AUTOSHIP
Autonomous Shipping Initiative for European Waters

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D4.5 - Scaled demonstrator report

WP n° and title	WP4 - Demonstration & Validation of Enabling technologies for short-sea shipping
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01	23/11/2021	Henrik Foss / Morten Skogvold	Draft version. Will be updated and finalized once the additional scaled demonstrator tests are completed.
02	29/11/2021	Henrik Foss / Morten Skogvold / Thoralf Ruud	Final version
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QUALITY CHECK REVIEW

Reviewer (s)	Main changes
Siv Randi Hjørungnes	Proof reading and some minor editorial changes proposed.

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1. LIST OF ABBREVIATIONS AND DEFINITIONS

Abbreviation	Definition
AIS	Automatic Identification System
ANS	Autonomous Navigation System
CPA	Closest Point of Approach
DoA	Description of Action
EC	European Commission
ECDIS	Electronic Chart Display and Information System
GNSS	Global Navigation Satellite System
H2020	Horizon 2020
KCC	Kongsberg Camera Clusters
KET	Key Enabling Technology
KVM	Keyboard, Video and Mouse
NTNU	Norwegian Teknisk-Naturvitenskapelige Universitet (Norwegian University of Science and Technology)
OSD	Ocean Space Drone (Target vessel)
OSL	Ocean Space Lab (Test vessel)
R&A	Remote & Autonomous
R&D	Research & Development
SA	Situational Awareness
SCC	Shore Control Centre
UHF	Ultra High Frequency
WP	Work Package

Short name	Name
KOGM	Kongsberg Maritime AS

2. EXECUTIVE SUMMARY

The purpose of the subtask T4.3.2 Scaled demonstrations was to demonstrate remote operation of a scaled vessel from the SCC in cooperation with subcontractor university NTNU, also involving student projects. This would both allow early testing of basic functions and be an important part of the dissemination of the project as well as inspire young talents within the R&D community. However, due to the COVID-19 pandemic, the cooperation with NTNU had to be through a digital student competition Njord – The Autonomous Ship Challenge, and the scaled demonstrator was done by KOGM in cooperation with linked 3rd party Kongsberg Seatex. Also due to COVID-19 and consequential restrictions and delays, demonstration of remote operation from the SCC was not included in the scope.

The all-digital competition was held in August 2021, and the students were put to the test in three categories: situational awareness, collision avoidance and docking. KOGM and Seatex assisted the Njord team before, during and after the date of competition through competency sharing and motivational talks.

The scaled demonstrator successfully integrates two of the Key Enabling Technologies (KETs), SA and ANS in a test vessel setup similar to the WP4 demonstrator vessel, MV Eidsvaag Pioner. This enables the project to run relevant test scenarios on real-world and real-time data, progressing from simulated data and pre-recorded data.

A demonstration of the selected KET capabilities was performed on the 29th of September 2021. The goal was to demonstrate SA and ANS in a decision support context, where deviations from a prep-lanned route was presented to a navigator to follow. Four collision scenarios were setup and run, with a successful integration of the different components.

3. INTRODUCTION

AUTOSHIP Work Package (WP) 4 has planned to perform testing of Key Enabling Technologies (KET) on a scaled test vessel. From the Description of Action (DoA) for the project, the following is stated:

This task will establish/hire a scaled vessel including a basic propulsion system, sensors for situational awareness, basic control systems and communication systems, also to setup communication between the scaled vessel and the SCC. The vessel shall be able to perform selected R&A operations (e.g. collision avoidance) from the SCC. The purpose of this test is to demonstrate remote operation of a scaled vessel from the SCC. This is planned to be done in cooperation with the subcontractor university NTNU and will involve student projects. This will both allow early testing of basic functions and be an important part of the dissemination of the project to create engagement and acceptance in the wider community and inspire young talents with in the R&D community. Mapping of operational context will also be attempted e.g. using mobile sensor and logging systems from Intelligent Awareness System and installation of connectivity equipment for mapping of communication quality in the real operational environment in the demonstration area (see T4.2.2).

The primary goal for the test is to assess the performance and integration of obstacle detection and collision avoidance algorithms. These KETs represent a subset of the complete system to be installed on the MV Eidsvaag Pioner, however they are also the part of the KETs which are the most complex to simulate. The R&D development teams of these KETs are also located in close proximity, Trondheim and Ålesund, which makes it easier to perform installation and live demonstration facing COVID challenges. Main systems/KET involved in this primary objective are

- ANS – Autonomous Navigation System
- SA – Situational Awareness System – SeaAware product

The plan was to include NTNU and involve student projects in this testing. Due to COVID related issues, this part of the demonstration became KOGM involvement in the pilot of Njord – The Autonomous Ship Challenge. The all-digital competition was held in August 2021, and the students were put to the test in three categories: Situational awareness, collision avoidance and docking. KOGM and Seatex assisted the Njord team before, during and after the date of competition through competency sharing and motivational talks.

Main sponsor

Kongsberg Maritime

Kongsberg Maritime is a subsidiary of Kongsberg Gruppen ASA and is developingand providing technology to the maritime industry worldwide. Development and commercialization of technology for autonomous ships is a focused area in Kongsberg Maritime AS. One of the projects for supporting this development is the **AUTOSHIP** project.

The AUTOSHIP project is a Horizon 2020 funded project(project number 815012) with the aim of developing key enabling technologies for autonomous ships and demonstrate this in full scale in a real operational environment.

Scaled demonstrations and involvement of student projects in cooperation with NTNU is part of the scope in the AUTOSHIP project "to create engagement and acceptance in the wider community and inspire young talents within the R&D community". KM and the AUTOSHIP project is excited to be the main sponsor of the **Njord – The autonomous ship challenge.**

KONGSBERG

AUTOSHIP

Autonomous Shipping Initiative for European Waters

Figure 1 - From https://www.njordchallenge.com

The first part of this document will shortly describe the highlights from Njord – The autonomous ship challenge. The remaining document will focus on the primary goal of the scaled demonstration and will outline the test vessel system upgrades, the collision scenarios to be investigated and the performed tests.

4. NJORD – THE AUTONOMOUS SHIP CHALLENGE

The Challenge had initially 10 participating teams, but due to the heavy workload and difficulties with establishing a well-functioning team due to the pandemic, some had to withdraw from the Challenge. In the end three teams submitted their technical reports and their guidance and navigation systems.

The Challenge began with a live stream with Robin Stokke and Frithjof Bugge from Njord. They guided the attendees through the program which included guest interviews with Thomas Skarshaug, co-founder of Zeabuz and Gemini, and also Stephanie Kemna, research manager at Maritime Robotics. The event finished off with a demonstration of the teams' guidance and navigation systems commented by the guest experts.

Later the same day Njord hosted an Inspirational talk at Havet Arena in Trondheim together with main sponsor Kongsberg Maritime - representing AUTOSHIP, Zeabuz and NTNU. The event was also streamed live for those not able to attend physically. Kongsberg Maritime and AUTOSHIP, represented by Morten Skogvold, offered a deeper insight into some of the emerging technologies within marine autonomy. In addition to this, it was also presented how KM and the AUTOSHIP project are approaching the challenges of marine autonomy, and how they envision the future of the industry. The event had good attendance with more than 40 participating physically, in addition to the digital attendees watching the stream.

The Challenge was ended with an award ceremony with Morten Skogvold again representing Kongsberg Maritime and AUTOSHIP. During the Challenge Njord saw a vast increase of visitors on their webpage and social media platforms. More than 300 visitors on the webpage during the days of the competition showed that there was a lot of interest in the Challenge. The hope is to gain more attention and attract more bright students from all over the world to take part in next year's planned Challenge.

The jury received the teams' technical reports two weeks ahead of the Challenge and agreed that the teams' efforts were high. One week before the Challenge, the teams handed in their navigation systems such that the jury could begin their evaluation. Despite the overall high quality of the teams, one team clearly stood out. Team Atlantics from the University of Porto had written a strong technical report, and their guidance and navigation system were capable of reaching set-points efficiently. Additionally, it consistently avoided obstacles, demonstrating satisfactory collision avoidance and situational awareness capabilities. Consequently, the jury could announce Atlantics as the winner of the first-ever Njord Challenge, receiving NOK 25 000 for their efforts. The jury could also congratulate the teams finishing in second and third place; Técnico Solar Boat from University of Lisbon and Team Strathclyde from University of Strathclyde respectively.

In conclusion the pilot of Njord - The Autonomous Ship Challenge was a success and created a platform to build on for years to come. The Njord team have already begun planning towards next year's Challenge and hope to attract even more attendees to the first physical competition in 2022.

5. SCALED DEMONSTRATOR

5.1. DEMONSTRATION SETUP

5.1.1. Demonstration Vessels

5.1.1.1. Test vessel

The Kongsberg Seatex's vessel Ocean Space Lab (OSL) is used as test vessel.

Figure 2 - Test vessel - Ocean Space Lab

OSL1 MAIN PARTICULARS

LENGTH	16,1m
BREADTH	3.8m
DRAFT	0.8m
MAX SPEED	45 knots

The vessel is a highly maneuverable high-speed patrol boat. It is well suited for carrying sensors and other necessary test equipment. The Situational Awareness (SA) sensor package installed is a near equivalent to the MV Eidsvaag Pioner installation.

The SA System outputs data for the Autonomous Navigation System (ANS) to process and suggest route deviations if needed. This is displayed to the vessel operator in real-time. On the final autonomous demonstration onboard the MV Eidsvaag Pioner, the avoidance maneuvers will be executed automatically by the control system. In this scaled demonstration, however, all vessel maneuvers are performed by the navigator, using conventional controls onboard the vessel. This means that the presentation of the avoidance maneuver needs to work well for a human operator.

The dynamics of the scaled test vessel is quite different from the full-scale MV Eidsvaag Pioner, as the vessel is capable of high-speed maneuvers, low turning circles and short stopping distances. This is one of the reasons for operating the ANS as an advisory system, where we focus on the maneuvers themselves more than the execution of the commands. The system is tuned for the same dynamics as the full-scale vessel, and all maneuvers are executed as if we were operating a larger vessel.

5.1.1.2. Target vessel

The Kongsberg Seatex's vessel Ocean Space Drone 1 (OSD1) is used as the target vessel.

Figure 3 - Ocean Space Drone 1 and 2

OSD1/2 MAIN PARTICULARS

LENGTH	12m
BREADTH	3m

DRAFT	-
MAX SPEED	5,6 knots

5.1.1.3. Demonstration Area

The test vessel is stationed in Trondheim and the scaled testing have been performed in the autonomous ship test area established in the Trondheim fjord.

5.1.1.4. Test Conditions

The demonstration was performed on the 29.09.2021. Daylight conditions, good visibility, blue skies. Sea state 2.

Figure 4 - Day of demonstration

5.1.2. Demonstration Equipment Description

KCC

2 x Kongsberg Camera Clusters (KCC), providing 360 degrees camera coverage around the vessel.

Radar

4 feet radar X-band radar

K-Bridge

Radar server/display and ECDIS application

Seapath / DPS

GNSS processing unit providing the vessel position.

MGC

Inertial navigation system with gyro compass.

SeaAware

4U processing unit with the SeaAware (providing Situational Awareness to ANS).

ProximityView

2U processing unit providing stabilized fused video feed from the camera clusters.

AIS

AIS receiver

ANS

Lenovo MC330 computer with the Autonomous Navigation System.

KVM

Black Box KVM solution to provide the equipment with keyboard, video and mouse the on-board workstations and bridge displays.

UHF

Radio communication between test vessel (OSL) and target vessel (OSD1) for coordination of the test scenarios.

5.1.3. Demonstration Objectives

1. Verify system integration of all components listed in the equipment description.
2. Verify that SeaAware can detect and report position-data of vessels in proximity of OSL.
3. Verify that ANS can suggest collision avoidance manoeuvers based on the data provided by SeaAware
4. Verify that the ANS suggested route deviations causes by observations made by SeaAware are consistent.

5.2. TEST SCENARIOS

This section describes the test scenarios including control instructions to both target and test vessel. The scenarios are described using the waypoints defined in section 5.5.

5.2.1. Pre-test verification

Before the proposed test scenarios can be performed, a pre-test verification will be performed to ensure that all vessel components are successfully integrated. Interfaces between all sensors and the SA system, between the SA and the ANS system, and between the ANS and the Bridge monitor will be tested. Both data flow and data integrity will be verified before starting the test campaign.

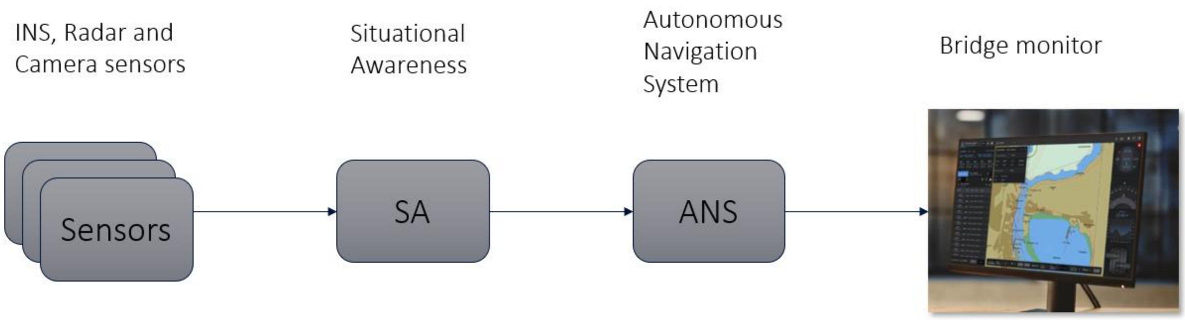

Figure 5 - Data flow

5.2.2. Scenario 1

Scenario 1 is a head-on collision situation, where the target vessel is approaching on reciprocal course to test vessel. The distance when target ship is detected by the ANS shall be large enough to be classified before entering the own ships prediction horizon. The target vessel should here not give way according to COLREG rule 14.

Test ID	1
Test objectives	1,2,3,4
Description	Test vessel and target vessel running head-on.
Expected results	SeaAware shall detect the vessel on collision course and provide information to ANS. ANS should suggest an alternative route to avoid collision.

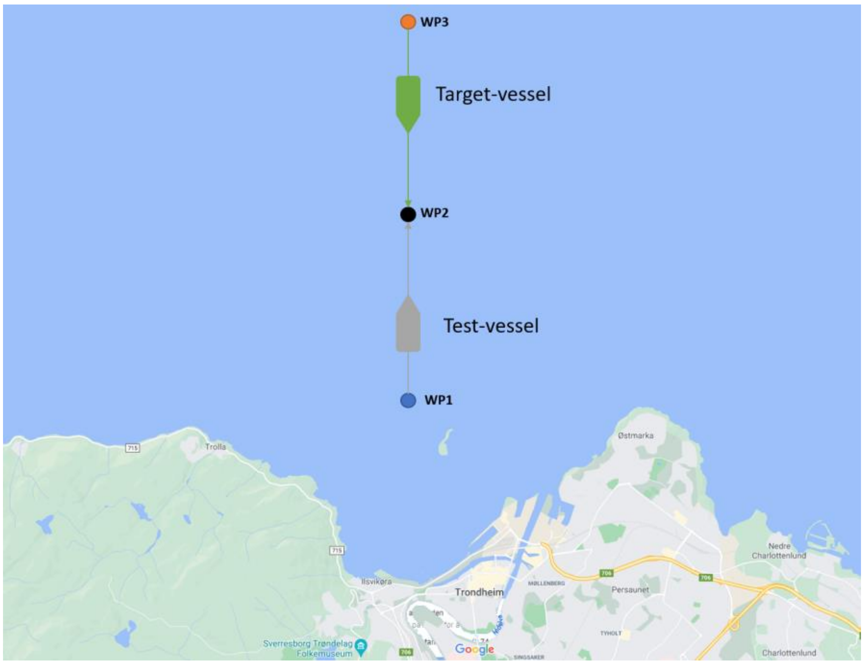

Figure 6 - Scenario 1

5.2.2.1. Test vessel

Route	WP1, WP2.
Speed	5 [kts]
Preparation	Establish a common start time for both vessels.
Execution	At the agreed start time, follow the route at the stated speed. When ANS provide alternative route, navigate vessel accordingly to avoid collision with target vessel. If ANS doesn't provide alternative route, or the alternative route is deemed to be unsafe, abort test by navigating the vessel to avoid collision. If aborted, the report shall clearly state the reason for aborting, in a way that brings valuable feedback to the SA and ANS development.

5.2.2.2. Target vessel

Route	WP3, WP2.
Speed	5 [kts]
Preparation	Establish a common start time for both vessels.
Execution	At the agreed start time, follow the route at the stated speed.

5.2.3. Scenario 2

This is a crossing give-way scenario where a target vessel is approaching from our starboard side, with a very small CPA (closest point of approach) if both vessels keep constant course and speed. According to COLREG rule 15, we are to keep away from the target vessel and avoid crossing in front of ahead of the other vessel. The other vessel is required to keep its current course and speed.

Test ID	2
Test objectives	1,2,3,4
Description	Test vessel and target vessel on collision course.
Expected results	SeaAware shall detect the vessel on collision course and provide information to ANS. ANS should suggest an alternative route to avoid collision.

Figure 7 - Scenario 2

5.2.3.1. Test Vessel

Route	WP1, WP2.
Speed	5 [kts]
Preparation	Establish a common start time for both vessels.
Execution	At the agreed start time, follow the route at the stated speed. When ANS provide alternative route, navigate vessel accordingly to avoid collision with target vessel. If ANS doesn't provide alternative route, or the alternative route is deemed to be unsafe, abort test by navigating the vessel to avoid collision. If aborted, the report shall clearly state the reason for aborting, in a way that brings valuable feedback to the SA and ANS development.

5.2.3.2. Target Vessel

Route	WP4, WP2.
Speed	5 [kts]
Preparation	Establish a common start time for both vessels.
Execution	At the agreed start time, follow the route at the stated speed.

5.2.4. Scenario 3

This is a crossing give-way scenario, similar to scenario 2, where a target vessel is approaching from our starboard side, with a very small CPA if both vessels keep constant course and speed. According to COLREG rule 15, we are to keep away from the target vessel and avoid crossing in front of ahead of the other vessel. The other vessel is required to keep its current course and speed.

Test ID	3
Test objectives	1,2,3,4
Description	Test vessel and target vessel on collision course.
Expected results	SeaAware shall detect the vessel on collision course and provide information to ANS. ANS should suggest an alternative route to avoid collision.

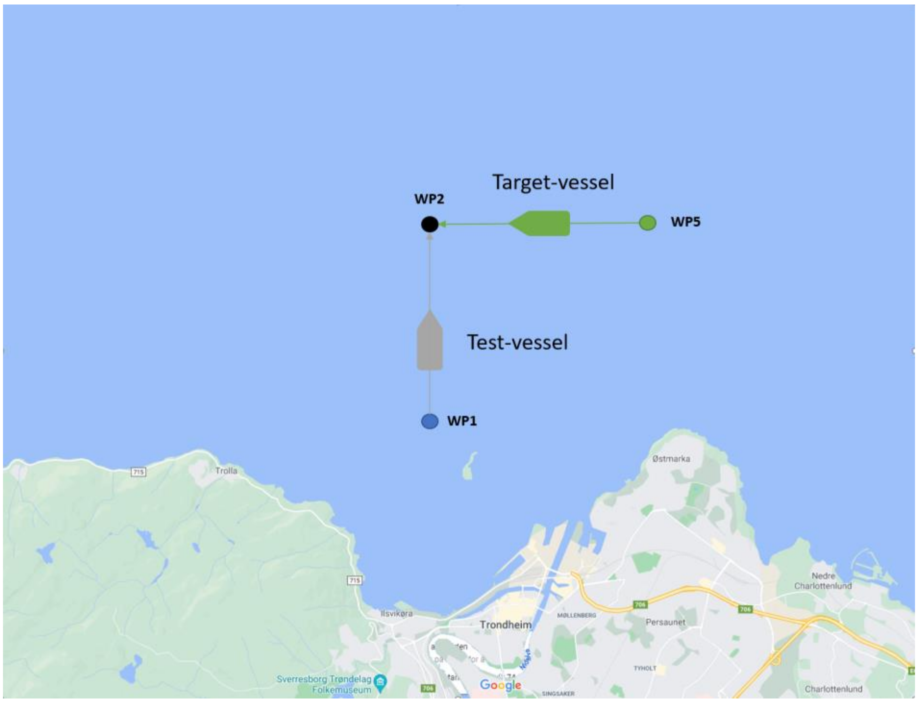

Figure 8 - Scenario 3

5.2.4.1. Test Vessel

Route	WP1, WP2.
Speed	5 [kts]
Preparation	Establish a common start time for both vessels.
Execution	At the agreed start time, follow the route at the stated speed. When ANS provide alternative route, navigate vessel accordingly to avoid collision with target vessel. If ANS doesn't provide alternative route, or the alternative route is deemed to be unsafe, abort test by navigating the vessel to avoid collision. If aborted, the report shall clearly state the reason for aborting, in a way that brings valuable feedback to the SA and ANS development.

5.2.4.2. Target Vessel

Route	WP4, WP2.
Speed	5 [kts]
Preparation	Establish a common start time for both vessels.
Execution	At the agreed start time, follow the route at the stated speed.

5.2.5. Scenario 4

This is an overtaking scenario, where the target vessel is in front of the test vessel, traveling at a lower speed.

Test ID	2
Test objectives	1,2,3,4
Description	Test vessel overtaking target vessel.
Expected results	SeaAware shall detect the vessel in front and provide information to ANS. ANS should suggest an alternative route to pass the vessel on a safe distance.

Figure 9 - Scenario 4

5.2.5.1. Test Vessel

Route	WP3, WP1.
Speed	10 [kts]
Preparation	Establish a common start time for both vessels.
Execution	At the agreed start time, follow the route at the stated speed. When ANS provide alternative route, navigate vessel accordingly to avoid collision with target vessel. If ANS doesn't provide alternative route, or the alternative route is deemed to be unsafe, abort test by navigating the vessel to avoid collision. If aborted, the report shall clearly state the reason for aborting, in a way that brings valuable feedback to the SA and ANS development.

5.2.5.2. Target Vessel

Route	WP6, WP1.
Speed	5 [kts]
Preparation	Establish a common start time for both vessels.
Execution	At the agreed start time, follow the route at the stated speed.

5.2.6. Waypoints

The test scenarios are defined using waypoints. The waypoint numbering is for identification only and not a sequential route. The route to be used for test vessel and target vessel is defined in each scenario.

Waypoint	Position (Lat, Lon)
WP1	63.460337164684105, 10.375038453316686
WP2	63.486921963927465, 10.374211604073059
WP3	63.514367692537434, 10.373186387742441
WP4	63.50534564591684, 10.418528732010358
WP5	63.48745123684432, 10.434343687768465
WP6	63.474014902322544, 10.375498422785771

Figure 10 - Waypoints

5.3. RESULTS

5.3.1. Summary

All four scenarios were performed to a satisfactory degree. The test vessel and the target vessel were able to follow the predefined routes and interact in the pre-planned area. The scenarios were also made more complicated by the consistent appearance of a smaller drone vessel in the vicinity (rogue vessel).

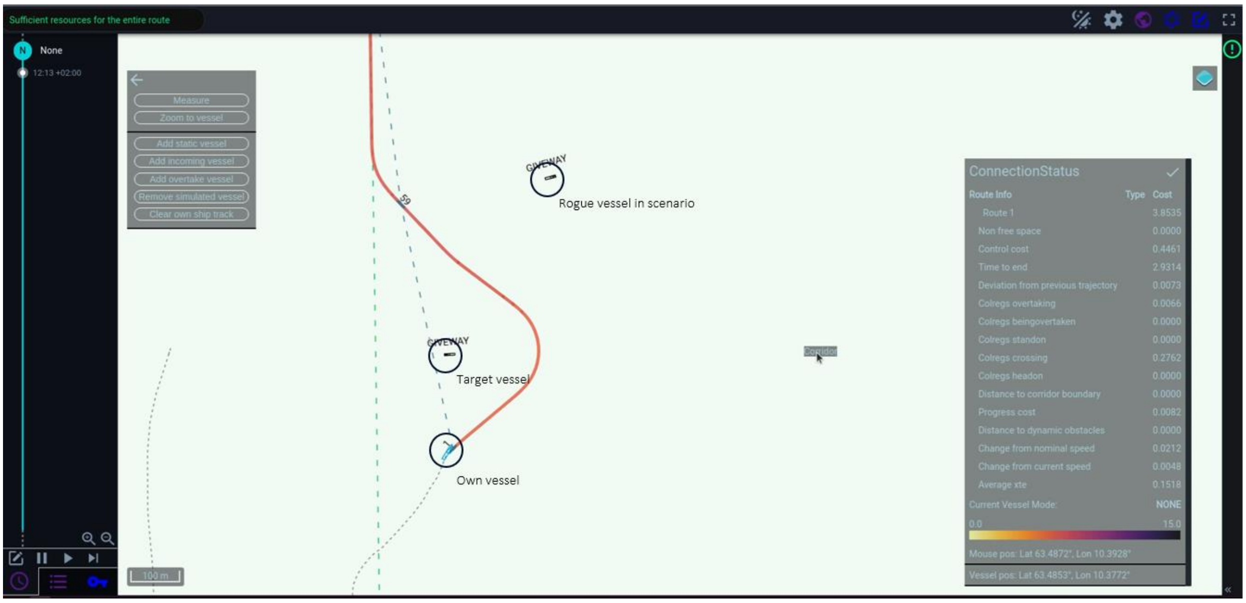

Figure 11 - Rogue vessel in scenario

There were 4 objectives for the demonstration. Objective 1-3

1. *Verify system integration of all components listed in the equipment description.*
2. *Verify that SeaAware can detect and report position-data of vessels in proximity of OSL.*
3. *Verify that ANS can suggest collision avoidance manoeuvers based on the data provided by SeaAware*

was demonstrated with success, objective 4

1. *Verify that the ANS suggested route deviations causes by observations made by SeaAware are consistent*.

was only a partial success and needs further work.

5.3.2. Results - short summary

5.3.2.1. Pre-test verification

In the pre-test verification all vessel components and interfaces between these were tested and shown to be integrated successfully.

5.3.2.2. Scenario 1-4

All four scenarios were successfully run, with the target vessel and test vessel able to create the wanted challenges.

The SA system successfully detected the test vessel in both radar and camera, and the ANS system successfully created route deviations based on the input from the SA system.

Through interaction with the navigator there was identified some challenges with regards to consistency in the user experience of the system.

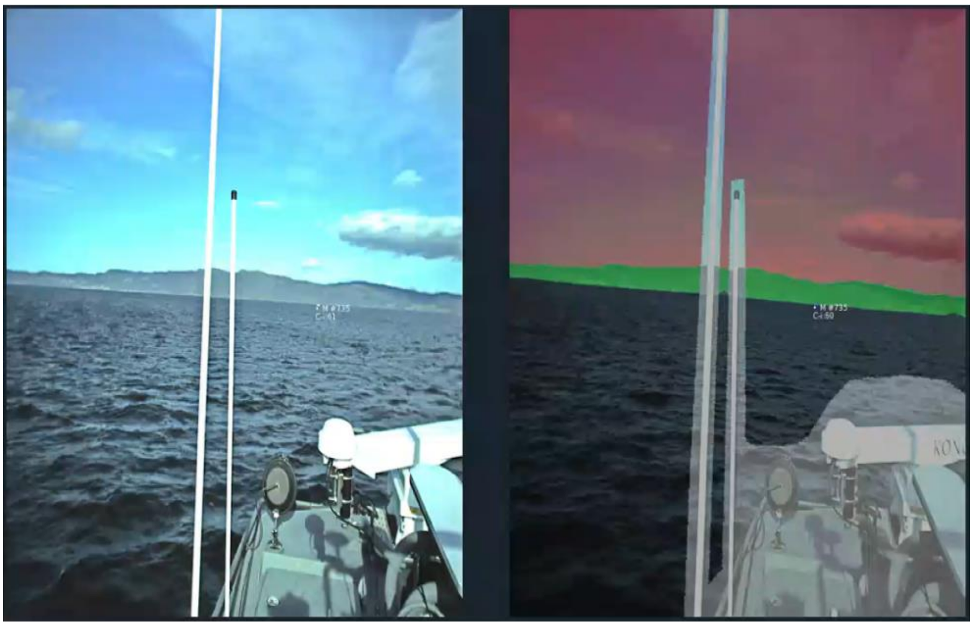

Figure 12 - Camera detected target vessel

6. CONCLUSIONS AND WAY FORWARD

The main outcome of the test was the setup of a test vessel which can be used for easy integration testing between the systems to be installed on the final demonstration vessel. It provided important data for integrating real world measurements into the systems which would otherwise be tested in simulators.

All interfaces between the installed systems were verified and worked as intended.

The test also provided good understanding of the strenghts and weaknesses of the combined system once SA and ANS are integrated and working on real data.

The demonstration day resulted in a large amount of logged raw data which will be reused in tests to incrementally improve the systems both on Situational Awareness (SA) processing of sensor measurements, and in ANS collision avoidance algorithms.

The demonstrastion day also resulted in a list of improvement areas, which will be improved in the office environment before it is tested on the same raw data from the scaled demonstration test. Once improvements has beend verified using the logged data, new field trials will be set up for further validation.