University of Ljubljana

AKADEMIA MORSKA SZCZECIN

sirm

MAGS

Maritime Adaptive GNSS Safety Concept

Document – ES
Executive Summary

ESA STUDY CONTRACT REPORT – MAGS EXECUTIVE SUMMARY		
ESA Contract No: 4000124022/18/NL/CRS	SUBJECT: Maritime Adaptive GNSS Safety Concept (MAGS) ES Executive Summary	CONTRACTOR: **German Aerospace Center** Linder Hoehe 51147 Cologne

ABSTRACT:

The project MAGS was focused on the development of a Maritime Adaptive GNSS Safety Concept supporting mariners especially within the vicinity of ports.

Critical maritime transport operations such as port approach or port docking among others require safety concepts. One opportunity for a new safety concept is the utilisation of an adaptive Alert Limit (AL) by creating a centralized port monitoring and processing of all the vessels in the port waters, instead of using a fixed AL.

This Executive Summary describes in concise form with few pages and illustrations the major achievements of the MAGS project, which was performed under the ESA Contract No 4000124022/18/NL/CRS.

ESA STUDY MANAGER: David Jimenez Baños DIV: TEC-ETN	

Prepared by:	Ralf Ziebold (RZ) Lucjan Gucma (LG) Pawel Zalewski (PZ) Michael Bergmann (MB) Franc Dimc (FD)	DLR MUS MUS SIRM UL
Checked by:	Ralf Ziebold (RZ) Christoph Lass (CL)	DLR DLR
Authorised by:	Thoralf Noack (TN)	DLR

Doc. No.:	MAGS_ES_Executive_Summary_Final_Version.docx
Issue	002
Revision	1
Date:	01/07/2020
Contract:	4000124022/18/NL/CRS

Change Record

Issue	Revision	Date	Change Status	Origin
V001	0	15/05/2020	Template	DLR
V002	1	23/06/2020	Draft for executive summary and editorial work	DLR
V100	0	01/07/2020	Final Version	DLR

Table of Contents

Table of Figures

List of Acronyms

AAL	Adaptive Alert Limit
AIS	Automatic Identification System
AL	Alert Limit
AWA	Available Water Area
ChDE	Chart Data Error
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ECDIS	Electronic Chart Display and Information System
ESA	European Space Agency
GNSS	Global Navigation Satellite System
HPL	Horizontal Protection Level
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IEC	International Electrotechnical Commission
IMO	International Maritime Organization
INS	Information Service
MAGS	Maritime Adaptive GNSS Safety Concept
MASS	Maritime Autonomous Surface Ships
MS	Maritime Services
MSC	Maritime Safety Committee
MUS	Maritime University of Szczecin (Poland)
MVPA	Marine Vessel Protection Area
NAS	Navigational Assistance Service
NCSR	Navigation, Communications and Search and Rescue
NSE	Navigation System Error
PL	Protection Level
PNT	Positioning, Navigation and Timing
PSS	Port Support Service
RADAR	Radio Detection and Ranging
RAIM	Receiver Autonomous Integrity Monitoring
SIRM	Società Italiana Radio Marittima
SMA	Safe Manoeuvring Area
SoL	Safety of Life
SOLAS	Safety Of Life At Sea
TOS	Traffic Organization Service
TSE	Total System Error
UL	University of Ljubljana
UPS	Uninterruptible Power Supply
VAAC	Virtual Adaptive Approach Channel
VDES	VHF Data Exchange System
VHF	Very High Frequency
VTE	Vessel Technical Error
VTS	Vessel Traffic Service

1 Executive Summary

This document is the Executive Summary of the MAGS project whose major aim was the development of a Maritime Adaptive GNSS Safety Concept supporting mariners especially within the vicinity of ports.

1.1 Background and Motivation

For vessel navigation Global Navigation Satellite Systems (GNSS) are the main source for receiving Position, Navigation and Timing (PNT) information. Nevertheless, a GNSS safety concept for the application of GNSS for Safety of Life (SoL) critical service is still missing. Therefore, the goal of the MAGS project was to develop such a GNSS safety concept for a specific application, namely port approach and port operation of vessels.

Comparing vessel navigation in ports with other modes of transport, where GNSS safety concepts have already been developed like the automatic landing for airplanes, additional challenges need to be considered. While for landing of airplanes the runway is always free of obstacles, for vessel operation in ports other vessels always need to be considered. Additionally, the duration of vessel operations is significantly longer and a safety concept has to deal with a large variety of vessels.

Taking all these challenges into account within the MAGS project a new safety concept under consideration of GNSS has been developed using Adaptive Alert Limits (AAL) for different vessels.

The work of the project has been divided into the five following work packages:

- WP1: State of the art
- WP2: Analysis of inputs
- WP3: System definition
- WP4: Feasibility analysis
- WP5: Conclusions and recommendations

In the following sections the main results of the project are described. For a better understanding all used terms are shortly explained in the Appendix.

1.2 The MAGS Concept

For the development of a GNSS safety concept a clear definition of the application was required. Only based on the safety concept for the whole application scenario the error budgets for each individual subsystem like the navigation equipment can be derived.

For MAGS, three applications have been considered:

- Navigation in ports and port approaches under bad visibility conditions
- General Navigation in ports and port approaches
- Enabling track control for navigation in ports and port approaches

The GNSS safety concept is based on the use of an **Adaptive Alert Limit (AAL)** for the GNSS positioning together with a **recommended track** (route defined by waypoints with associated time) and its safety boundaries generated at a shore-side service (e.g. Vessel Traffic Service (VTS)). The recommended routes together with its safety boundaries define the **Virtual Adaptive Approach Channel (VAAC)** and are associated to each individual vessel, taking the other traffic into account. The VAAC is defined in a geodetic reference frame and takes chart errors into account. In that sense it is virtual, because it is finally defined in a virtual reality on an Electronic Chart Display (ECDIS), rather than in the real world. The VAACs are free of obstacles for the planned timespan and can be seen as an analogy to the fixed runway dimension for the automatic landing of airplanes.

The MAGS concept is divided into two phases: a) the port approach planning phase and b) the monitoring phase.

a) Planning Phase

A vessel gets support from a shore side service (VTS) before entering the port. The shore side service provides an optimum route to the vessel including safety margins by VAAC.

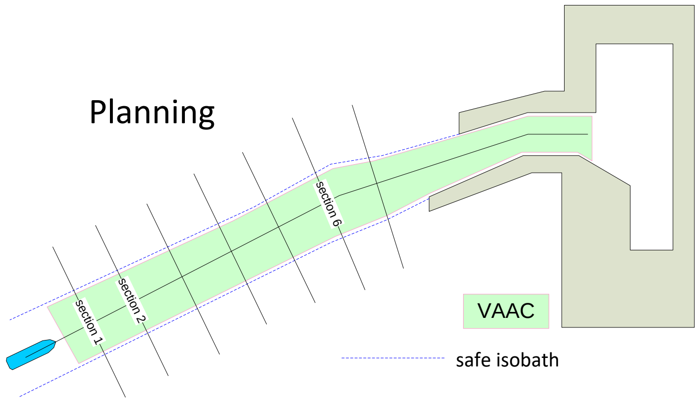

Figure 1-1: Port approach planning, Sketch of optimum route together with VAAC

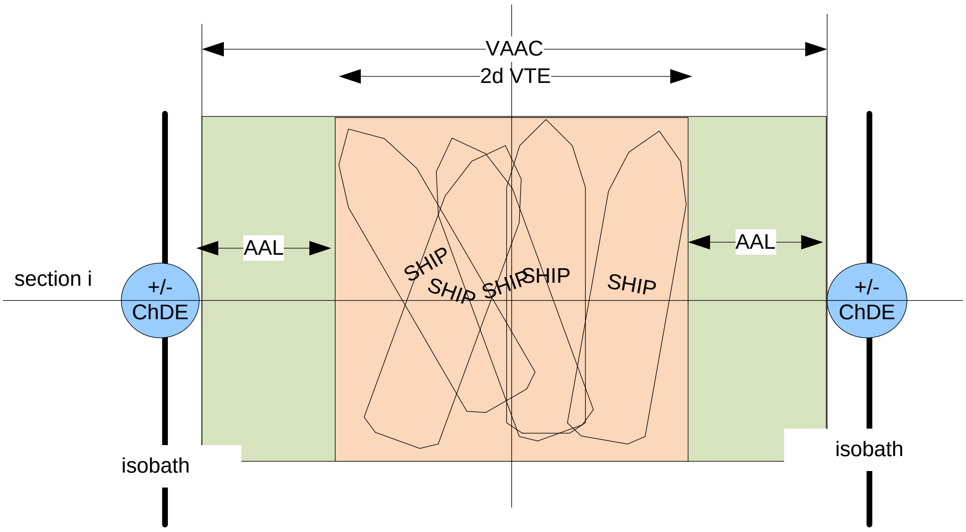

Figure 1-2: Illustration of determination of Adaptive Alert Limits (AAL)

For the given vessel and given conditions the system calculates an overbound of the 2d Vessel Technical Error (VTE). Based on VAAC and the overbound of the 2d VTE, the required navigation performance is calculated for each waypoint. This required navigation performance defines the allowed Adaptive Alert Limit (AAL) for each waypoint.

This optimum route can be determined with no other vessel in the surrounding, but also considers the other vessels, so that all vessels will be provided with an optimum route including safety margins.

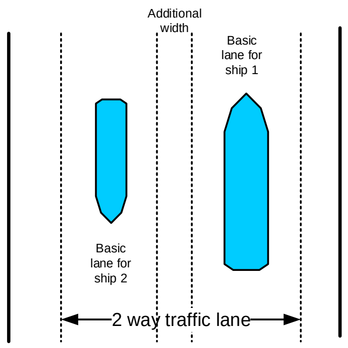

Figure 1-3: Two way traffic approach

Based on the performance forecast for the GNSS system together with its augmentation services the feasibility of a GNSS based navigation for that vessel is evaluated and a decision is taken to allow port approach based on GNSS positioning.

The proposed method aims to be a substantial improvement to the risk assessment by the decision makers and enables them to quantitatively determine the associated risks. Regularly at a rate depending on communication standard or whenever the traffic situation has changed, an update of the planning is performed.

b) Monitoring phase:

During the approach, the Horizontal Protection Level (HPL) is continuously calculated and checked against the Adaptive Alert Limit (AAL). Furthermore, also the drift angle and cross track error (distance to planned trajectory) is measured and checked against the maximum error in the assumption (simulation).

Additionally the Marine Vessel Protection Area (MVPA) is calculated. This is an area on a nautical chart where under consideration of a given integrity risk it can be guaranteed that the vessel is inside this area. It includes the vessel hull curve, the horizontal Protection Level (PL) and the uncertainty in the heading determination.

Regularly at a rate depending on communication standard or when state/situation of traffic has changed, an update takes place.

The display to mariner contains:

- Ship contour + MVPA
- Planned trajectory + safe margins
- Actual AL, PL, and cross track distance
- Trajectory and safe margins of relevant other vessels
- Traffic light display (to inform the mariner about the status)

Figure 1-4: Display to the mariner in the Monitoring Phase - MVPA with respect to the VAAC

Note: More information about the concept are explained in document MAGS D1 - Safety Concepts State of the Art – Version 1.0 Issue 2.

1.3 MAGS System definition

The overall system is composed of two sub systems:

- Ships onboard system
- Shore based VTS system

Both systems collect relevant data, prepare data output streams and communicate those to each other. The output of the different sub-systems will be used to enhance situation awareness and support decisions on board and on shore.

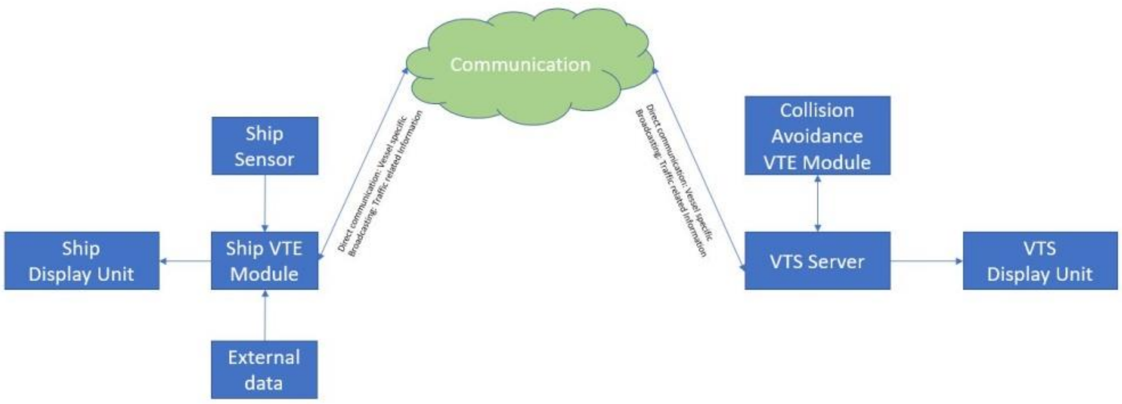

Figure 1-5: High Level System Information Flow Diagram

The system functions need to be performed using as much as existing capabilities possible. The ship display unit should utilise the existing Electronic Chart Display (ECDIS) to visualise the recommended route with its safety limits as well as the MVPA. Similarly, on shore existing systems, e.g. ECDIS or VTS units should be used to display the necessary information.

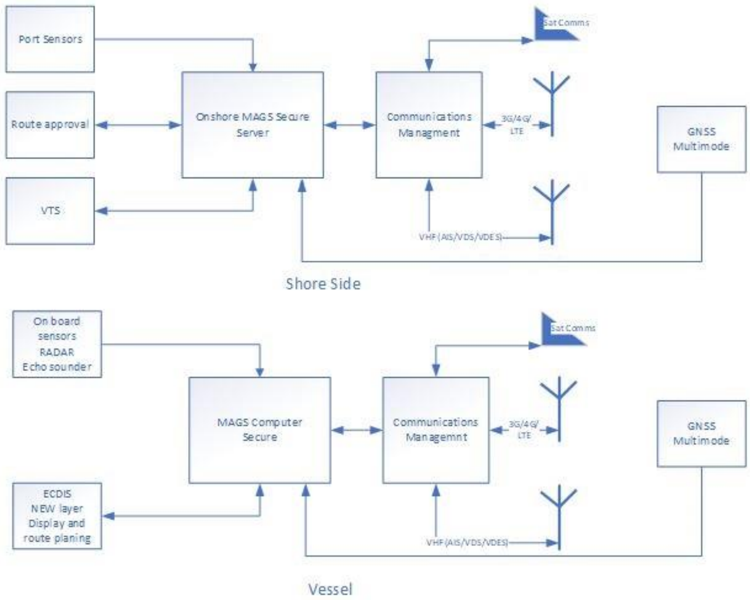

Figure 1-6: High Level System Component Diagram

It is expected that the ship related information will be communicated between ship and shore as well as shore and ship using direct secure peer to peer communication, while generic traffic information is being broadcasted by the shore centre and received by the ship.

The shore centre will transmit to the ship the recommended route with its safety limits, the corresponding adaptive alert limits as well as the routes of other ships affecting the voyage of the receiving ship via this direct data exchange.

Note: Further information about the required components shore-side and on the vessel as well as related to the required input data can be found in documents MAGS D2 – Input Data Requirements– Version 1.0 Issue 2 and MAGS D3 – System Definition Document – Version 1.0 Issue 1

1.4 Feasibility Analysis

Within the scope of the feasibility Analysis empirical methods, simulation data and AIS data were used to create statistical and empirical model of MVPA and VAAC which include both Navigation System Error (NSE) and VTE. Moreover statistical and empirical models of MVPA were created and validated. The models were implemented in full mission ship's bridge simulator to demonstrate the potential benefits of the concept.

Under consideration of the proposed user integrity concept by using adaptive safety margins as well as the navigation traffic lights concept, six situations could occur depending on HPL and AL values, and MVPA position in relation to VTEL and VAAC during passage of one way water channel. All situations were simulated and conceptual presented in ECDIS.

The positive influence of MAGS system on navigation safety has been assessed in several dimensions:

1. Influence on manoeuvring areas that ships need to use for the port approach.
2. Increasing situation awareness of the captain and pilot by decision support.
3. Ordering and structuring of ships traffic.
4. Delivering the information to the captain of ship.
5. Delivering a new type of information to VTS and therefore increasing the awareness of VTS operators.
6. Decreasing the risk of maritime operation in two ways:
    a. Decreasing the standard deviation of ships' manoeuvring areas and in result probability of ships going aground or striking the structures.
    b. Delivering the information of positioning system status and performance.

Every captain performing simulations was asked about the MAGS system performance. There were several feedbacks to the system performance like:

1. Graphic information in the form of MVPA and VAAC functionality seems to be more useful than alphanumeric warnings.
2. System increases the navigator's situational awareness.
3. System can serve as an extension to standard ECDIS alerts/warnings (dead reckoning, position or heading system fault, RAIM).
4. MAGS is very useful in planning the anti-collision manoeuvre for two way traffic. More research shall be done to establish the location of the passing area in more optimal and dynamic way.

The operational conclusions are:

1. Multipath error component of MVPA can be quite significant, but its estimation needs further research as stressed in EMPONA and other ESA projects.
2. Gyro heading error based on real studies can be up to 2° standard deviation.
3. The determination of VTE was done statistically based on several hundred ship simulation scenarios. The multiple regression method was applied. The method show good statistical convergence to reality.

Note: The whole feasibility study is available in document MAGS D4 – Feasibility Analysis – Version 1.0 Issue 1.

1.5 Way Forward

To implement the MAGS concept, which intends to contribute to the Safety of Life at ships, and with that, makes it a reality and fully capitalise on the benefits, various activities are needed. The roadmap for implementation of MAGS has to take three different aspects into account:

1. Standardization
2. Regulatory framework
3. Technical and operational solutions

The MAGS project has developed and validated specific aspects of the MAGS concept, like Adaptive Alert Limit (AAL), Maritime Vessel Protection Area (MVPA) or Virtual Adaptive Approach Channel (VAAC). In order to further implement MAGS and make it available for the maritime domain, those aspects need to be internationally known, accepted and put in use. The first step in this direction is to identify the responsible international bodies who can endorse and implement it. Those are the IMO, IALA and IEC.

In the regulatory environment the IMO plays a major role on all ship equipment. IMO instruments like the SOLAS conventions define the equipment required for safe navigation. The MAGS concept is directly related to the goal of the IMO to increase safety and efficiency of maritime transport as well as protection of the maritime environment and as such affects the work of IMO, especially on SOLAS.

Besides the activity establishing international standards for the relevant MAGS aspects, the IMO should be made aware of the positive results of the development and validation of the MAGS concept. An initial approach would be to encourage one of the IMO member states to submit a work proposal to IMO Maritime Safety Committee (MSC).

There are activities underway, which may impact the further implementation on the MAGS deliverables. Of most interest and to be taken in consideration on the way forward are the following four activities:

1. Further development of the IMO e-Navigation initiative, especially the development of new Maritime Services (MS), e.g. on MS 1 – VTS Information service (INS), MS 2 – VTS Navigational assistance service (NAS), MS 3 – Traffic organization service (TOS), MS 4 – Port support service (PSS)
2. Development at IMO at MSC and NCSR on regulatory work for MARITIME AUTONOMOUS SURFACE SHIPS (MASS)
3. IALA committee work at “ENAV – e-Navigation Information Services and Communications Committee” and “VTS – Vessel Traffic Services Committee”

Finally, a dedicated roadmap for implementation and standardization of the MAGS concept is proposed.

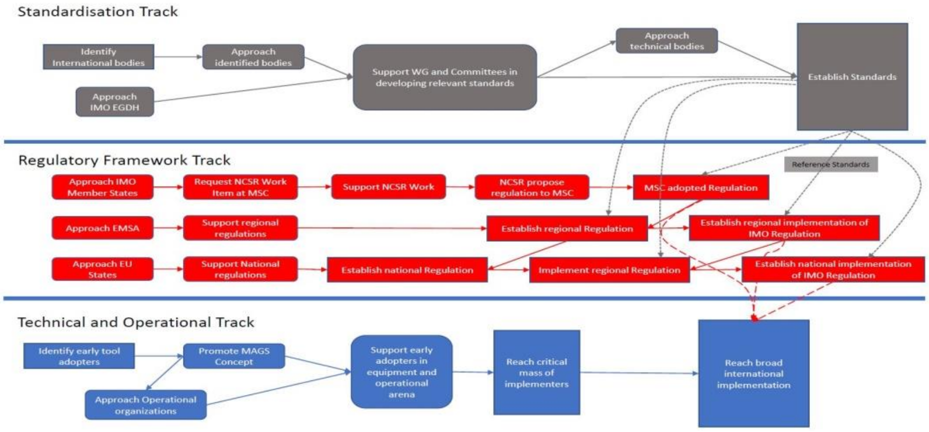

Figure 1-7: Possible Roadmap for implementation and standardization of the MAGS concept

Note: More information about the implementation plan (way forward) is available in document MAGS D5 – Conclusions and recommendation document – Version 1.0 Issue 1.

2 Appendix: Definitions of terms used in the MAGS concept

Isobath (planning)

An Isobath is defined as a line on a chart connecting points of equal water subsurface depth.

Chart error (planning)

The chart error is the difference between a position of an element in the nautical chart as indicated in the chart and its true position.

It needs to be considered when determining safe isobaths.

Safe Isobath (planning)

Safe Isobath is defined as a line on a chart connecting points of such underwater depth which is equal to the current draft of the vessel increased by minimum required under keel clearance. The Safe Isobaths additionally takes the chart error into account. Within a port the maneuvering space and hence the isobath can also be the line in the chart of the quay wall.

AWA **(**planning**)**

The Available Water Area (AWA) is the area that a ship can use for maneuvering and is bounded by the safe isobaths.
It is used for determination of VAAC

VAAC (planning and monitoring)

Is determined in the port approach planning and used the monitoring phase. The recommended routes together with its safety boundaries define the Virtual Adaptive Approach Channel (VAAC) for each individual vessel. The VAAC is provided by the VTS taking the available water area and other traffic into account. The VAAC is defined in a geodetic reference frame.

The VAAC is assigned to each vessel individually ensuring that when all vessels follow the planned routes within their safety boundary they pass each other safely.

AAL (planning and monitoring)

Adaptive Alert limit for horizontal positioning defines the allowed horizontal position error for each part of the VAAC. It is determined in planning phase taking a heading error overbound into account and used in the monitoring phase.

TSE (1d) (planning)

Total system error (TSE) is the difference between the true position and the desired one. It is a combination of the Vessel Technical Error (VTE) and the Navigation System Error (NSE).

TSE 2d (planning)

The TSE 2d is the difference between the true vessel hull curve in the horizontal plane and the desired one.

VTE 1d **(**monitoring**)**

This Vessel Technical Error 1d is the difference between the indicated craft position and the indicated command or desired position. It is a measure of the accuracy with which the craft is controlled.

VTE 2d (planning and monitoring)

The Vessel Technical Error 2d is the difference between the indicated vessel hull curve determined by the navigation system in the horizontal plane and the desired one.

Overbound VTE2d (planning)

Overbound VTE2d sometimes also referred as Safe Manoeuvring Area (SMA) describes the area the vessel needs for save manoeuvring without taking the navigation system error into account. In a simple calculation it includes an overbound of the 1d VTE the width of the vessel and the drift angle.
For complex manoeuvres the overbound VTE 2d can be estimated by full mission simulators running multiple simulations in a Monte Carlo approach. The Overbound VTE 2d takes the different acceptable risks for the different vessels into account.

NSE 1d (planning)

Navigation System Error is the difference between the true horizontal position and the estimated horizontal position by the navigation system.

NSE 2d (planning)

Navigation System Error 2d is the difference between the true vessel hull curve in the horizontal plane and the estimated one by the navigation system based on horizontal position and heading determination.

MVPA (monitoring)

Marine Vessel Protection Area describes an area on a nautical chart where under consideration of a given integrity risk it can be guaranteed that the vessel is inside this area. It includes the vessel hull curve, the horizontal protection level and the uncertainty in the heading determination. The MVPA was defined in the EMPONA project.

END OF DOCUMENT