert is repeated 3 times, making 4 consecutive messages including the alert. Therefore, a user who loses 4 or more consecutive messages should stop using ESMAS.

5.2.2. GNSS RECEIVER ALERTS

Services such as EGNOS can monitor service status and provide service alerts. However, there are aspects that cannot be monitored from the system and can only be detected by monitoring from the user's side. Therefore, there are techniques to monitor the integrity of the measurements provided by a GNSS receiver autonomously, without the need to make use of specific services such as EGNOS.

Therefore, GNSS receivers have the capability to provide some alerts based on such monitoring. Currently, an IEC 61108-3 type-approved GNSS receiver shall be able to provide the following alerts:

- **Position loss alert**: The GNSS receiver shall provide a warning within 5 seconds of loss of position or if a new position has not been calculated for more than 1 second.
- **DOP alert**: The accuracy of GNSS receivers depends on the distribution of visible satellites at any given time. Depending on the geometry of the satellites, there is a greater or lesser Dilution of Precision (DOP). GNSS receivers provide a warning when the DOP is very high, as it implies that the position quality is compromised.
- **Integrity alert**: GNSS receivers are capable of calculating a Protection Level. This can be compared with an Alert Limit set so that an alert is triggered when the protection level exceeds the Alert Limit. In this way, the Alert Limit sets the maximum uncertainty in the position that is acceptable and, when the uncertainty of the calculated position is higher, the user is warned.
- **Navigational status**: GNSS receivers shall always display a navigation status that serves as an indication of the navigation status. This is mainly related to the integrity calculated at the receiver level. The states that can be provided by the GNSS receiver are:
    - Safe: When integrity is available, and the Protection Level does not exceed the Alert Limit.
    - Caution: When integrity is not available for a period of at least 3 seconds
    - Unsafe: When integrity is available and the Protection Level exceeds the Alert Limit.

On the other hand, although it is not a functionality that is currently standardized in GNSS receivers, it is becoming more and more common to implement **anti-spoofing alerts**. For this purpose, it is very interesting to use the Galileo OSNMA service. With this service, it is possible to authenticate that the navigation message received comes from Galileo's own system and has not been spoofed by third parties. Therefore, by applying some logic in the receiver, it is possible to generate alerts about possible spoofing attacks. Note that these alerts can be raised each time an authentication is performed. Currently, the time between authentications achievable with OSNMA is 30 seconds, so this is the frequency at which this alert can be provided.

Although there is no specific anti-jamming alert within the alerts expected in a GNSS receiver with IEC 61108-3 type-approval, when under the effects of jamming there is performance degradation that would lead to the integrity alert being triggered. In the event that the jamming is so strong as to deny service, the position loss alert will be triggered.

5.3. STATE-OF-THE-ART OF COPERNICUS ALERTS

In this chapter, we provide an overview of the state-of-the-art alerts system which are derived from Copernicus-based services.

- **European Flood Awareness System** (EFAS): EFAS offers pan-European flood forecasts and alerts, helping authorities prepare and respond to flood events. It uses a combination of in-situ data, satellite observations, and hydrological models to predict flood risks up to 10 days in advance. The EFAS flood probability layer is designed to predict the likelihood of flooding within a river network, focusing on areas with a minimum upstream area of 50 km². It calculates the probability of exceeding specific flood thresholds, such as the 2-year, 5-year, and 20-year return periods. These probabilities are determined using the maximum forecast discharge value over a 10-day forecast horizon. The flood probability layer highlights areas on the map where these thresholds are likely to be exceeded, with different colors indicating the recurrence levels: yellow for 2-year, red for 5-year, and purple for 20-year events

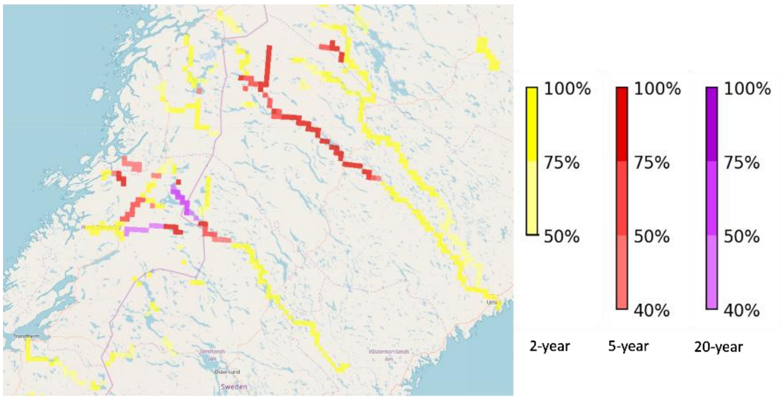

Figure 5-1 Example of the Flood probability layer on the forecast June 25 2024 12 UTC

- **European Forest Fire Information System** (EFFIS) utilizes advanced satellite-based technologies for active fire detection. The system primarily relies on data from NASA's Fire Information for Resource Management System (FIRMS), which includes sensors MODIS (1km spatial resolution) and VIIRS (375m spatial resolution). The mapping of active fires is performed to provide a synoptic view of current fires in Europe and as a means to help the subsequent mapping of burnt fire perimeters. Information on active fires is normally updated 6 times daily and made available in EFFIS within 2-3 hours of the acquisition of the MODIS/VIIRS images. To minimize false alerts and filter out active fires not qualified as wildfires (e.g. agricultural burnings), the system only displays a filtered subset of the hotspots detected by FIRMS. To this end a knowledge based algorithm is applied that takes into account the extent of surrounding land cover categories, the distance to urban areas and artificial surfaces, the confidence level of the hotspot.

- **The Copernicus Atmosphere Monitoring Service** (CAMS) provides an Aerosol Alert Service that delivers near-real-time monitoring of air quality. The service utilizes data from multiple satellite sensors, including Sentinel-5P/TROPOMI and MODIS, combined with advanced atmospheric modeling to generate air quality estimators. The spatial resolution varies depending on the input data and varies between 7x3.5 km resolution to 10 km resolution depending on the particular air quality component. The update frequency is daily, with forecasts available up to four days in advance, while near-real-time observations are processed within a few hours of satellite overpass. The system also integrates ground-based measurements for validation, ensuring high accuracy in pollution tracking and early warnings for extreme events such as dust storms, wildfire smoke, and industrial emissions. The computation of the aerosol alerts is based on the evaluation of forecasts. Depending on the parameter, different references are used to detect anomalies, and different thresholds are used to describe the alerts levels. **Three levels** of alerts are retrieved:
    - **1: high level**, triggered when the forecasted parameter is greater than the **first** threshold
    - **2: very high level**, triggered when the forecasted parameter is greater than the **second** threshold
    - **3: extreme level**, triggered when the forecasted parameter is greater than the **last** threshold

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6. ANALYSIS OF POTENTIAL ALERTS THAT COULD BE PROVIDED IN THE CONTEXT OF AVIS

6.1. PRELIMINARY PROPOSAL FOR GNSS ALERTS

From an AVIS solution point of view, it is considered that the alerts described in section 5.2, concerning the state of the art of GNSS alerts, could be included. These alerts are considered useful and helpful for safe automated navigation and for navigation assistance systems at lower automated level.

Therefore, it is recommended to implement and use them according to what is established in the regulations or official documentation available. No alerts other than those described above are identified as GNSS-based only alerts. However, other alerts that combine GNSS information with other data sources are identified. Section 6.3 details these proposed new alerts specifically designed for automated navigation on inland waterways.

6.2. PRELIMINARY PROPOSAL FOR COPERNICUS ALERTS

6.2.1. INFORMATION AVAILABLE FROM COPERNICUS IMAGES THAT MAY BE RELEVANT FOR SAFETY

In this section we describe the relevant factors that contribute to generation of errors in the alerts produced by the ad-hoc services from Copernicus Sentinel 1 and 2 images. Such error in alerts can lead to safety issues. Due to its inherent spatial resolution of Sentinel 1 and 2 satellites, any variations occurring within 10m (for Sentinel 2) and 20m (for Sentinel 1) cannot be detected. When an alert is generated (or fail to generate), it can be one due to presence of false negatives (FN) and false positives (FP) in the ad-hoc services. Below we describe the false positives and false negatives with a relevance to safety for related ad hoc services.

6.2.1.1. RIVER EDGE

In a river edge monitoring system using Sentinel-1 and Sentinel-2 images, for AVIS, alerts are triggered when the observed river edge in a river section is narrower than (below a threshold) than ones extracted from the EU-Hydro reference data. However, both FP and FN can occur due to a range of technical and environmental factors. The principal reason for the generations of FP and FN in alerts for river edges are,

- A FP alert is generated where the service incorrectly flags a narrowing. In Sentinel-1 radar data, urban areas introduce strong backscatter due to buildings and infrastructure, which can obscure the actual river boundary or create artificial narrowing. Similarly, steep riverbanks can cause radar shadowing or layover effects, where the signal either misses the river or reflects in misleading ways, resulting in underestimation of the river edge. In Sentinel-2 optical imagery, turbidity from suspended sediments can make water appear spectrally similar to land, especially in the near-infrared bands, leading to misclassification. Additionally, sunlight reflecting off the water surface can saturate pixels and obscure the river edge, while dense riverbank vegetation can overhang or blend with water pixels, falsely narrowing the detected edge and hence generating a false alert. Additionally, floating debris, bridges or vessels can obstruct the view during satellite overpasses, leading to misinterpretation of river edge which can generate a FP alert.

- On the other hand, a FN alert is generated where an actual decrease in river width is missed. Such cases are often more critical for safety and can be caused by a combination of sensor limitations, environmental interference, and outdated reference data. For sentinel 1 SAR images, high radar backscatters from rough water surfaces can mask narrow sections, especially during high flow or wind events. Additionally, radar shadowing from steep terrain or nearby infrastructure can hide parts of the river, making it appear wider than it is. Moreover, the EU-Hydro dataset may be outdated, failing to reflect recent sedimentation, erosion, or anthropogenic changes. Its generalized river polygons can smooth over tight bends or constrictions, making real-time narrowing events appear insignificant or invisible. Additionally environmental factors can mask the water surface, making the river appear wider in both radar and optical imagery.

6.2.1.2. RIVER DEPTH

The estimation of river depth using Sentinel is usually derived from logarithmic band ratio models that map surface reflectance to bathymetric values based on calibration data. These models are sensitive to both environmental conditions and calibration quality. An alert is triggered when the estimated depth falls below a threshold. The threshold value will vary depending on the river zone and fairway requirements. Both FP and FN can arise, particularly due to the mathematical and physical limitations of the band ratio approach.

- The FP alerts, where the system incorrectly flags a shallow depth, often arise due to the sensitivity of the logarithmic transformation to small reflectance variations. This is especially problematic as the models are trained on limited available in-situ data and as a result can fail to generalize. Additionally, the logarithmic relationship between band ratios and depth also breaks down in the presence of colored dissolved organic matter, high bottom reflectance, or multiple scattering in turbid water. Similarly, sun glint can artificially elevate reflectance values, particularly in the blue and green bands, leading to underestimation of depth. Floating vegetation, debris, or even surface foam can also interfere with the water signal, causing the model to interpret the area as shallower than it actually is.
- The FN alerts, where a genuinely shallow section is missed, can result from calibration errors that cause the model to underestimate the severity of depth reduction. In very shallow waters, the logarithmic transform becomes insensitive to small depth changes, especially when riverbed type or sediment concentration varies subtly.

6.2.1.3. OBJECT DETECTION

The object detection alert system is based on detected vessel within the River edge generated by the River Edge ad hoc-service. A vessel can be falsely detected (FP) or missed (FN) due to different reasons,

- A FP alert, occurred due to a false detection, can occur due to several factors. Structures in river edge (docks, buoys, moored platforms) can be misclassified as vessels, especially when they fall within the detected river extent. If the river width algorithm slightly overestimates the river boundary, adjacent land objects may be included in the detection zone, increasing the chance of false positives. Additional structures like temporary riverbank can also lead to false detection. In Sentinel-1 data, several radar-specific artifacts contribute to false detections. Speckle noise can result in random bright spots that resemble small vessels. Additionally, in Sentinel-1 radar images, ghost vessels may appear which is caused by aliasing of the Doppler spectrum reflections for structures with strong backscattering like bridges, infrastructures. In Sentinel-2 optical data, sun glint can generate bright, specular reflections that resemble ship hulls. Floating vegetation or debris may have similar reflectance to small boats, and unidentified cloud shadows can introduce dark, vessel-like shapes.
- A FN alert, where a vessel is present but goes undetected, can occur due to several factors. In Sentinel-1 SAR data, vessels made of materials with low radar cross-section can go undetected. Additionally vessel moored to a dock or very near shoreline can be missed as they are excluded from river extent. In Sentinel-2 optical data, turbidity can lead to a vessel being undetected.

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6.2.2. COPERNICUS ALERTS

This section presents the alert generation for ad hoc services based on the historical/non-historical nature of reference data used.

6.2.2.1. ALERTS NOT BASED ON COPERNICUS HISTORICAL DATA

The alerts described in this section are generated when there is a deviation from reference data that is not derived from the Copernicus services. This reference data may or may not depend on historical data.

6.2.2.1.1. RIVER DEPTH

The river depth ad-hoc service creates bathymetry maps from Sentinel 2 data waterways. Then to generate alert, the system compares the estimated depth against minimum fairway depth requirements for safe navigation. One such example is defined by European inland navigation standards. For example, the European Agreement on Main Inland Waterways of International Importance (AGN) [RD.4] specifies minimum fairway depths ranging from 2.5 to 4.5 meters, depending on the class of the waterway and vessel type. Depending on the estimated depth in a river segment and required thresholds, there will be **levels** of alerts:

- **1: low level**, triggered when the river depth is lower than a first threshold. The first threshold will refer to lowest level of deviation.

2: high level, triggered when the river depth than a second threshold (for example, 2.5m) denoting the minimum required depth for navigation

6.2.2.1.2. OBJECT DETECTION

The alert generation for vessel detection comes from a fusion and synchronization of detected vessels through satellite data and AIS data. By comparing vessels detected through AVIS object detection ad-hoc service with AIS data in a specific waterway area, the system can identify discrepancies where vessels are visible in satellite imagery but absent from AIS logs. The alerts raster images will then contain masks denoting these non-AIS vessels.

6.2.2.1.3. DATA AVAILABILITY ALERT SYSTEM

The alert system is designed to monitor the availability of Sentinel-1 and Sentinel-2 satellite data from which the ad-hoc services are generated. With Sentinel-1A and Sentinel-1C operating together, the effective revisit time over Europe is expected to remain between 3-6 days whereas Sentinel-2 provides a 5-day revisit time globally. Combining both, the expected availability of the Sentinel data is between 1-3 days. Though generating services for Sentinel 2 can be less frequent due to cloud cover and other conditions like sun glint. Subsequently, the alert system for Copernicus data will have two **levels** of alerts:

- **1: low level**, triggered when the Sentinel data is not updated after 3 days
- **2: high level**, triggered when the Sentinel data is not updated after 1 week

6.2.2.2. ALERTS BASED ON COPERNICUS HISTORICAL DATA

The alerts described in this section are derived from deviation from Copernicus service based historical data. Below we describe the alert generation ad-hoc services,

6.2.2.2.1. RIVER EDGE

The alert system for river edge service will be created by comparing to historical river width data from the **EU-HYDRO (See Ref. [RD.3])** river network dataset. EU-HYDRO is a part of Copernicus Land Monitoring Service and provides at pan-European level a photo-interpreted river network, consistent of surface interpretation of water bodies (lakes and wide rivers), and a drainage model (also called Drainage Network), derived from EU-DEM, with catchments and drainage lines and nodes. The EU-Hydro product integrates data from different sources—including space-based imagery, member country reporting, and various databases—to provide information on the physical characteristics and geographical distribution of Europe's water bodies, including rivers, lakes, and catchment areas. Within Copernicus Land Monitoring service, the most recent data set present is EU-HYDRO river database extracted from a temporal window of 2006-2012. The dataset has a Minimum Mapping Unit (MMU) of 1 ha and is available as vector data. The predicted river edge, derived from river width, will be compared to historical river edge derived from EU-HYDRO dataset. The alerts will be generated based on the severity of the deviations. Similar to the Aerosol Alert Service described in Section 5.3 of this document, there will be t**hree levels** of alerts:

- **1: low level**, triggered when the deviation is greater than a first threshold. The first threshold will refer to lowest level of deviation and can happen due to seasonal variation.
  - **First threshold: 30m deviation historical river width.**
- **2: medium level**, triggered when the deviation in parameter is greater than a second threshold
  - **Second threshold: 50m deviation of the historical river width**
- **3: high level**, triggered when the deviation is greater than the **last** threshold.
  - **Third threshold: 90m deviation of the river width.**

It should be noted that the value for the above threshold is based on minimizing the false alerts. Additionally. while considering Copernicus based alerts for river widths, it should be noted that due to the issue of FP and FN discussed in Section 6.2.1.1, River edge ad-hoc can have a large error rate for channels and rivers with width lower than approximately 100-150m.

6.2.2.2.2. RIVER DISCHARGE/WATER SPEED

The alerts for the river discharge ad hoc service will be created by comparing to the average of historical data accessed from Copernicus in situ Marine service products. There will be two levels for alerts,

  - **Level 1 is** triggered when the river discharge is 3-standard deviation lower than the historical average for that month.
  - **Level 2: is** triggered when the river discharge is 3-standard deviation higher than the historical average for that month.

6.2.2.2.3. FLOOD FORECASTING

The alerts for flood forecasting will be provided using the European Flood Awareness System from Copernicus. The alert system has a time horizon of 10 days. This is different from the flood forecast service mentioned in [AD..4] which have a higher forecasting time window for flood related hydrological variables. The alert service has three alert levels,

- **Alert Level 1 – 2-Year Return Period**

- This means there's a **50% chance** that a flood of this size will happen in any given year.
- These floods are **more common** and usually **less severe**.

- **Alert Level 2 – 5-Year Return Period**
  - This means there's a **20% chance** that a flood of this size will happen in any given year.
  - Less common than level 1, but **more serious**.
- **Alert Level 3 – 20-Year Return Period**
  - This means there's a **5% chance** that a flood this big will happen in any given year.
  - These are **rare and severe** flooding events.

A *return period* is a way to describe how likely a flood (or any natural hazard) of a certain size is to happen each year. It doesn't mean the event happens *regularly* every few years—rather, it's about probability. This helps emergency managers and decision-makers understand the risk and severity of incoming floods so they can prepare the appropriate response. The higher the alert level, the more likely it is that significant impacts (damage, evacuations, infrastructure issues) could occur.

6.3. COMBINED AVIS ALERTS

From the perspective of the AVIS project, GNSS and Copernicus technologies can be combined and also with other tools to generate alerts. This type of alerts obtained by combining different data sources is what we call combined alerts.

6.3.1.NAVIGABLE AREA BOUNDARY EXCEEDING ALERT

One of the most important features of navigating inland waterways is to ensure that it is possible to navigate within a navigable area with the appropriate characteristics. This area is generally called fairway and it is defined to minimal cross section (most shallow and most narrow points of a certain river section) at low navigable water level. The "Fairway" object into the S57 format of Inland ENC represents the preferred or recommended navigable channel within a waterway. It is the designated route for safe vessel navigation, usually maintained or marked by a competent authority. However, each particular vessel even with a particular status of cargo, has a different draught. Then a general fairway concept is not the most efficient way of showing the navigable area for vessels. So, what is relevant is to ensure that the vessel is navigating in areas that are deep enough for the vessel's draught. Then, the depth area is used taking advantage of the S57 depth area information/object for each particular vessel and particular cargo, where the "Depth Area" object represents a water area with known depth characteristics, typically bounded by depth contours (isobaths). It may include minimum, maximum, and/or average depth values. The pilot introduces per each trip the current draught into the Inland ECDIS so then it is shown those isobaths in different colours highlighting the particular navigable area for this vessel trip.

In any case, the user could generate the navigable area following the criteria considered appropriate (i.e. the intended track for optimized routes) beyond the depth. Therefore, it is very relevant to be able to have an alert that warns in case of danger of exceeding the navigable area limits, either based on the depth area or other criteria.

The position of the vessel, provided through the use of GNSS services, has a certain error associated with it that makes its actual position unknown. It is therefore necessary to bound the position of the vessel with an envelope protection level (EPL), computed locally at the level of the GNSS receiver, that guarantees that the position error is within this boundary with a very low probability of failure. The envelope protection level would be calculated as the protection level provided by the GNSS receiver plus the dimensions of the vessel. In this way, when considering the position of the vessel, it is not considered as a point, but as the whole area in which statistically the vessel could be at that moment. This is as if the vessel had a kind of protective volume and, when considering the vessel's dimensions, not only its structural size is considered but also the volume surrounding it. The following figure is a graphical representation of how it might be thought of as a vessel with a protective volume around it.

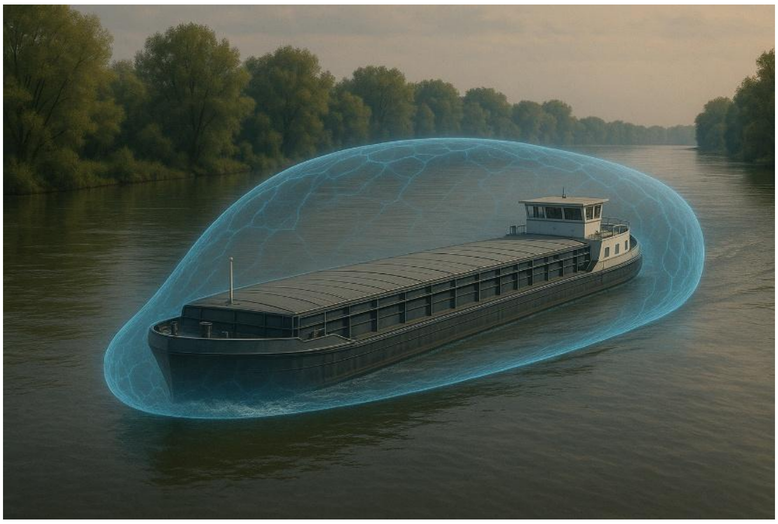

Figure 6-1 Graphical representation of a volume surrounding a vessel

Not only the position of the vessel is subject to uncertainties. The navigable area boundary may have changed and may not be properly updated on the inland nautical chart. Therefore, it would also be necessary to define a safety margin of the navigable area boundary. This safety margin could ideally be estimated using Copernicus, so that the nautical chart could be updated with the most recent imagery. However, with the current accuracy obtained with Copernicus, it would not be possible to obtain a margin that is operationally useful. Therefore, in practice, a certain safety margin could be added to take into account possible uncertainties in the determination of navigable area boundaries.

In addition, for this alert to be more applicable, it is not enough to know whether the navigable zone is currently being exceeded, but whether it is expected to be exceeded in the future. Due to the characteristics of European rivers, vessels have to perform many manoeuvres during navigation. This added to the fact that each vessel has a different drift and motion model, makes it very complex in practice to predict the position in which a vessel will be in the future. Therefore, this alert would only be available to vessels with Track Guidance Assistant (as described in AVIS D1.1 document [RD.5.]) that allows the intended trajectory to be known in advance. In this way, it is possible to estimate the intentional position of the vessel in the future.

With this, the alert can be raised when the EPL exceeds the safety margin of the navigable area boundary. This alert is considered to have two alert levels, one that occurs when at the current time the EPL is already exceeding the navigable area boundary, and another when the intended position of the vessel in a certain time produces that the EPL will exceed the fairway boundary. A 2-minute intended position of the vessel's position is considered for this alert, following as a basis to cover the Operational Safety zone described in TGAIN: Aspects of Safe Use [RD.6.].

The case of the EPL exceeding the navigable area boundary at the current time is considered more critical than the alert for exceeding the navigable area boundary when considering the intended position at a future time according to the Track Guidance Assistant. Therefore, for automated navigation there would be 3 states related to the navigable area boundary exceeding alert:

- **State 0 (No alert)**: The current envelope protection level and the one associated to the intended position in two minutes into the future are within the safety margins of the navigable area boundaries.
- **State 1 (Future EPL exceeding the safety margin of the navigable area boundary)**: The current envelope protection level is inside the safety margins of the navigable area

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boundaries but the one associated to the intended position in two minutes into the future exceeds the safety margin of the navigable area boundary.

- **State 2 (Current EPL exceeding the safety margin of the navigable area boundary)**: The current envelope protection level exceeds the safety margin of the navigable area boundary.

Figure 6-2 shows graphically the different states that the alert can provide.

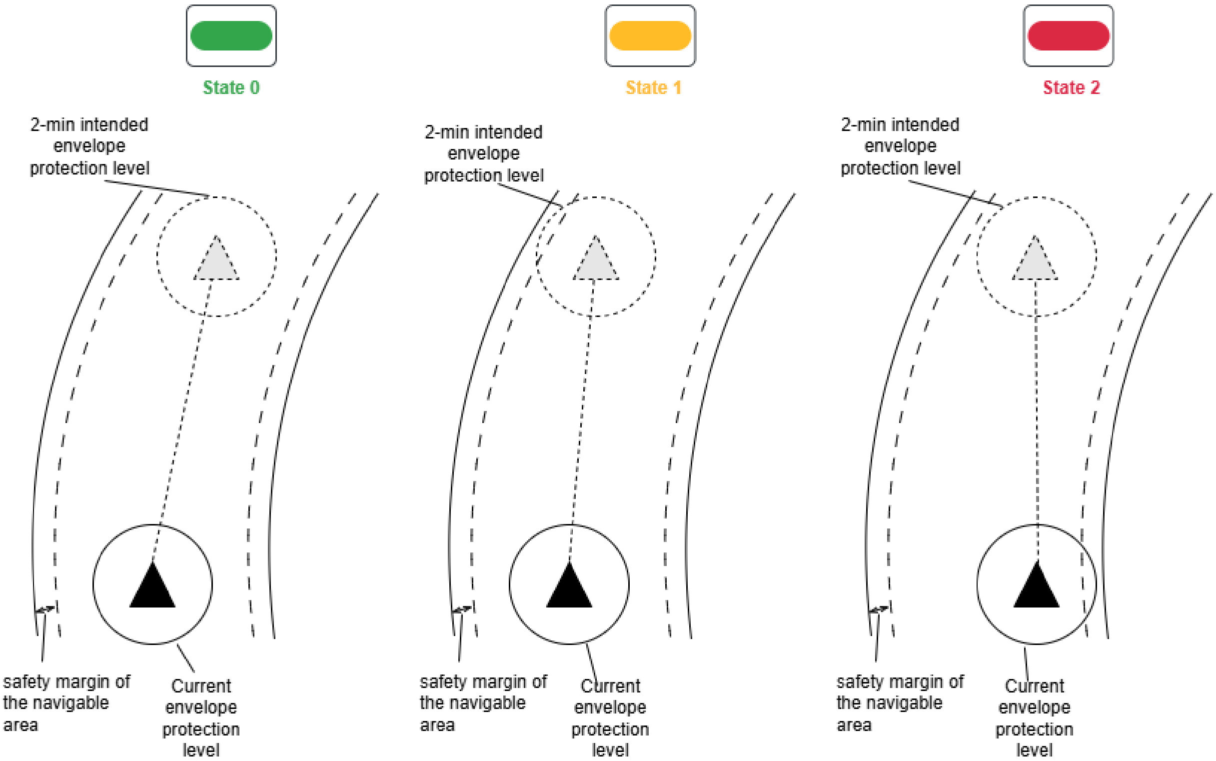

Figure 6-2 Representation of the different alert states of the fairway boundary exceeding alert

This navigable area boundary exceeding alert is considered to be helpful in safe autonomous navigation, especially to achieve AL2, as it reduces the likelihood of an autonomous vessel leaving the navigable zone. The time to alert for this alert is considered that it should be the same as the general time to alert requirement established in document D2.1, which is 6 to 10 seconds.

6.3.2.SEPARATING LINE OVERRUN ALERT

In inland waterway navigation, usually there are no traffic separation zones to manage traffic in two-way ways. Sometimes there are one-way fairways that separates the traffic, for example, in Budapest around Margit-island, right river branch is used for downstream while left is for upstream. However, the dynamic characteristics of the rivers mean that in certain areas, only a section of the fairway is used, for example to take advantage of the currents. In addition, in some narrow or shallow parts, it is impractical to have separate lanes.

However, with a view to helping for safe automated navigation in inland waterways, it is considered interesting that in the future there could be at least certain sections where traffic could be separated by a separating line of the lanes. It would be interesting to identify areas where it would be feasible to have several lanes constantly throughout the year. In this way, it would be easier to control the crossing between upstream and downstream vessels. Moreover, it has also to be considered that when two vessels pass close to each other, attraction effects may occur that could lead to a collision.

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With this, an alert could also be defined in the case of overrunning the safety margin at the separating line of the lanes. It should be noted that this alert cannot be used in a general way in any area. It would be an alert that could be implemented when entering areas where different lanes may exist (for example at the Budapest stretch, the idea to define lanes comes up regularly, but discussions are still ongoing).

The logic of this alert would be analogous to that of exceeding the safety margin of the fairway boundary. It would also only be applicable to ships using Track Guidance Assistant. A intended position of the 2-minute future position and the 3 alert states is also proposed:

- **State 0 (No alert)**: The current envelope protection level and the one associated to the intended position in two minutes into the future do not overrun the safety margin of the separating line of the lanes.
- **State 1 (Future EPL overrunning the safety margin of the separating line of the lanes)**: The current envelope protection level does not overrun the safety margin at fairway centreline but the one associated to the intended position in two minutes into the future does.
- **State 2 (Current EPL overrunning the safety margin at fairway centreline)**: The current envelope protection level overruns the safety margin of the separating line of the lanes.

Figure 6-3 shows graphically the different states that the alert can provide.

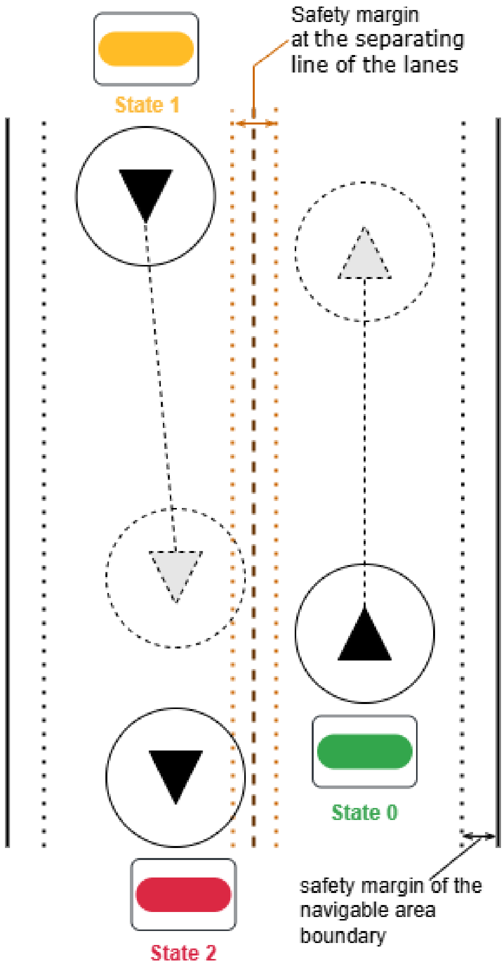

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Figure 6-3 Representation of the different alert states of the separating line overrun alert

This alert, if implemented, would help reduce the risk of collision between crossing vessels, allowing progress towards an AL3.

6.3.3.SUPPORT FOR COLLISION AVOIDANCE ALERT

The alerts seen above only consider information relating to the vessel itself and the navigable area. In order to ensure safe navigation with AL3, it is necessary to have an alert that also takes into account elements of the vessel's environment. For this type of alerts, other sensors such as RADAR, cameras and proximity sensors are very important. However, it is also possible to take advantage of GNSS EU Space data positioning and future possibilities of sharing information for supporting the collision avoidance issue.

In the case of ships using Track Guidance Assistant, it could be considered that they communicate the trajectories they plan to follow using i.e. AIS. Thus, by knowing the future intentions of vessels, it would be possible to analyze whether there is a risk of collision between vessels and raise an alert.

To this end, it is also proposed to generate different levels of alert. In this case, two future states are considered. One at 2 minutes, to cover the Operational Safety zone mentioned above. Then another future intention consideration would be made at 3.3 minutes, to cover the Tactical Reaction zone described in TGAIN: Aspects of Safe Use [RD.6.]. This analyzes the intentions of all surrounding vessels sharing the future intention to assess whether there are intersections in the projections and thus risk of collision.

The states of this alert would be:

- **State 0 (No alert)**: The 2-min future intended position and the 3,3-min future intended position do not collide with the future intention of other vessels
- **State 1 (intersection detected in Tactical Reaction zone)**: The 3,3-min future intended position collide with another vessel future intention.
- **State 2 (intersection detected in Operational Safety zone)**: The 2-min future intended position collide with another vessel future intention.

Figure 6-4 shows graphically the different states that the alert can provide. In the figure the alert is considered for the colored vessel on the bottom of the picture.

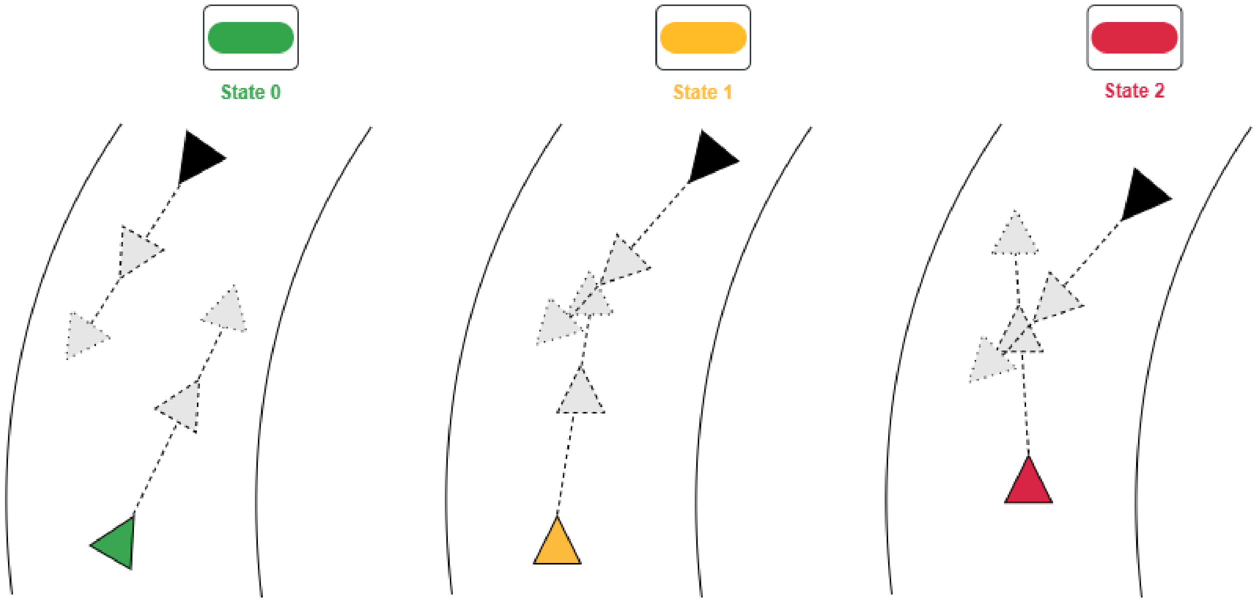

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Figure 6-4 Representation of the different alert states of the support for collision avoidance alert

This alert is considered to be interesting, although it cannot be considered the only one to guarantee an AL3, it allows to bring value in autonomous navigation based on GNSS data. The better the GNSS data, the more accurate this alert can be.

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7. CONCLUSIONS

This document reviews the state of the art of alerts currently available for navigation. The study has shown that there are GNSS-based alerts currently used in navigation. These alerts are generated both at the system level, through EGNOS, and at the receiver level. On the other hand, it has been observed that Copernicus alerts are not currently used for navigation. However, in other types of applications, Copernicus has been seen to provide alerts, and the way in which it provides them has served as a reference for proposing possible new Copernicus alerts.

Following the state-of-the-art analysis, a study has been conducted to propose new potential alerts based on Copernicus or GNSS combined with other tools. The purpose of this analysis is to assess which alerts could be useful for potential future automated navigation. Therefore, the alerts raised in section 6 should be understood as a conceptual proposal.

In the context of AVIS, for the pilots it is proposed implementing Copernicus alerts defined in this document. In any case, the alerts that are ultimately made available in each pilot will depend on the availability of the information and services necessary to implement them. Therefore, some Copernicus alerts may not be available in some of the pilots.

With regard to alerts based solely on GNSS, the aim is to have all the alerts that currently exist in the state of the art. No new potential alerts that can be defined based solely on GNSS have been identified in this document.

With regard to the three alerts defined as combined AVIS alerts, there is only one alert that can currently be implemented in practice. The Navigable area boundary exceeding alert is the only one that can be implemented, as it depends solely on the information currently available and on the pilot vessel. The Separating line overrun alert would require the definition of separation lines that are not currently defined. Therefore, it aims to propose a new approach for evaluation, even though it cannot be applied at present. Finally, the Support for Collision avoidance alert cannot be applied in an AVIS pilot, as it requires several vessels to share their intended trajectory, and AVIS only contemplates the use of a single vessel for pilots. It therefore remains a conceptual idea so that its potential usefulness can be assessed.

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