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1 EXECUTIVE SUMMARY

1.1 Problem definition

NOVIMAR researches a new system of waterborne transport operations for short-sea, sea-river, and inland waterways. A manned leader vessel (LV) controls several follower vessels (FV) that together form the vessel train (VT). Based on the work of task 3.1 “Navigation requirements and procedures” [1] and task 3.2 “Command and control system” [2] several simulated tests were performed on MARIN’s ship handling simulator and the DST simulator. Towing tank tests with scaled models and the “Control and command system” were performed at DST [3]. In this task 3.6 the developed principles, systems, and knowledge was used to successfully build and demonstrate the working principle of a VT on two real vessels. Due to the COVID situation the demonstration was delayed several times. Finally, it was successfully carried out in March 2021.

1.2 Technical approach and work plan

The technical means to build a VT were already developed in previously performed tasks, leaving up to task 3.6 to compose the modules, adapt them to the situation on the vessels, and calibrate the overall system. The following activities were performed:

- Preparation of the demonstration plan including requirements, resources, time planning, and safety/risk analysis
- Selection of demonstrator vessels
- Selection of demonstration location and handling of legal implications
- Analysis of suitability of demonstrator vessels
- Completion (installation, update) of mandatory equipment where necessary
- Preparation, installation, and calibration of the control system
- Selection and installation of communication solution between the vessels
- Demonstration
- Preparation of task deliverable D3.6

1.3 Results

The VT was composed of the 135m long container vessel “Oxford” as LV and the 135m long inland cruise liner “Viva Moments” as FV. The demonstration took place in the Netherlands on the 24th and 25th of March 2021 in an area called Haringvliet. During one preparation trial and two test trials around the island Tiengemeten, the following VT functionalities were successfully demonstrated:

- Encrypted direct wireless **communication** between LV and FV
- **Coupling** the train at the entrance of the test area west of the Haringvlietbrug at the entrance of the Vuile Gat

- Sailing in “**automatic guidance**” north of the island Tiengemeten through the Vuile Gat and demonstration how the **offset** and **distance** setpoint can be used to **manoeuvre** in different traffic scenarios
- Demonstration of **safety contours** during sailing in the Vuile Gat
- Sailing around the north-western end of the island Tiengemeten from the Vuile Gat into the Haringvliet in “**assisted guidance**”
- Following the bendy Haringvliet south of Tiengemeten back to the entrance and passing below the Haringvlietbrug **bridge** as VT in “assisted guidance”
- **Decoupling** the train

This test sequence was performed three times, one time on the first day during preparation phase, two times during the trial on the second day, without the necessity to decouple the train during each test sequence.

The following remarks highlight open questions and can be used to develop the post-NOVIMAR VT:

- The stopping procedure could not be demonstrated because the existing speed control system on the FV was not able to reduce speed by inverting thrust or operating at zero speed through water. In further research a combination of the VT control system with a virtual anchoring system can provide this functionality by reverting the engine, controlling the azimuth of the propeller if available, or using bow thrusters to control the rate of turn.
- During fast and narrow turns of the VT, the FV turned with a significantly higher rate of turn than the LV. This effect is influenced by the set point of the speed. The control algorithm needs to account for this under these circumstances.
- Crossing a VT between LV and FV happened once by a smaller vessel. This crossing did not lead to an issue during the trial; however, larger vessels could obscure the line of sight between the vessels necessary for a reliable inter-ship communication. Furthermore, the crossing shows that the chosen distance of 350m at the time was too big to have the VT be recognized as a linked unit.

1.4 Conclusions and recommendation

The demonstration was successfully performed without any major issue and shows that the developed system performs well under real life conditions. The test area was very well suited due to its size and the low number of vessels sailing in this area in general. This way the demonstration could take place in a safe environment and risks could be kept low. Research beyond NOVIMAR should focus on more dense sailing areas to further improve the VT system.

2 INTRODUCTION

2.1 TASK T3.6: Full scale demonstrator

The task objectives are:

- To demonstrate on full scale the working principle of a VT using two vessels sailing in VT configuration.

Envisaged activities are:

- Sub-task T3.6.1: Prepare a detailed plan for the full-scale demonstrator: requirements, resources, time planning, safety analysis and risk assessment.
- Sub-task T3.6.2: Prepare the “Command and Control” modules for demonstration. Check demo-vessels for suitability to link with the “Command and Control” system, install if needed complementary systems.
- Sub-task T3.6.3: Demonstrate the “Command and Control” system under real life conditions. The full-scale demonstrator will consist of two vessels, one mother vessel and automatically following vessel. This slight simplification is justified as the concept of following does not change based on the number of ships. The demonstrator will be both ships following each other on a location that needs to be selected. Both ships will sail in a straight line and manoeuvre through the waterway. More complex manoeuvres will be demonstrated on model scale or on the simulator to contain the risk level of the demonstrators with respect to hazardous situations.
- Sub-task T3.6.4: Prepare the task deliverable (D3.6)

Role of the Partners:

Originally, it was planned that VIA provides the vessels for the demonstrator and supports IN with managing the demonstration plan. However, during the beginning of T3.6 it was decided to use bigger vessels which VIA was not able to provide. As a result, the budget available for the vessels was shifted from VIA to IN. Bureau Telematica Binnenvaart took over the organizational part from VIA. The demonstrator location was changed from the Danube River to the Netherlands.

- IN (leader) with BTB will prepare and manage the demonstrator plan. IN will provide the software modules and ECDIS systems developed in T3.2 and T3.3 and bring the two vessels to the technical level required for the demonstration.
- IN will provide two vessels for execution of the demonstrator in accordance with the corresponding plan.
- ARG will configure the ships’ control modules, tune these to the scenario requirements and support the tests

Input/output relations:

- Task T3.6 receives input from tasks T1.5, T3.1, T3.2, T3.3, T3.5.

- Task T3.6 provides output to tasks T1.6

2.2 Analysis

Within the preceding tasks (see Figure 1) the VT systems have been developed and tested under various aspects:

- Manoeuvring simulations (direct numerical simulations, fast-time ship handling simulations, full mission bridge ship handling simulations)
- Towing tank model tests

Where applicable the results of these tests have been included in the VT systems during the development phase in T3.2, except for the communication solution between the vessels that was not part of any test so far. Therefore, the major goal of task 3.6 is to organize and demonstrate the working principle of the developed VT.

The development plan of the VT concept described in D3.1 foresees demonstrations on simulators performed within 2019 and the full-scale demonstration T3.6 to be started in 2020.

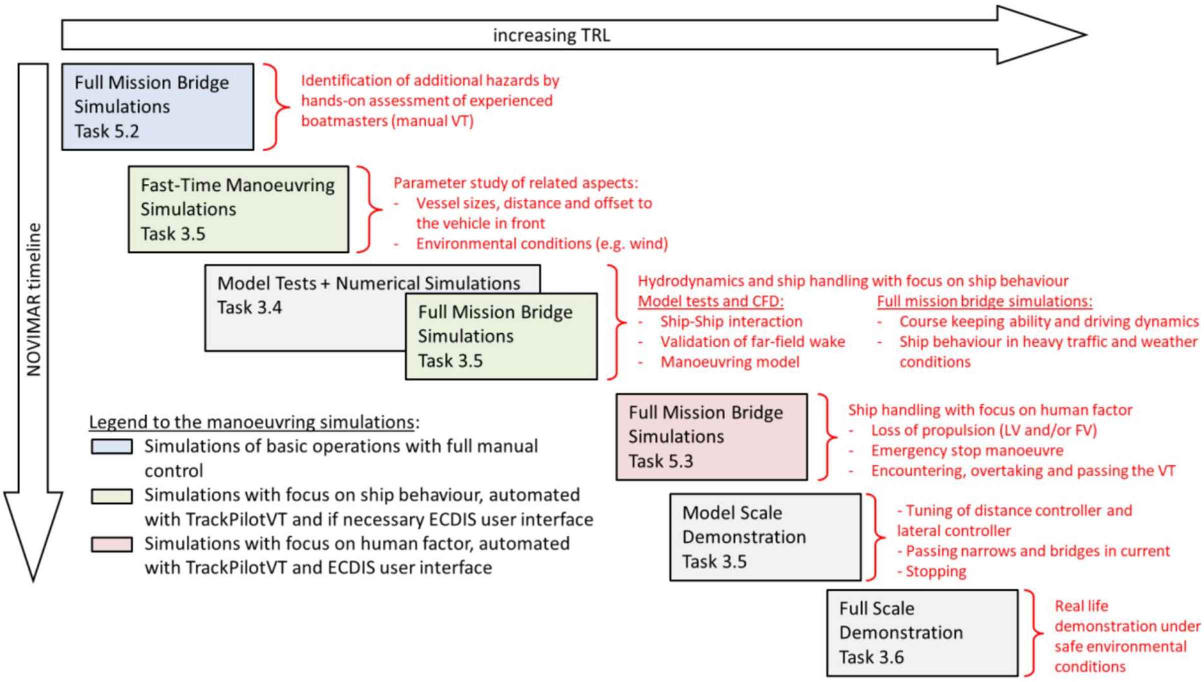

Figure 1: Description and procedure of the research methods

On the one hand, the demonstration should make the work done in WP3 visible to the stakeholders and other interested parties. On the other hand, the demonstration falls into the time of pandemic where rules change frequently and events with many people cannot be carried out. Therefore, special attention needs to be paid to the latest COVID regulations and a suitable realization needs to be found to keep the health risk low for everyone involved in this task in the first place.

Two vessels need to be selected that can operate as a LV or as a FV. The technical minimum requirements need to be ensured in T3.6.2. The vessels will be taken out of service for the duration of the installation and demonstration as well as the time to sail to the test area and back. Within T3.6.1

this needs to be organized, including the definition of the test, finding a proper test area, and checking the legal aspects at the destination. The responsible government agency needs to be involved to ensure the demonstration is permitted.

Once the vessels are selected, it needs to be ensured in T3.6.2 that the minimum technical equipment is installed:

- For the LV, a GPS compass is necessary, an interface to control the rate of turn of the vessel, an interface to the radar system, as well as to the AIS transceiver. These interfaces need to be connected to the VT track controller and the VT ECDIS
- For the FV, a GPS compass is necessary, an interface to control the rate of turn of the vessel, an interface to control the speed of the vessel, an interface to the radar system, as well as to the AIS transceiver. These interfaces need to be connected to the VT track controller and the VT ECDIS
- A communication solution between the vessels needs to be selected and installed including a temporary VT network

For the demonstration the test scenarios need to be defined and the required configurations need to be prepared:

- Coupling and Decoupling
- Sailing in “automatic guidance” and “assisted guidance”
- Demonstrating “safety contours”
- Varying offset and distance to LV

2.3 Approach

The demonstrator plan as requested in T3.6.1 is a vital part of the organizational procedure of how T3.6 is organized. The document is “living” and updated in regular bi-weekly meetings that ensure the timely coordination between the partners.

The following main activities need to be performed:

- Preparatory activities (select vessels, work out demonstration schedule, contact authorities)
- Selection of communication solution
- Technical evaluation of the vessels’ systems and installation of hardware
- Planning of the demonstration scenarios
- Perform the demonstration

To successfully document the demonstration results the key parameters need to be recorded. After the trial the recorded data can be evaluated and reported.

3 PLAN

3.1 Objectives

The T3.6 task objective is to demonstrate that two vessels equipped with a VT system can sail in a VT configuration. To demonstrate the VT concept several defined procedures shall be tested during the trial.

3.2 Planned activities

All activities performed in T3.6.1 are organized in bi-weekly meetings. The demonstrator plan is used to coordinate the planned activities (list of actions) and is updated through time. It contains the description of the location and ships for the demonstrator (including requirements), a risk register, list of stakeholders to be invited, and the schedule.

3.2.1 Preparatory activities

Besides the technical realization several important activities need to take place. The vessels need to be selected and the owners need to be involved in the project. It is desirable to select two different types of vessels. A demonstration location needs to be defined that both vessels can easily reach and that grants safe environmental conditions. This means that there should be enough space and low traffic density. In addition, the responsible authorities need to be involved so that a permit is available for the sea trials.

3.2.2 Communication solution

In deliverable D3.2 the technical solution of the VT is described. Furthermore, different technical communication solutions have been discussed. However, none has been selected and tested in another task so far. Therefore, before the demonstration takes place a solution has to be selected and tested to reduce the risk of a system failure during the trial. The expected distances between LV and FV should be considered during this test. If possible, the tests should be performed under a similar or comparable situation. Preferably on a vessel as well.

3.2.3 Technical evaluation of the vessels' systems and installation of hardware

Once the vessels are selected the installed equipment needs to be evaluated. If additional components need to be installed this should be done in advance if possible. Furthermore, the Argonics TrackPilot should be installed so that the helmsman can be familiarized with this system in advance. Shortly before the demonstration the Argonics TrackPilot needs to be updated with VT functionality, the RadarpilotVT needs to be installed, and both vessels need to be equipped with the communication solution so that the system is technically ready for the demonstration.

3.2.4 Planning of the demonstration procedures (scenarios)

The trial is split up into different segments. In each segment vital functions of the VT concept are demonstrated. The sequence depends on the test area, but the different functionalities that need to be demonstrated are the following: coupling and decoupling of the train, sailing in "automatic guidance", sailing in "assisted guidance", varying distance and offset to demonstrate how to manoeuvre with the VT, and demonstrating the use of "safety contours". As stopping of the train is only possible when there is enough current it will depend on the location if it is possible to demonstrate this functionality or not.

3.2.5 Demonstration

Once the vessels have been equipped from the technical standpoint the demonstration can take place. During the first day installation work is finished, and the system is calibrated during a first sailing trial. On the second day the planned scenarios are demonstrated in the defined stretches of the demonstration area. During the demonstration, the helmsman of every vessel stays responsible for his or her vessel.

3.2.6 Preparation of deliverable

After the demonstration, the deliverable is prepared based on notes and recordings taken during the sea trials.

3.3 Resources and involved partners

Role of the partners:

- IN (leader) together with BTB prepares and manages the demonstration
- BTB coordinates communication with authorities and is responsible for the permit
- IN provides two vessels for the execution of the demonstrator and brings them to the technical level required for the demonstration
- ARG will configure the ship control modules, tune these to the scenario requirements and support the tests

3.4 Timeline

According to the time schedule of the NOVIMAR project the demonstration as part of T3.6 takes place end of 2020. An estimated preparation time of 5 months is expected.

4 PLAN EXECUTION

4.1 Introduction

In June 2020 after the major work in the previous tasks were finished, practical work started on the full-scale demonstration. This chapter describes the activities carried out together with the changes of the plan.

4.2 Performed activities

4.2.1 Preparatory activities

4.2.1.1 COVID considerations

Originally, the full-scale demonstration was planned to be carried out with an audience, giving the stakeholders the opportunity to see the VT perform under real-world conditions. For this reason, the trial was shifted several times from autumn 2020 into 2021. However, in spring 2021 it became clear that the situation would not allow for an audience to be present. Therefore, it was decided to reduce people involved to the absolute necessary minimum and do the trial under strict COVID terms.

4.2.1.2 Permit

Assessing the legal aspect, the sea trial was reported to RWS (Rijkswaterstaat) and a permission was requested. RWS is part of the Dutch Ministry of Infrastructure and Water Management and the executive agency for the design, construction, management, and maintenance of the main infrastructure facilities in the Netherlands including the waterways. In an application form the test was described and finally granted in February 2021 for execution in the area of the Haringvliet (Het Vuile Gat) between March and April 2021.

4.2.1.3 Selection of vessels

Two vessels were selected for the trial. One vessel of the WeBarge fleet and one cruise vessel from Scylla AG. At first the container vessel MVS Denford and the cruise liner MPS Annika were selected but later on due to the availability of the vessels the container vessel “Oxford” was selected as LV and the cruise liner “Viva Moments” (previously Robert Burns) was selected as FV.

Leader Vessel

Figure 2: Leader Vessel "Oxford"

Table 1: Leader Vessel

Vessel	**Detail**
Name	Oxford
Type	Inland container vessel
Size	135m x 14.20m
Tonnage	5500t
Container capacity	421 TEU
ENI	6105018
MMSI	205288990
Callsign	OT2889
Flag	Belgium

Follower Vessel

Figure 3: Follower Vessel "Viva Moments"

Table 2: Follower Vessel

Vessel	**Detail**
Name	Viva Moments
Type	Passenger vessel (inland cruise ship)
Size	135m x 11.4m
Draft	1.5m
Engine	2130hp
ENI	7002085
MMSI	269057635
Callsign	HE7635
Flag	Switzerland

4.2.1.4 Selected location

The test location was selected after checking the typical sailing areas of the vessels. The Oxford sails in Belgium, especially in the Antwerp area and southern Netherlands, while the Viva Moments was not sailing at that time and at anchor in the southern part of the Netherlands as well. Having this in mind, the area around Hollands Diep was selected. After requesting the permit from RWS the location was changed to Haringvliet near Willemstad in the southern part of the Netherlands.

Figure 4: Test area: Haringvliet, Het Vuile Gat

4.2.1.5 Familiarization

During the test trials on the installation day the captains need to be introduced to the VT system and to the test procedures. To reduce risk and ensure the schedule it was decided to have at least one NOVIMAR expert on each bridge who can assist the captain and ensure that the tests are performed as planned.

4.2.2 Communication solution

The developed communication strategy in Task 3.2 [2] foresees a point-to-point communication from vessel to vessel. Each vessel serves as a hub to pass on data from the following vessels.

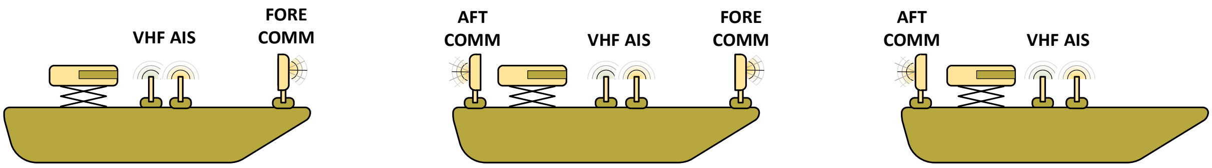

Figure 5: VT communication strategy

This chapter describes the evaluation of two different wireless links selected in preparation to the sea trial. Besides the FORE COMM and AFT COMM units the concept foresees VHF communication for performing procedures and AIS for exchange of binary application specific messages as a redundant channel to the wireless link (see chapter 9.2).

4.2.2.1 Evaluated solutions

On 4th of June 2020 a test was performed on the MS Bingen approaching the lock in Koblenz. Two different antennas in combination with two different modems (on different frequencies) were evaluated.

Table 3: Assessed communication solution

	Solution 1	**Solution 2**
Product	Ubiquiti Rocket M2 + AMO-2G13	Ubiquiti UAP-AC-M-PRO
Frequency	2.4GHz	5GHz (2.4GHz modem switched off)
Antenna type	Omni directional 13dBi gain 7° elevation beamwidth (2° downtilt) 360° azimuth beamwidth 2 x dual polarization	Patch panel 8dBi gain 90° elevation beamwidth 120° azimuth beamwidth 3 x dual polarization
Wi-Fi Standards	airMAX TDMA (modulation 802.11n)	IEEE 802.11 a/b/g/n/ac

4.2.2.2 Communication test

For the test the MS Bingen (ENI 05042160) – a work-vessel of the German water and shipping authority WSA Bingen – was equipped with two wireless antennas located midships 5.5m above water. The antennas had a good view to the front. Another set of antennas were placed besides the lock chamber in the same height on a fixed pole.

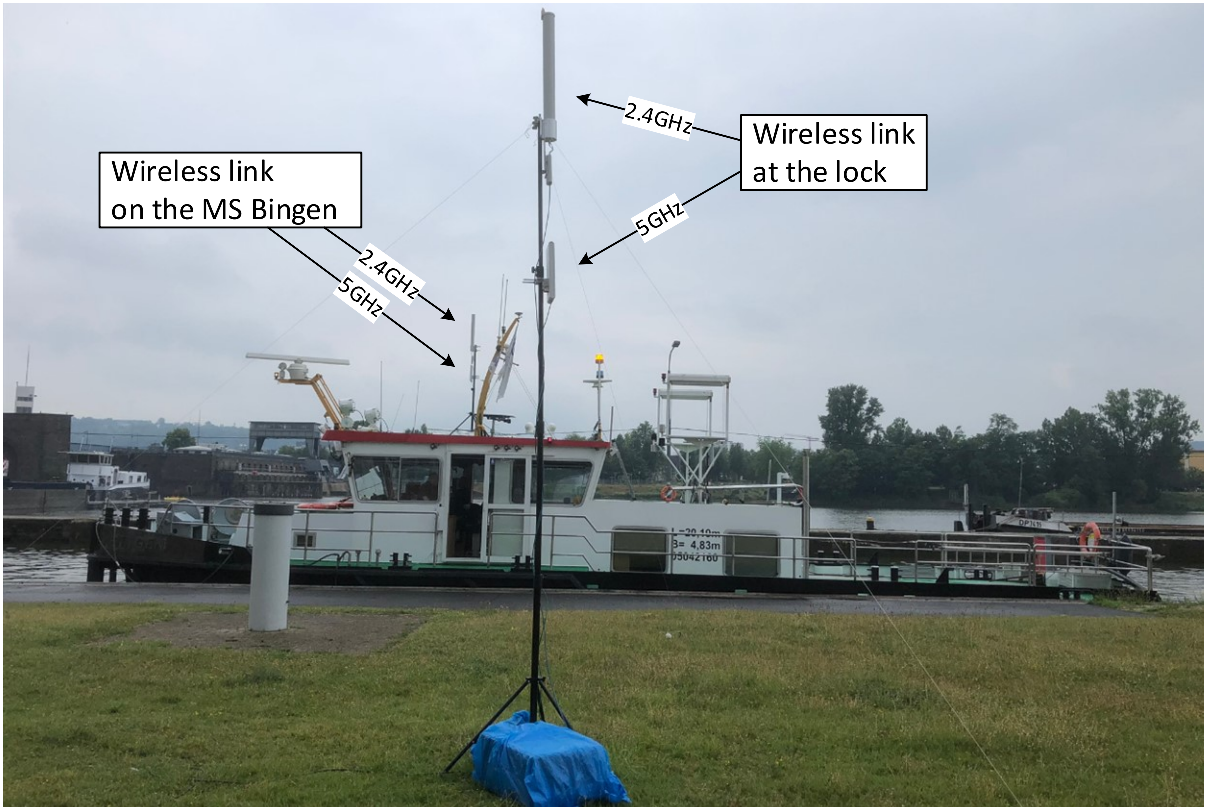

Figure 6: Communication test: MS Bingen at the Koblenz lock

While approaching the lock the transfer speed between the vessel and the lock was measured by copying a random file of 1MB size over the air link, one time over the 2.4GHz link and after that over the 5GHz link. This was repeated while the vessel approached the lock slowly. The vessel started in a distance of 930m to the lock. From 930m to about 450m the antennas had to transmit through bushes attenuating the signal. From 450m up to the lock there were no obstacles attenuating the signal.

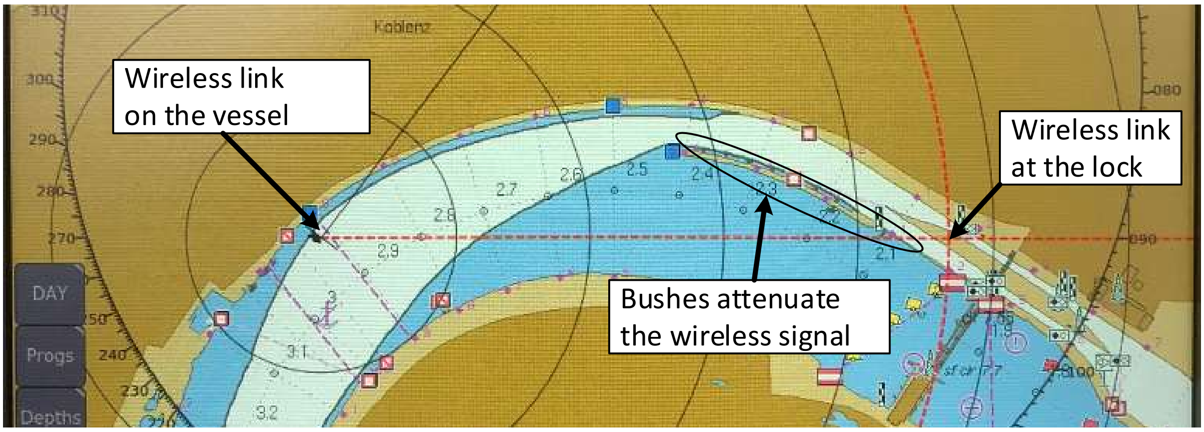

Figure 7: Approaching the lock in Koblenz

4.2.2.3 Selected solution

The 2.4GHz link got a stable connection at 930m distance to the lock. While the signal was attenuated between 930m and 480m the 5GHz solution did not get a link. The 5GHz devices connected successfully at 480m.

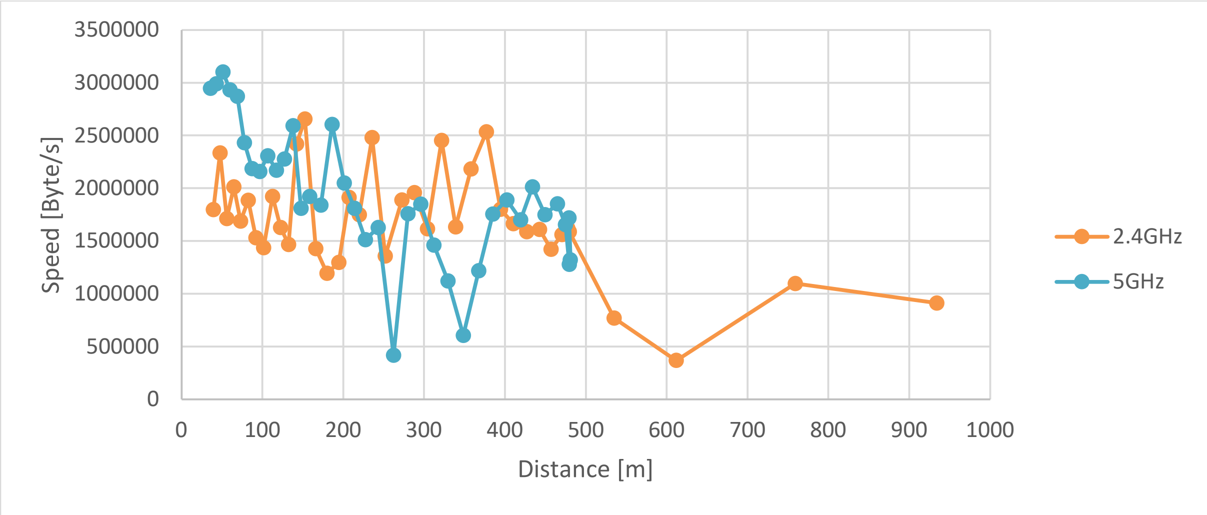

Figure 8: Wireless transfer speed

These measurements were taken in an urban area (Koblenz) with many family homes north of the river Mosel spanning up 60 WLAN nets in the test area.

In close range < 80m the 5GHz solution shows significantly better performance than the 2.4GHz solution. However, at 348m distance and 262m reception significantly dropped. In summary, the 2.4GHz solution provided equal performance in the range of 100m to 500m and still delivered acceptable throughput up to 930m. The required minimum of 1Mbit/s was met at any distance. Up to 500m 10Mbit/s were reliably delivered.

Besides the throughput the directivity characteristic of the antenna was considered. The 2.4GHz antenna system provides 360° coverage thus giving perfect radiation in curves and narrow turns while the 5GHz panel antenna only provides conus-like radiation. This makes it necessary for the 5GHz system to rotate the antenna in the direction of the other vessel during turns as described in D3.2 [2].

Figure 9: Selected 2.4GHz communication link

With the 2.4GHz omni-directional setup a reliable, performant, and long-range system was chosen for the full-scale demonstrator.

4.2.3 Technical evaluation of the vessels' systems and installation of hardware

4.2.3.1 Evaluation of equipment on LV "Oxford"

The minimum navigation equipment necessary for a VT leader vessel as defined in D3.2 [2] is a GNSS system delivering position and orientation, an AIS transceiver, a radar system, and an autopilot providing control of the rudder. Control of the speed of the vessel is not necessary on the LV. The equipment shown in Table 4 is available or needs to be installed in advance.

Table 4: LV Oxford equipment

Equipment	Evaluation	Preparation and test equipment
GNSS	Only GPS available	Installation of GPS compass system JLR21-T
AIS	Available	Installation of MOXA RS422 converter
Radar	Available	Connection to RadarpilotVT
Autopilot	Alphatron Autopilot	Connection to argoTrackPilotVT
VT specific	Not available	Installation of emergency switch, wireless link, VT network, RadarpilotVT, and argoTrackPilotVT

4.2.3.2 Evaluation of equipment on FV "Viva Moments"

The minimum equipment necessary for a VT follower vessel is a GNSS system delivering position and orientation, an AIS transceiver, a radar system, an autopilot providing control of the rudder, and control of the throttle. The equipment shown in Table 5 is available or needs to be installed in advance.

Table 5: FV Viva Moments equipment

Equipment	Evaluation	Preparation and test equipment
GNSS	Available	Installation of MOXA RS422 converter
AIS	Available	Installation of MOXA RS422 converter
Radar	Available	Connection to RadarpilotVT
Autopilot	Veth Autopilot	Connection to argoTrackPilotVT
Speed Control	Alphatron AlphaFuelControl	Connection to argoTrackPilotVT
VT specific	Alphatron Trackpilot	Installation of wireless link, VT network, RadarpilotVT and update of the trackpilot with the argoTrackPilotVT software

4.2.3.3 System setup on LV

Figure 10 shows an overview of the existing and installed devices on the LV.

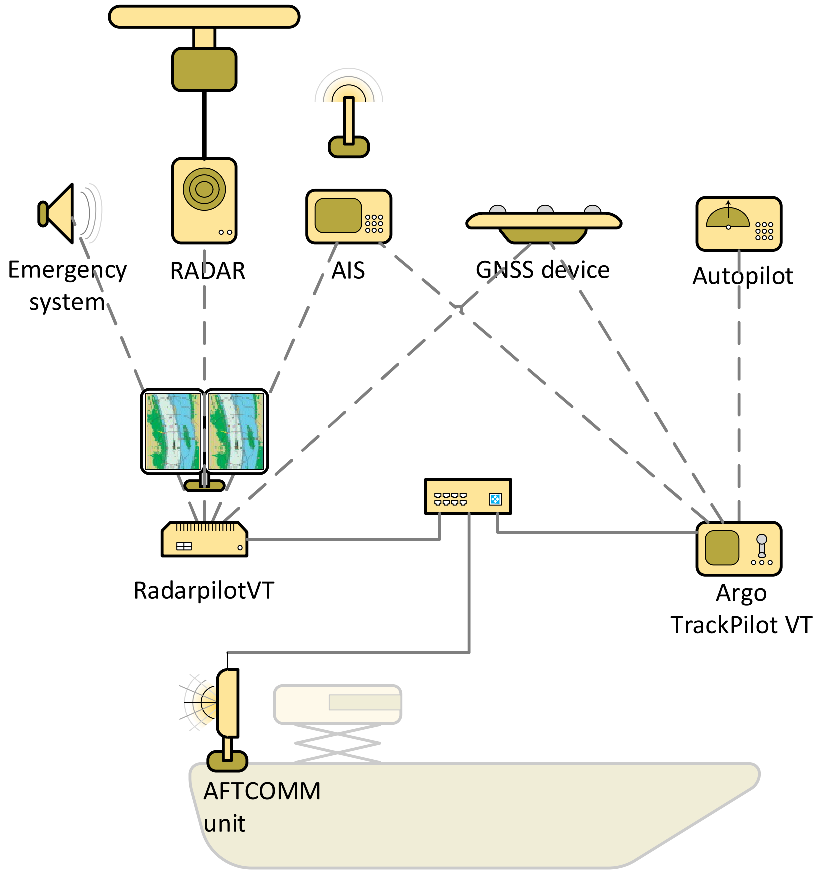

Figure 10: VT system on LV

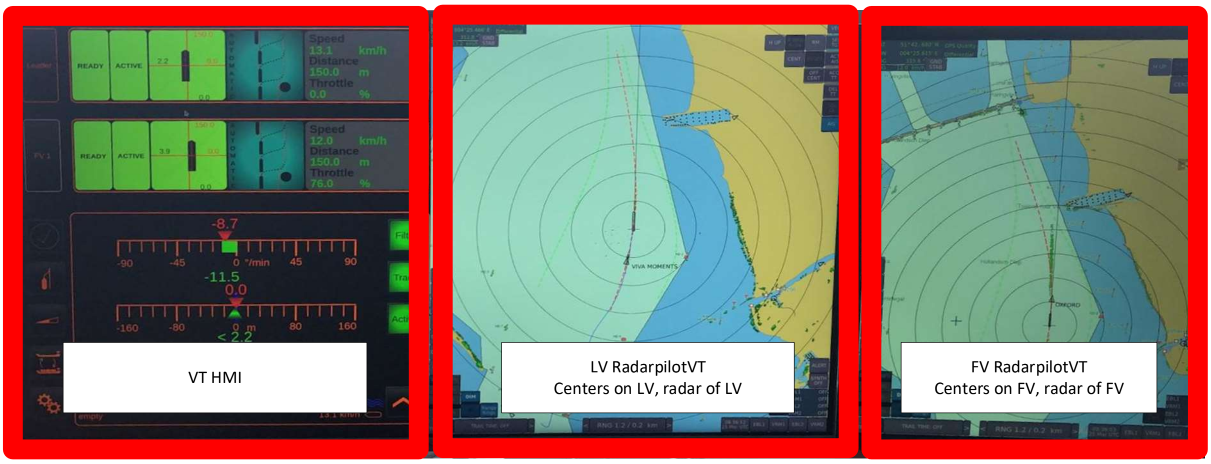

Figure 11: VT screens on the LV: VT HMI, ECDIS screen of LV, ECDIS screen of the FV

Figure 12: Alphatron Autopilot on LV

Figure 13: JRC GPS Compass on LV

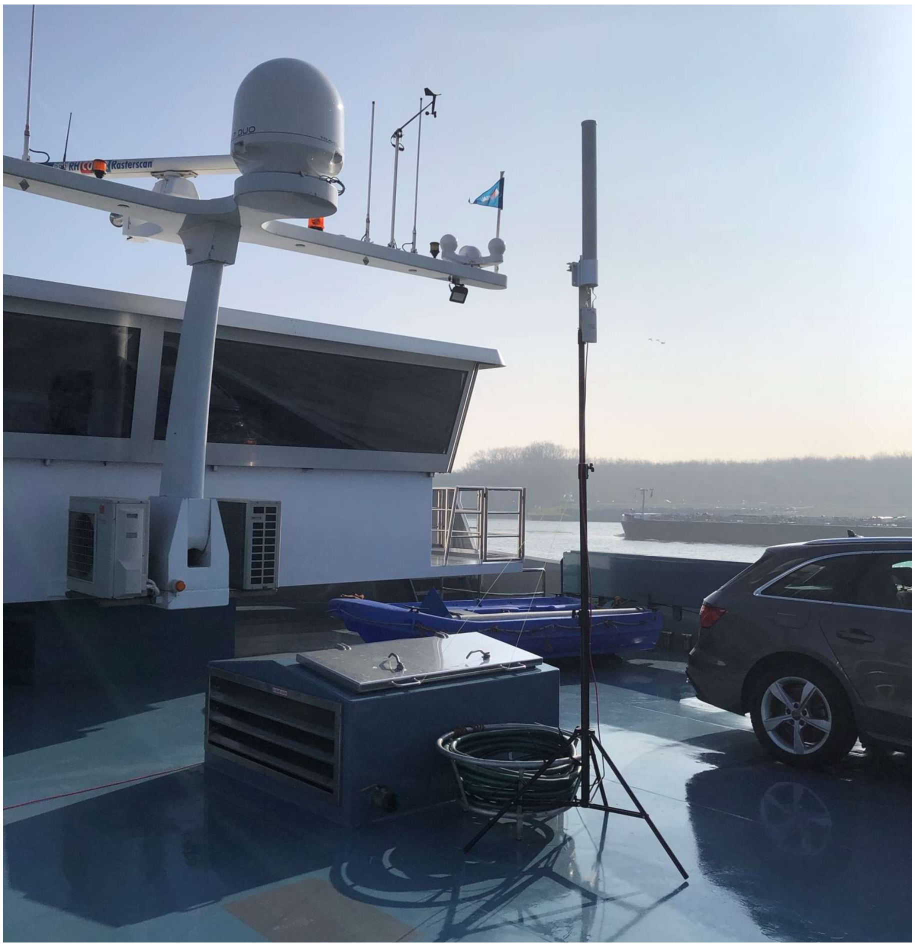

Figure 14: AFT COMM on the LV

4.2.3.4 System setup FV

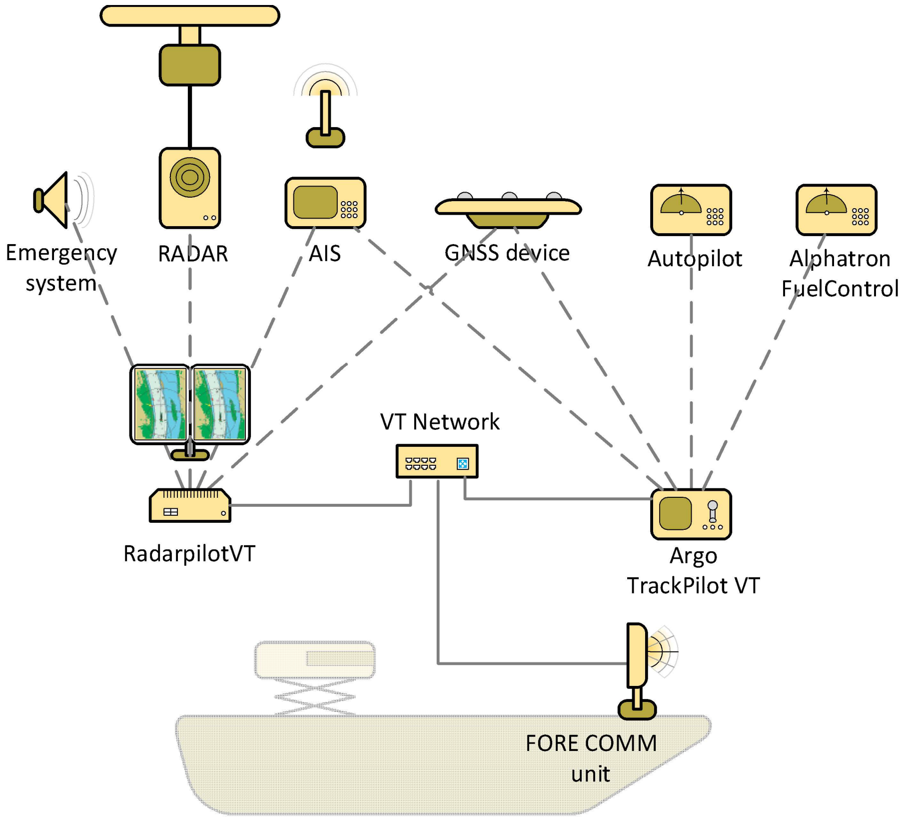

Figure 15: VT system on FV

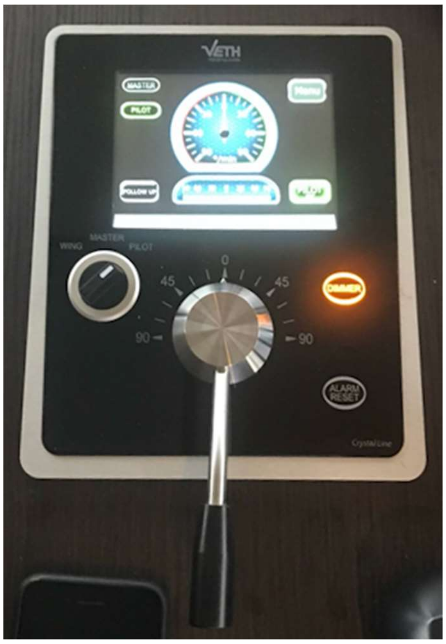

Figure 16: Veth Autopilot on FV

Figure 17: AlphaFuelControl on FV

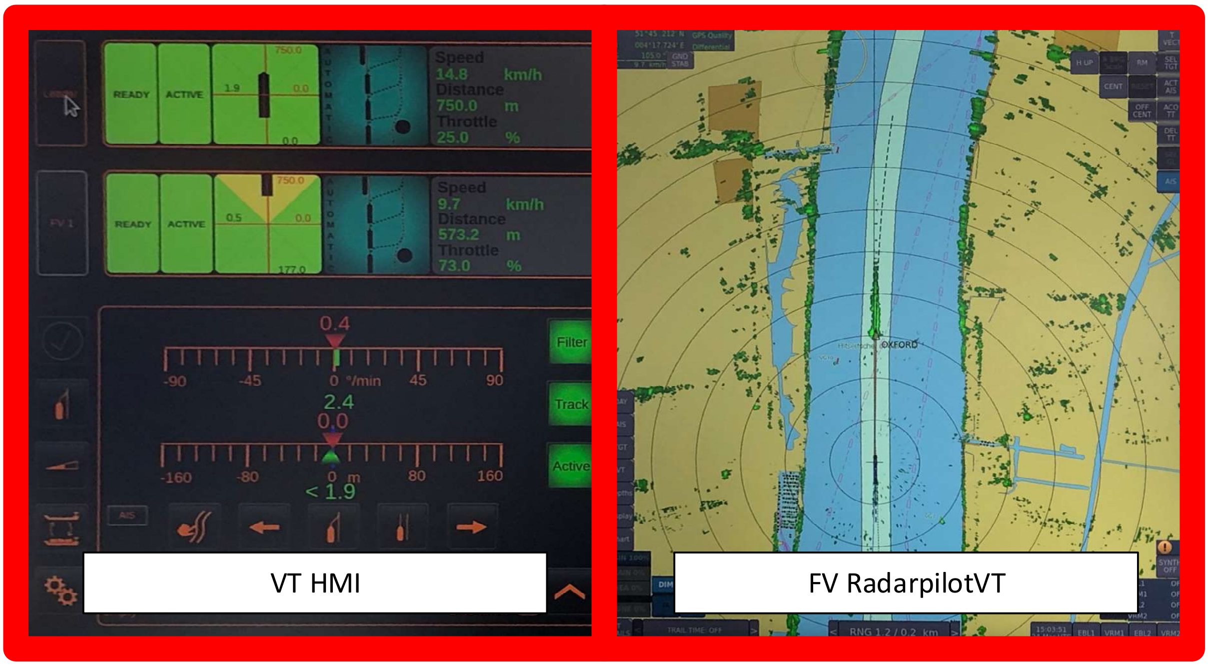

Figure 18: VT screens on the FV: VT HMI, ECDIS screen of FV

Figure 19: FORE COMM on the FV

4.2.4 Demonstration

4.2.4.1 Scenario 1: Coupling

Sailing a VT starts with formal procedures to couple. Coupling is the procedure to

- prepare the LV
- prepare the FV
- perform the navigational actions to be able to safely activate the VT controller system on the FV
- electronically couple one vessel with a LV into a VT formation

During coupling both captains, on the LV and on the FVs, are involved and follow a pre-defined procedure. The end of the coupling procedure defines the responsibility transfer for steering the FV from the captain of the FV to the captain of the LV. The coupling procedure involves radio communication and is technically realized by VT-specific AIS ASM messages, see chapter 9.2. The messages are exchanged via AIS and via the wireless link. The coupling process can be performed while the LV or VT is (electronically) anchored or while it is travelling.

After entering the test area west of the Haringvlietbrug at the entrance of the Vuile Gat the coupling procedure is performed immediately. As there is no stream expected the procedure takes place at low speed.

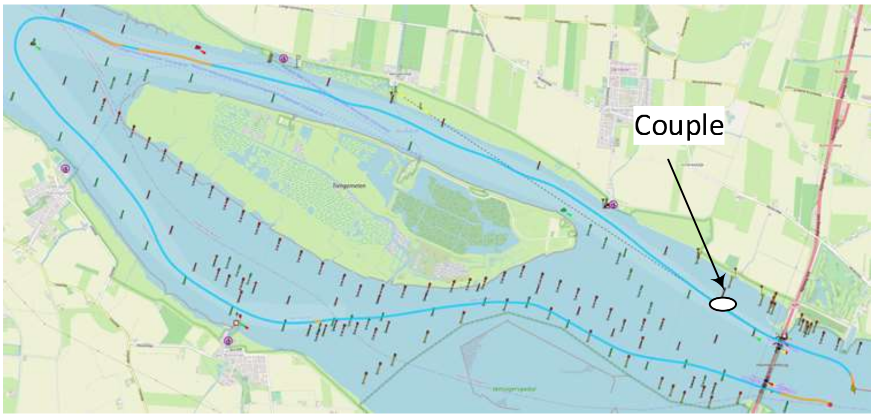

Figure 20: Position where the coupling procedure is performed

Coupling of a vessel to a LV while LV is anchored

A potential FV that approaches communicates its arrival time via radio. The FV steers into the train position behind the LV with the desired distance to the LV and requests electronically to build a VT. If the captain of the LV accepts the FV he or she acknowledges the request electronically.

Table 6: Procedure to couple a vessel to a LV, while LV is anchored

Step	Comm	Procedure of joining FV	Procedure of LV / VT	Crew
		Sails to the destination	LV waits at the destination	
1	Radio	Communicate arrival time and desired position in train to LV		LV, joining FV
2	Radio		LV waits for FV to arrive	LV
3			LV selects / checks appropriate fairway borders for joining FV	LV
4	Wireless link	When the approaching vessel is close enough the wireless link gets active.	VT network is available	
5		FV is positioned behind the LV		joining FV
6	AIS	FV requests building a train electronically by sending out a VT AIS ASM message: • Source ID of joining vessel • Convoy state = 1 (passively coupled and request for acknowledged coupling) • train formation with joining vessel added at desired position in the train		joining FV
7	AIS		LV acknowledges the request by sending out an VT AIS ASM message: • Source ID of LV • Convoy state = 2 (active acknowledged coupling) • train formation	LV
8	Wireless link	VT relevant data is exchanged and processed	VT relevant data is exchanged and processed	
9			VT departs	LV

Coupling of a vessel to a LV, while LV is travelling

A FV that is approaching communicates its arrival time via radio. The train now prepares the joining of a new vessel. The FV steers into the train position with the desired distance to the LV and requests electronically to join the train. If the captain of the LV accepts the new FV, he or she acknowledges the request electronically.

Table 7: Procedure to couple a vessel to a LV, while LV is travelling

Step	Comm	Procedure of joining FV	Procedure of LV / VT	Crew
		FV travelling	LV travelling	
1	Radio	Communicate arrival time and desired position in train to LV		LV, joining FV
2	Radio		LV waits for FV to arrive	LV
3			LV selects / checks appropriate fairway borders for joining FV	LV
4	Wireless link	When the approaching vessel is close enough the wireless link gets active.	VT network is available	
5		FV is positioned in the VT		joining FV
6	AIS	FV requests joining the train electronically by sending out a VT AIS ASM message: • Source ID of joining vessel • Convoy state = 1 (passively coupled and request for acknowledged coupling) • train formation with joining vessel added at desired position in the train		joining FV
7	AIS		LV acknowledges the request by sending out a VT AIS ASM message: • Source ID of LV • Convoy state = 2 (active acknowledged coupling) • train formation	LV
8	Wireless link	VT relevant data is exchanged and processed	VT relevant data is exchanged and processed	
9			LV corrects / checks convoy distances	LV
10			VT travelling	LV

4.2.4.2 Scenario 2 & 3: Varying distance and offset while sailing in “automatic guidance”

The whole VT follows a common reference track with the LV navigating automatically, too. This mode assists the operator when the VT is encountering traffic or passing slower ships. In order to adjust the VT's position relative to traffic the operator is able to adjust the lateral offset to the guiding line (see Figure 21). This offset is applied to all followers immediately. To ensure that all vessels stay inside the fairway and do not collide with any obstacles the VT control system includes a set of pre-defined fairway boundaries that define the navigable area excluding obstacles such as bridge pillars and shallow waters. If the operator on the LV sets a lateral offset the value is checked by the control system on the FV and adjusted according to the fairway boundaries (Figure 21).

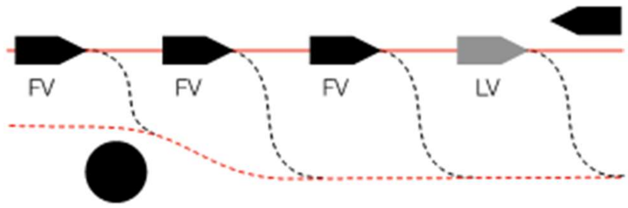

Figure 21: Automatic guidance with guiding line (red line), fairway boundary (red dotted line), simultaneously manoeuvring (black dotted line)

The operator on the LV can adjust the speed of the VT by changing the speed of the LV. The FV will automatically adjust its speed to keep the desired distance to the LV in front.

For the demonstration the river stretch north of Tiengemeten is selected for sailing in automatic guidance. During this stretch, the distance and offset is varied.

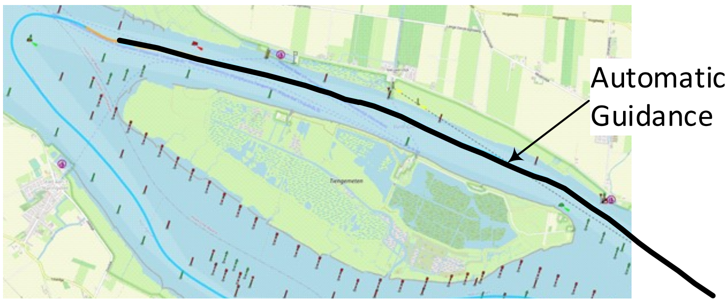

Figure 22: River stretch where the VT is sailing in automatic guidance

4.2.4.3 Scenario 4: Safety contours

Safety contours provide a limitation of the water-way in which the VT control mechanism can sail automatically. This is realised by modification of the selected offset, so that when trying to sail outside of the safety contours, the vessel is limited to an offset inside the safety contour. This concept solves two issues. On the one hand, fixed structures can be avoided, e.g. bridge pillars and one-way signs. Also, traffic separation areas can be respected. On the other hand, the question of different vessel dynamics and the distance from these fixed structures can be considered in the concept of safety contours. The safety contours can be created having the vessel class in mind thus all limitations that come along with this vessel type can be applied.

The safety contours are tested during sailing north of Tiengemeten. Two narrow passages are prepared.

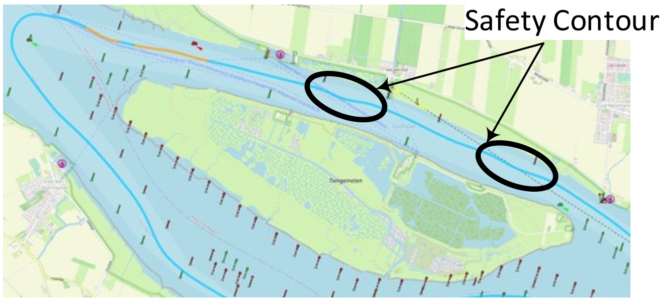

Figure 23: River stretch where the safety contours are tested

4.2.4.4 Scenario 5: Sailing in “assisted guidance”

To navigate the VT around stationary objects on an arbitrary track the operator steers the LV manually. The FVs will automatically track the path of the LV using a guiding line generated from AIS and tracked target position reports (see Figure 24).

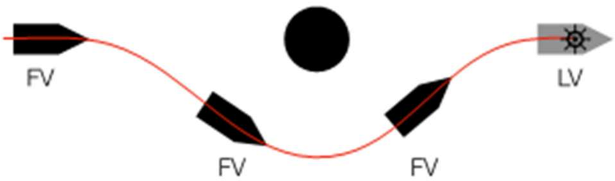

Figure 24: Assisted guidance, red: guiding line

To ensure that all following vessels can stay on the desired track the operator must sail the LV as if it was the vessel with the slowest dynamics in the train.

After sailing in automatic guidance and shortly before turning into the southern part of Tiengemeten the VT is switched to assisted guidance. After the turn the VT keeps sailing in assisted guidance and passes south of Tiengemeten.

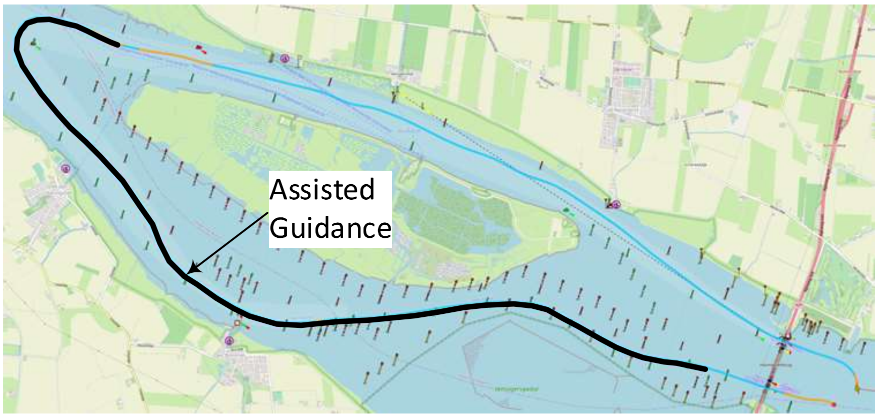

Figure 25: River stretch where the VT is sailing in assisted guidance

4.2.4.5 Scenario 6: Decouple

During decoupling both captains, on the LV and on the FVs, are involved and follow a pre-defined procedure. The end of the decoupling procedure defines the responsibility transfer for steering the FV from the captain of the LV back to the captain of the FV. The decoupling procedure involves radio communication and is technically realized by VT-specific AIS ASM messages, see chapter 9.2. The messages are exchanged via AIS and via the wireless link.

Decoupling of vessel while VT is travelling

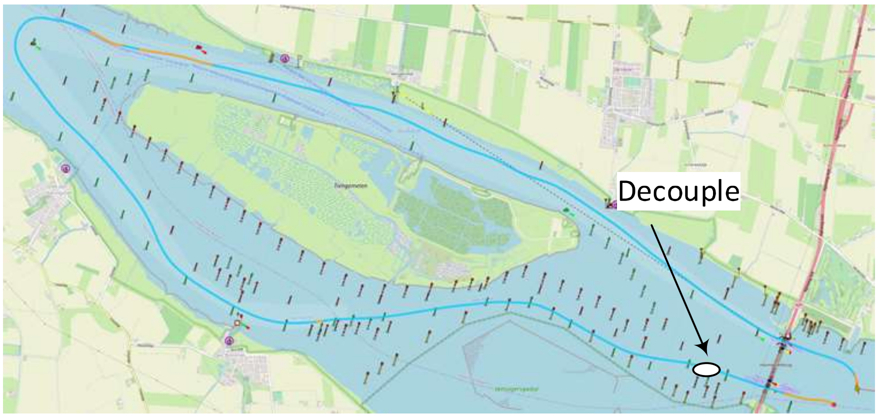

Figure 26: River stretch where the VT is decoupled

At the end of the full-scale demonstration trial, the VT needs to decouple. The captain of the LV prepares the disassembly of the train and calls the captain on the FV on the bridge. The LV electronically requests to decouple. If the captain of the FV accepts the disassembly he or she acknowledges the request electronically.

Table 8: Procedure to decouple last vessel while VT is travelling

Step	Comm	Procedure of joining FV	Procedure of LV / VT	Crew
			VT travelling	
			LV transmits the VT convoy by sending out a VT AIS ASM message: • Source ID of LV • Convoy state = 2 (active acknowledged coupling) • train formation	
1	Radio	Communicate wish to leave LV	LV calls FV crew on board for initiation of decoupling procedure	LV, leaving FV
2	AIS	FV requests leaving the train electronically by sending out a VT AIS ASM message: • Source ID of leaving vessel • Convoy state = 3 (decoupled and decoupling request in case of acknowledged coupling) • Train formation		leaving FV
3	AIS		LV acknowledges the request by sending out an VT AIS ASM message: • Source ID of LV • Convoy state = 3 (decoupled and decoupling request in case of acknowledged coupling) • Train formation	LV
4		FV travels in its normal operation mode	LV travels in its normal operation mode	LV

4.3 Deviations from the plan

Initially the demonstration was planned to take place in October 2020. However, at that time COVID restrictions were increased and it was decided to shift the demonstration to January 2021. In January, the situation was even worse, so it was decided to again postpone the demonstration to March 2021 where it finally could be carried out. Due to the COVID restrictions it was still not possible to invite guests to the trial, so it was decided to perform the test without stakeholders.

The planned stopping procedure of the VT could not be demonstrated as there is no significant current within the test area. In a river situation where the VT is sailing upstream, zero speed over ground can be realized. Without current the engine needs to be reversed or the propeller needs to be turned 180° if the vessel is equipped with an azimuth propeller. The VT control system of the FV used the existing speed control system AlphaFuelControl. This system is not designed to actively reduce speed by inverting the thrust or operating at zero speed through water. However, technically such a system could be designed.

Even though unplanned another vessel crossed the coupled VT. Furthermore, after successfully sailing in a VT formation without major issues, the Haringvlietbrug was passed in “assisted guidance”.

5 RESULTS

5.1 Introduction

This chapter describes how the full scale demonstration was executed and the results gained from it in chronological order.

5.2 Demonstration

The demonstration took place on March 25th 2021. The VT sailed around the Tiengemeten island two times, one time in the morning (Figure 27), one time in the afternoon (Figure 35).

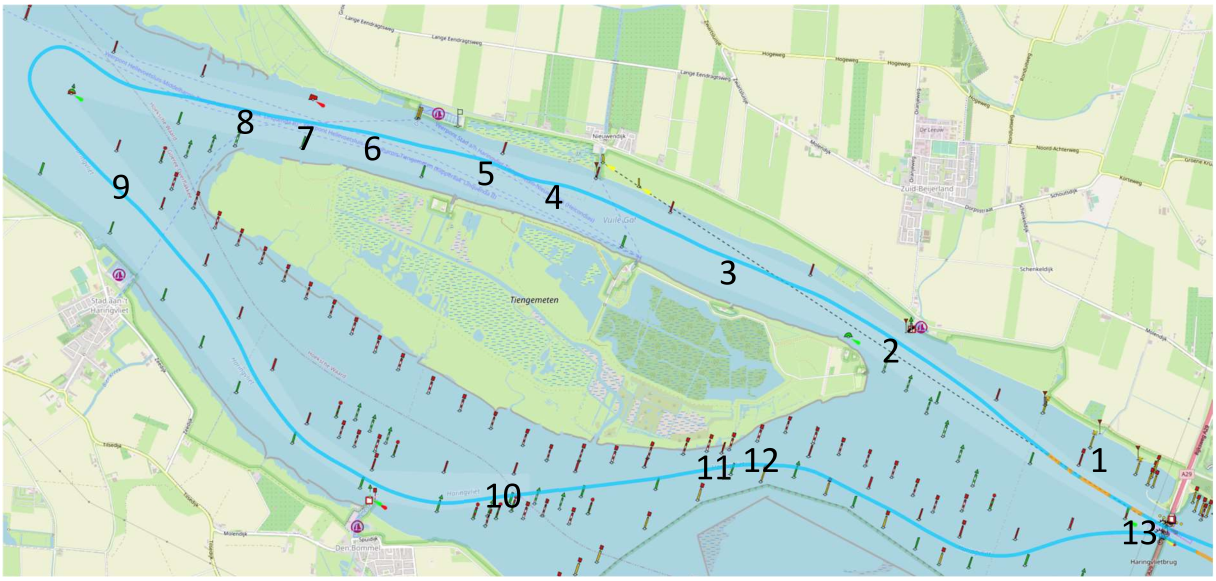

Figure 27: 1st demonstration run on March 25th 2021

5.3 First run

The first run started at 08:50 GMT and ended at 10:38 GMT.

The first half of the trip was executed in "automatic guidance" mode. Both vessels used the same guiding line and lateral offset to the guiding line. Several changes in the lateral offset were applied while keeping a constant longitudinal distance setpoint of 350m. Additionally, the use of safety contours was demonstrated by introducing an artificial obstacle on the starboard side of the fairway.

On the second half of the trip the "assisted guidance" mode was used to steer the VT. The LV was steered manually, while the follower vessel was steered by automatic track control. The track used by the follower vessel consisted of the past positions of the LV. During the second half of the trip the lateral distance offset was set to 0 and the longitudinal distance setpoint was varied between 200m and 500m.

5.3.1 Scenario 1: Coupling

The coupling was successfully executed at 08:53 GMT, see marker 1 in Figure 25.

5.3.2 Scenario 2 & 3: Sailing in "automatic guidance" with varying lateral offset

During the first half of the trip 5 changes of the lateral offset from the track were made to test the response of the VT. Both ships executed the shifts simultaneously as expected. Due to strong winds from the south, there was a constant offset to the starboard side of the track for both ships. Most of the time the distance to the desired track was below 10m, it only increased once to more than 20m due to a change in the lateral offset. Figure 28 shows the desired distance to the track as a grey line and the distance error as a green line. After each change of the desired distance the error is reset to zero and a transition to the new setpoint is computed. Since the transition to the new lateral offset takes some time the distance error increases at first and then decreases to its final value (see changes at 09:00 GMT and 09:25 GMT).

The changes that were executed are listed below:

- 09:00 GMT (2): Lateral offset from 43m to 20m
- 09:10 GMT (3): Lateral offset from 20m to 44m
- 09:22 GMT (5): Lateral offset from 44m to 32m
- 09:25 GMT (6): Lateral offset from 32m to 0m
- 09:28 GMT (7): Lateral offset from 0m to -20m

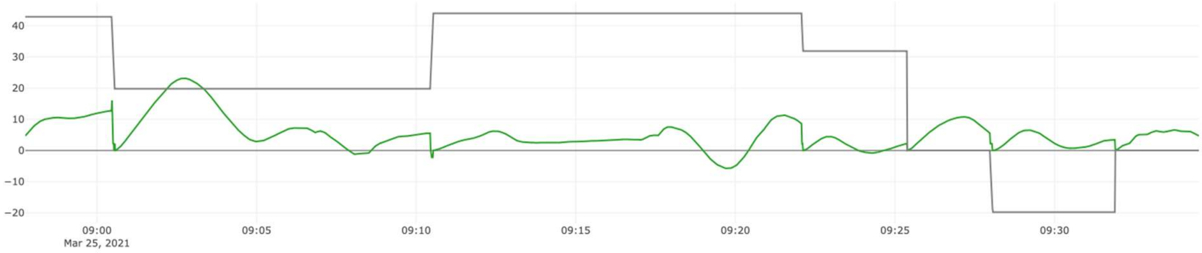

Figure 28: 1st Run: Desired distance to track in meters (grey), lateral distance error (green)

Figure 29 and Figure 30 show the deviation from the desired longitudinal distance of 350m. Most of the time the deviation from the desired distance was below 10m, larger deviations were caused by speed changes of the leader vessel. The largest deviation at 09:16 GMT was caused by the safety contour when the LV had to turn to portside. The change in direction led to a drop of the speed from 15.5 km/h to 14.5 km/h. When the LV accelerated again, the speed of the follower vessel had an overshoot. This can be addressed by adjusting the settings of the speed control.

Figure 29: 1st Run: Longitudinal distance in meters (blue) during experiment with lateral offsets, longitudinal distance setpoint 350m (orange)

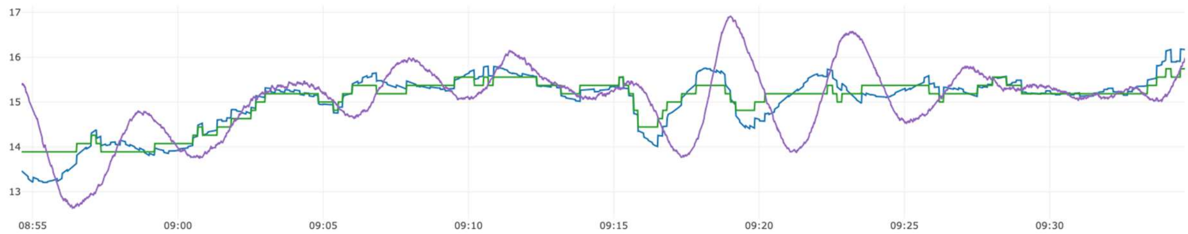

Figure 30: 1st Run: Desired (blue), leader (green) and measured (purple) speed in km/h during experiment with lateral offset

5.3.3 Scenario 4: Sailing in "automatic guidance" with safety contours

At 09:16 GMT (see marker 4 in Figure 27) the starboard safety contour limited the width of the fairway which led to both ships swerving to portside. Both ships were able to avoid the virtual obstacle and sailed safely around it. The manoeuvring led to changes in forward speed that resulted in deviations from the longitudinal distance setpoint of 20m. This deviation is acceptable.

5.3.4 Scenario 5: Sailing in "assisted guidance"

At 09:30 GMT (see marker 8 in Figure 27) the VT control system was switched to "assisted guidance" from "automatic guidance". The first manoeuvre was a tight turn with a turning rate of almost 50°/min. The follower vessel was able to execute the turn but had a lateral deviation of approximately 20m to the outside of the turn. This needs to be addressed by tuning the track control system better which was not possible due to a tight time schedule.

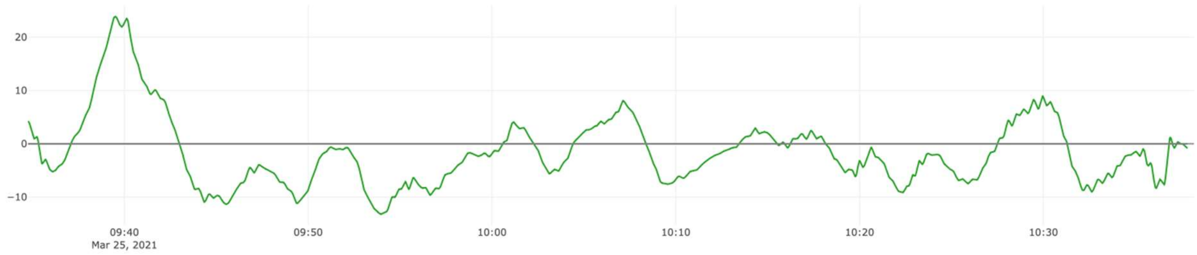

Figure 31: 1st Run, Distance to track in meters (green) during "assisted guidance"

Due to experience from the test run the day before the leader vessel reduced its speed at the end of the turn. Otherwise, the increased speed of the leader vessel that already finished the turn would result in an increased speed and turning rate of the follower vessel. After the turn was finished a series of changes in the desired longitudinal distance were executed:

- 09:48 GMT (9): Setting longitudinal distance from 350m to 200m
- 10:09 GMT (10): Setting longitudinal distance from 200m to 500m
- 10:18 GMT (11): Setting longitudinal distance from 500m to 300m
- 10:20 GMT (12): Setting longitudinal distance from 300m to 200m

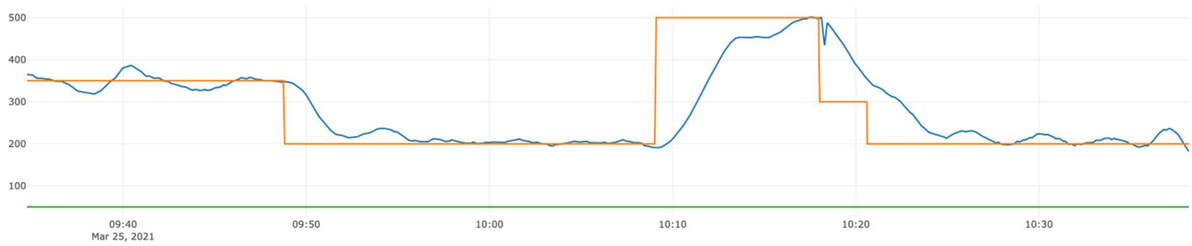

Figure 32: 1st Run: Longitudinal distance (blue) and distance setpoint (orange) in meters during "assisted guidance"

Figure 32 shows the changes in the desired longitudinal distance and the response of the FV. The actual distance (blue line) follows the setpoint nicely, but large changes of the distance take up to 5 minutes of time. The reason is that the speed and distance control loop is set up very slow because sudden changes in speed and engine rpm are not desirable.

The shortest distance between the vessels was limited to 200m because the limitations of the distance control loop needed to be tested in a safe manner. The maximum overshoot of the distance control loop was 40m. This value can be reduced furthermore by tuning the speed and distance control loop. Additionally, it is recommended to implement speed control on the LV and propagate a common speed setpoint for all ships in the vessel train. This would lead to a faster reaction to speed changes of the FV. These measures enable safe operation of these vessels with distances around 100m.

Figure 33 shows the speed setpoint (blue line) and the actual speed of the follower vessel (purple line). Again, there is a slight overshoot of the speed that can be addressed by the setup of the speed control loop. At 09:48 GMT the desired distance was decreased from 350m to 200m. This means that the follower vessel had to accelerate (see step in desired distance at 09:48 GMT). When the follower vessel got closer to the leader vessel the desired speed was reduced (09:53 GMT). At 10:09 GMT the desired distance was increased to 500m. To increase the distance the follower vessel had to decelerate (see negative step in desired speed at 10:09 GMT). Since the ship is not able to actively reduce speed by reversing the thrust the deceleration takes close to two minutes.

Figure 33: 1st Run: Desired (blue), leader (green) and measured (purple) speed in km/h during "assisted guidance"

Figure 34 shows an aerial picture of the VT executing the turning manoeuvre.

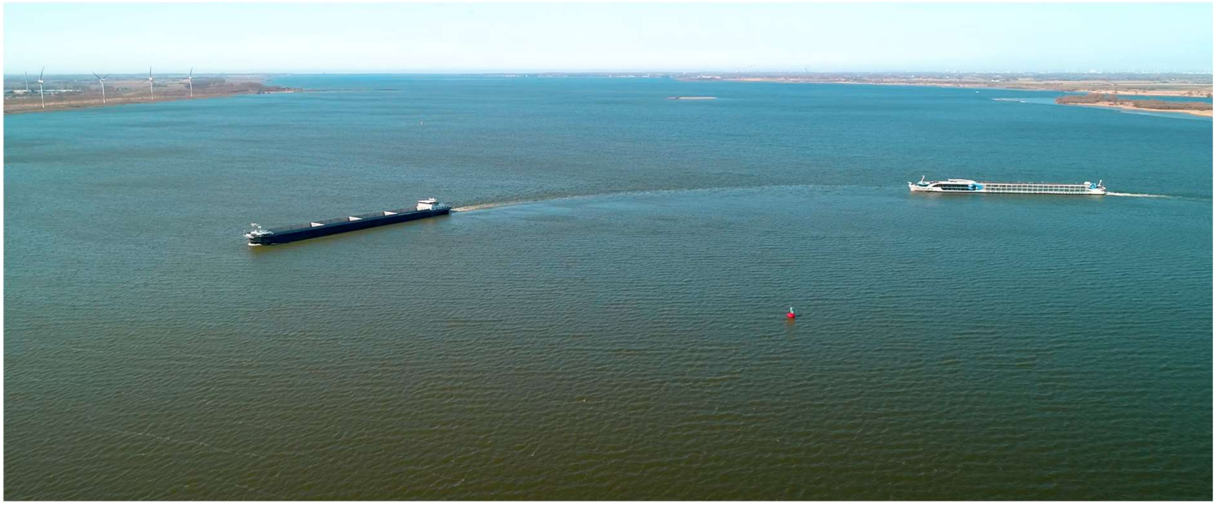

Figure 34: 1st Run: Turning manoeuvre in "assisted guidance"

5.3.5 Scenario 6: Uncoupling

At 10:37 GMT the follower vessel requested to uncouple, was given the acknowledgement of the leader vessel and both ships sailed to the designated waiting area using manual steering.

5.3.6 Additional tests

5.3.6.1 Passing bridge in "assisted guidance"

At 10:36 GMT (see marker 13 in Figure 27) the Haringvlietbrug was passed in assisted guidance mode. Due to an unnecessary course change close to the bridge by the leader vessel the track used by the follower vessel contained a slight turn close to the bridge. The captain of the follower vessel had to engage the bow thruster to pass the bridge safely.

5.4 Second Run

The second run started at 11:55 GMT and ended at 13:40 GMT.

The first half of the trip was executed in "automatic guidance" mode. Both vessels used the same guiding line and lateral offset to the guiding line. Several changes in the lateral offset were applied while keeping a constant longitudinal distance setpoint of 250m. Additionally, the use of safety contours was demonstrated by introducing two artificial obstacles on the starboard side of the fairway.

On the second half of the trip "assisted guidance" was used to steer the VT. The LV was steered manually while the follower ship was steered by automatic track control. The track used by the follower ship consisted of the past positions of the LV. During the second half of the trip the lateral distance offset was set to 0 and the longitudinal distance setpoint was varied between 200m and 350m. Additionally, acceleration and deceleration of the VT was tested. At the beginning and the end of the second run the Haringvlietbrug was passed.

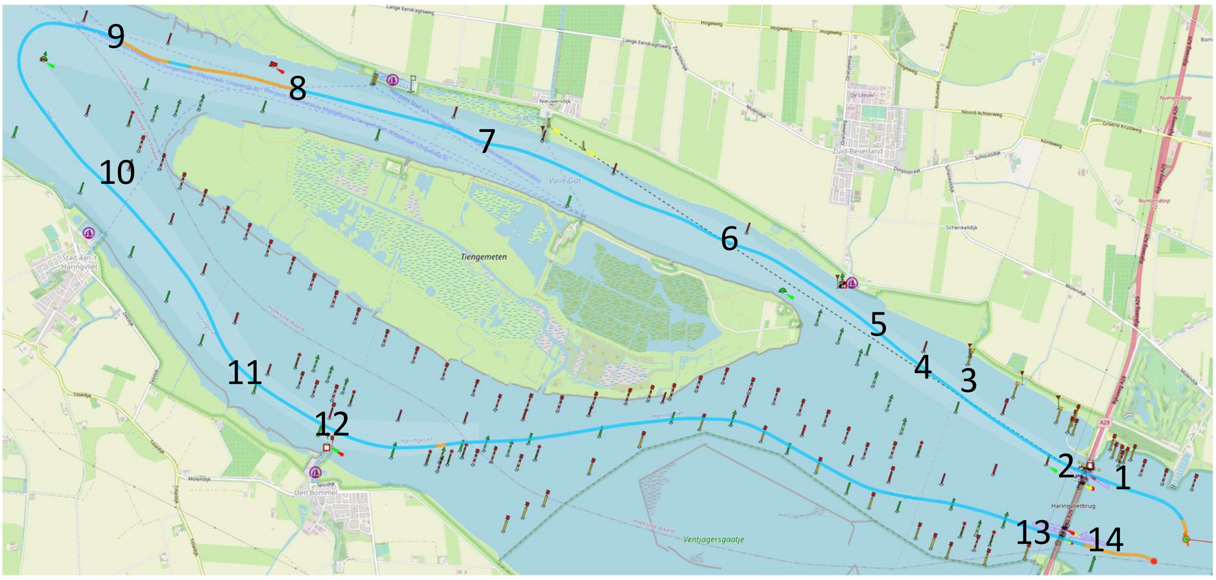

Figure 35: 2nd demonstration run on March 25th

5.4.1 Scenario 1: Coupling

The coupling was successfully executed at 12:08 GMT, see marker 3 in Figure 35.

5.4.2 Scenario 2 & 3: Sailing in "automatic guidance" with varying lateral offset

During the first half of the trip two changes in the lateral offset from the track were made to test the response of the VT. Both ships executed the shifts simultaneously as expected. Due to strong winds from the south there was a constant offset to the starboard side of the track for both ships. Most of the time the distance to the desired track was below 10m, it only increased due to the avoidance of the safety contours. The changes that were executed are listed below:

- 12:10 GMT (4): Lateral offset set to 20m
- 12:12 GMT (5): Lateral offset set to 40m

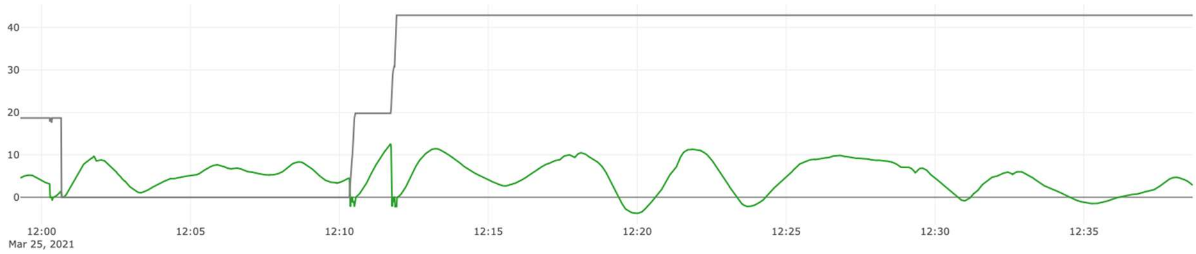

Figure 36: 2nd Run: Desired distance to track in meters (grey), distance to desired position (green)

5.4.3 Scenario 4: Sailing in "automatic guidance" with safety contours

At 12:19 GMT and 12:30 GMT (see markers 6 and 7 in Figure 35) the starboard safety contour limited the width of the fairway which led to both ships swerving to portside. Both ships were able to avoid the virtual obstacles and sailed safely around them. The manoeuvring led to changes in forward speed that resulted in deviations from the longitudinal distance setpoint of 30m (see Figure 37). The lateral deviation during these tests was below 10m. These deviations are acceptable.

Figure 37: 2nd Run: Longitudinal distance (blue) and distance setpoint (orange) in meters during experiments with lateral offset. Distance control was activated at 12:07 GMT

Figure 37 Figure 38 shows the speed of the LV (green line) and the speed of the follower vessel (purple line). After the activation of the speed control loop at 12:07 GMT the follower vessel accelerated to close the distance to the LV. The speed was reduced when the desired distance was reached at 12:11 GMT.

At 12:16 GMT and 12:27 GMT the speed of the LV was reduced during manoeuvring around the safety contours. The follower vessel adjusted its speed accordingly.

This experiment shows that the performance of the speed control loop should be improved because the measured speed overshoots the desired speed both while accelerating and decelerating.

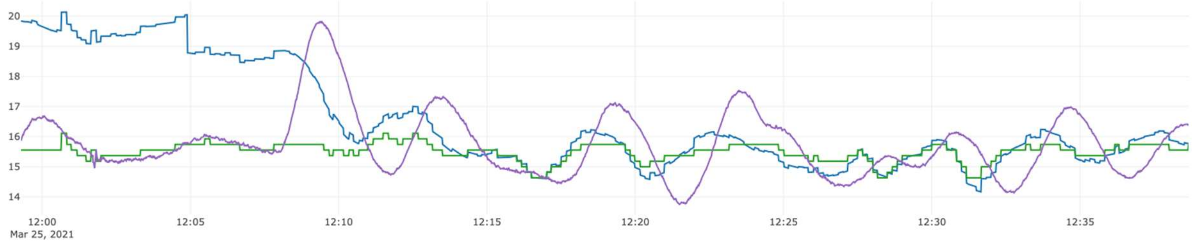

Figure 38: 2nd Run: Desired (blue), leader (green) and measured (purple) speed in km/h during "automatic guidance"

5.4.4 Scenario 5: Sailing in "assisted guidance"

At 12:46 GMT (see marker 9 in Figure 35) the VT control system was coupled and switched to "assisted guidance". Again, the first manoeuvre was a turn with approximately 35°/min turning rate. The follower vessel was able to execute the turn and this time had a lateral deviation of less than 10m to the inside of the turn (see Figure 39 starting from 12:50 GMT). The deviation was smaller in this test run because the turn was not so tight. Afterwards the lateral deviations were in the range of 10m as before, with one exception at 13:15 GMT when a course change of the LV caused a larger deviation. By tuning the settings of the track control the lateral deviations can be decreased.

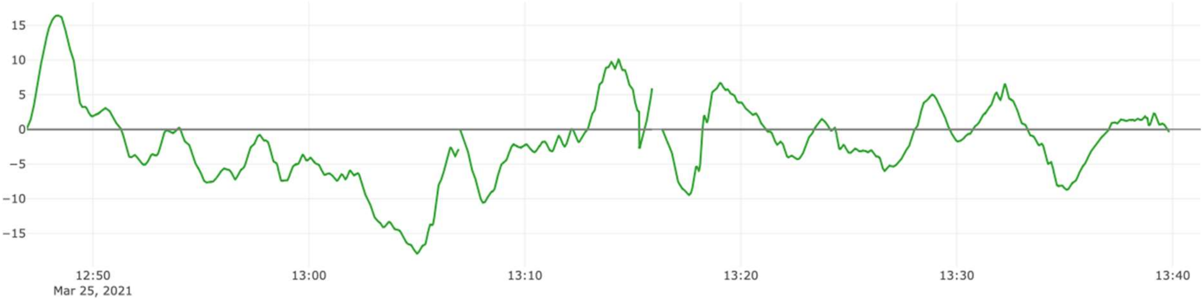

Figure 39: 2nd Run: Distance to desired position in "assisted guidance"

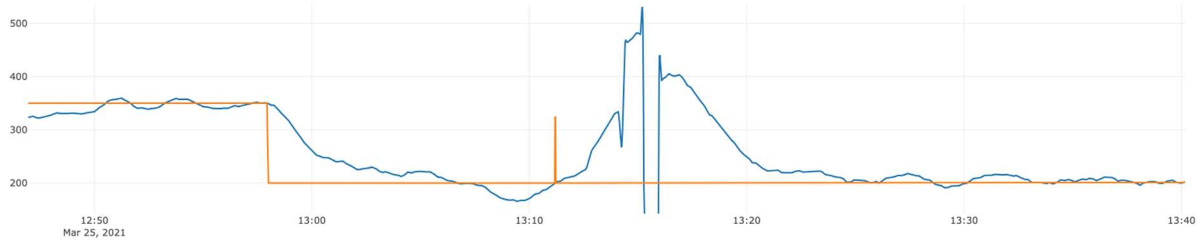

Figure 40: 2nd Run: Longitudinal distance (blue) and distance setpoint (orange) in meters during "assisted guidance"

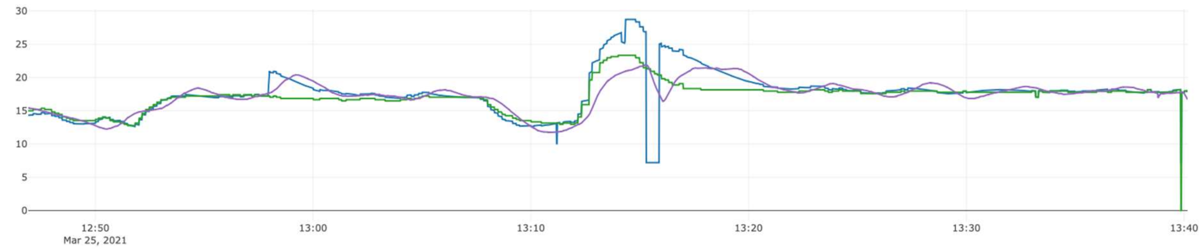

Figure 41: 2nd Run: Desired (blue), leader (green) and measured (purple) speed in km/h during "assisted guidance"

At 12:58 GMT (see marker 10 in Figure 35) the longitudinal distance was set to 200m from 350m. After approximately 5 minutes the new distance was reached as expected. Figure 40 and Figure 41 show the change of the setpoint and the increase of the desired speed to be able to close the gap between the two ships.

At 13:07 GMT (see marker 11 in Figure 35) the LV reduced speed from 17 km/h to 13 km/h. The FV slowed down as well with an overshoot of 30m of the longitudinal distance. Figure 41 shows the reduction of the speed of the leader and follower vessel. Since the deceleration of the LV is small the FV is able to reduce the speed without much overshoot.

At 13:12 GMT (see marker 12 in Figure 35) the LV accelerated to its maximum speed of 23 km/h. The FV accelerated as well but reached its maximum speed at 22 km/h (see purple line Figure 41). The distance between the two ships increased to nearly 500m because the follower vessel was not able to keep up.

At 13:16 GMT the automatic control had to be switched off. This is the reason for the steep step in Figure 40 and Figure 41. The automatic control was switched on again and the follower vessel was able to catch up with the LV. For the rest of the trip the follower vessel held the distance to the LV with a deviation below 10m.

Figure 42 shows the VT sailing in "assisted guidance" mode. The wake of the LV can be clearly seen, and the follower vessel is sailing directly in the trail of the LV.

Figure 42: 2nd Run: VT sailing in "assisted guidance"

5.4.5 Scenario 6: Uncoupling

At 13:40 GMT (see marker 14 in Figure 35) the VT was decoupled successfully.

5.4.6 Additional tests: Passing bridges

The Haringvlietbrug was passed two times using automatic track control in the second test run. At the beginning of the test run, the VT was not coupled yet. However, the follower vessel was sailing in track control mode with distance control switched off (see Figure 43). Shortly before the passing of the bridge the lateral offset was set to zero (see marker 1 in Figure 35). This is why the lateral offset was approximately 10m beneath the bridge.

At the end of the test run at 13:38 GMT, the VT passed the bridge in "assisted guidance" mode with at lateral deviation of less than 3m. Both bridge passages were executed safely.

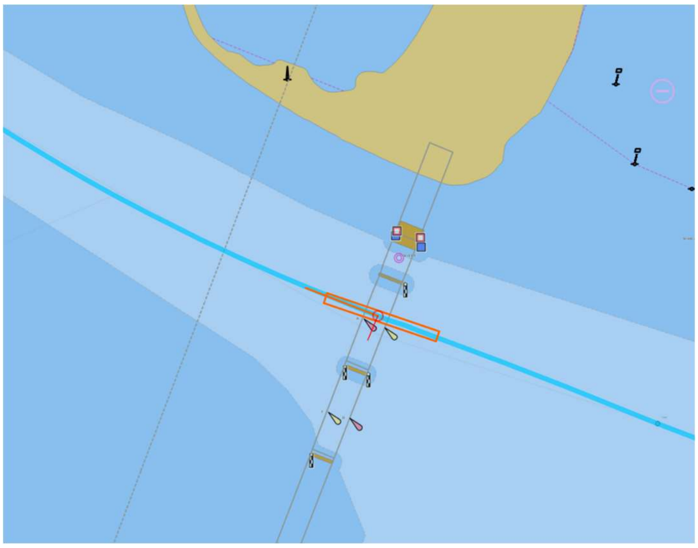

Figure 43: 2nd Run: Bridge passage in track control mode

5.4.7 Additional tests: Crossing of vessel between LV and FV

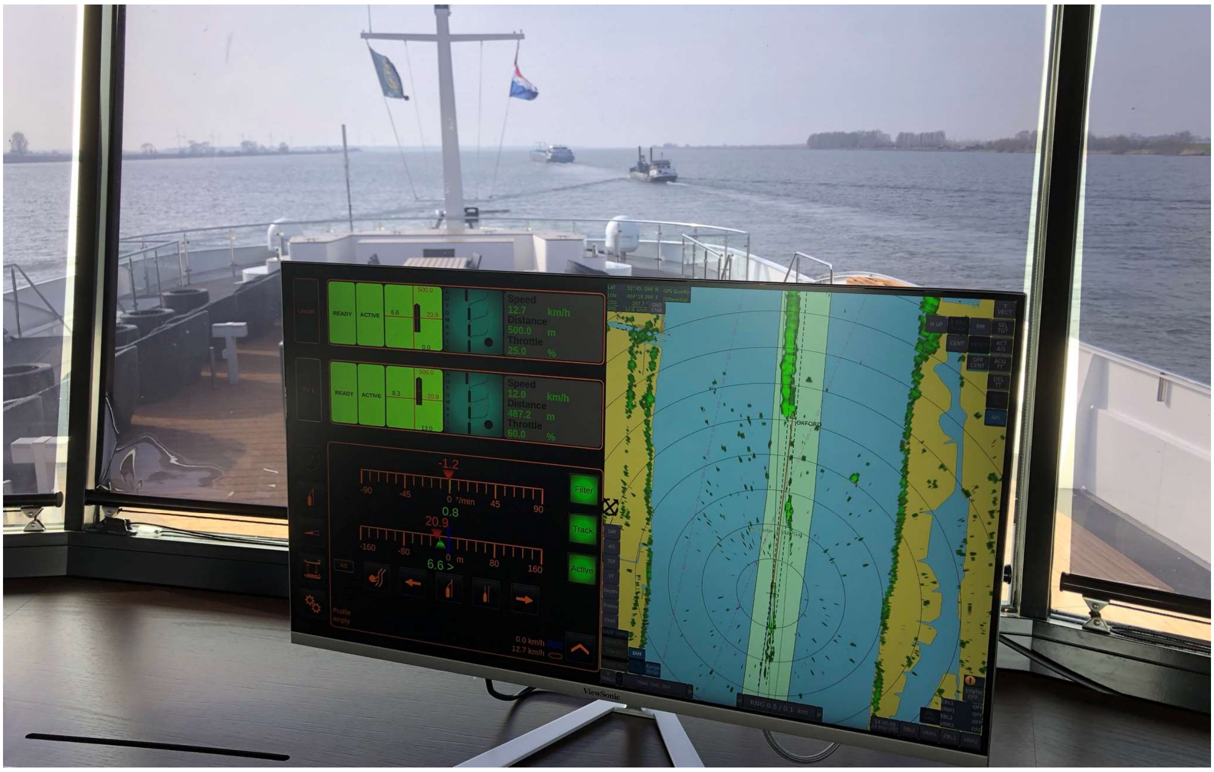

Figure 44: Crossing of vessel between LV and FV

During preparation and the first test run on the 24th a vessel crossed in between the LV and the FV on 14:30 GMT. The crossing had no impact on the communication link.

Table 9: Wireless link parameter during crossing of vessel

Signal strength	-51dBm
Noise floor	-92dBm
TX Rate	121.5 Mbps
RX Rate	300 Mbps
Channel	2412 MHz
Channel bandwidth	40MHz

5.4.8 Additional tests: "Emergency Call"

Figure 45: Emergency button

On the LV an emergency switch was installed. This switch was used when the alien vessel crossed the VT. The emergency call was received by the FV and an acoustic alarm was triggered. The helmsman of the FV informed the LV by radio that he was on the bridge to secure the situation on the FV.

6 ANALYSIS OF RESULTS

6.1 Summary of results

The full-scale demonstration successfully proved that the developed concept of a VT solution works. The trial could demonstrate that

- a VT can be assembled by a defined procedure communicated over radio, AIS ASM messages, and an encrypted wireless link to communicate,
- a VT can be manoeuvred using the concept of automatic guidance, assisted guidance, and safety contours
- bridges can be passed, and vessels can cross a VT when monitored
- the helmsman on the LV can use the radar video and processed targets of the FV to be aware of the surroundings
- the helmsman on the LV can use the alarming system to exchange relevant status information and have an overview of the issues within the VT
- a VT can be disassembled by a defined procedure and AIS ASM messages

6.2 Analysis of results

Table 10: Objective measures

Objective	Requirement source	Solution realised	Solution evaluated and described	Not addressed
Demonstrate on full scale the working principle of a VT using two vessels sailing in VT-configuration	GA	✓		
T3.6.1: Prepare a detailed plan for the full-scale demonstrator: requirements, resources, time planning, safety analysis and risk assessment.	GA	✓		
T3.6.2: Prepare the “Command and Control” modules for demonstration. Check demo vessels for suitability to link with the “Command and Control” system, install complementary systems if needed	GA	✓		
T3.6.3: Demonstrate the “Command and Control” system under real-life conditions	GA	✓		

Objective	Requirement source	Solution realised	Solution evaluated and described	Not addressed
The full-scale demonstrator will consist of two vessels, one mother vessel and one automatically following vessel.	GA	✓		
Both ships will sail in a straight line and manoeuvre through the waterway	GA	✓		

6.3 Corrective measures

The objectives were fully met. Therefore, no corrective measures are planned.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Within this report a successful demonstration of a VT that consisted of two inland vessels has been documented. All defined procedures were performed several times and the developed concept and control system was be demonstrated successfully.

7.2 Recommendations

Further work beyond NOVIMAR is recommended that could not be addressed during the project in WP3:

- Automatic lock passing, already ongoing research: e.g. BMWi-funded project “SCIPPPER” [4]
- Simulated and real-world drift free control including thruster control. Partwise ongoing research in “SCIPPPER”
- Electronic anchoring
- Tests in dense traffic scenarios
- Test and realisation of PTU supported inter-vessel communication
- Simulated and real-world tests of path modification algorithms

8 REFERENCES

[1] DST, „NOVIMAR D3.1 - Navigational requirements and procedures of the VT,“ NOVIMAR, Duisburg, 2019.

[2] Innovative Navigation, „NOVIMAR D3.2 Vessel Train Control System,“ NOVIMAR, Kornwestheim, 2020.

[3] MARIN, „NOVIMAR D3.5 Demonstrator results,“ NOVIMAR, Wageningen, 2020.

[4] Innovative Navigation, Argonics, „SChleusenassistenzsystem basIerend auf PPP und VDES für die BinnenschifffahRt (SCIPPPER),“ 2018. [Online]. Available: https://www.innovative-navigation.de/allgemein/entwicklung-eines-schleusenassistenzsystems-im-rahmen-von-scippper-beginnt/.

[5] Innovative Navigation, „RADARpilot720°,“ [pdf], 27 01 2020. [Online]. Available: https://www.innovative-navigation.de/wp-content/uploads/2014/12/RADARpilot720.pdf.

[6] Argonics, „ArgoTrackPilot,“ 27 01 2020. [Online]. Available: http://www.argonics.de/argoTrackPilot.

9 ANNEXES

9.1 Annex A: Public summary

NOVIMAR researches a new system of waterborne transport operations for short-sea, sea-river, and inland waterways. A manned leader vessel controls several follower vessels that together form the vessel train. In this task a demonstration of a vessel train of two vessels was conducted. The vessel train was composed of the 135m long container vessel "Oxford" as leader vessel and the 135m long inland cruise liner "Viva Moments" as follower vessel. The demonstration took place in the Netherlands on the 24th and 25th of March 2021 in an area called Haringvliet.

It was proven that such a system can be realised even by retrofitting existing vessels. Common sensor devices on board are combined with an Inland ECDIS system of Innovative Navigation, a track controller of Argonics and a GNSS positioning device. These core components form the requirements for a vessel train. Communication through encrypted wireless links from one vessel to the other ensures the exchange of control information, radar video information, and target data. Using AIS Application Specific Messages the vessel train reports its position and vessel arrangement to other traffic and VTS systems.

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9.2 Annex B: Suggested AIS ASM VT Message[1]

Published:	-	Version:	0
DAC:	-	FI:	-
Sent from:	**Ship (default off)**	Sent to:	**Base Station, other vessels with integrated navigation system**
Summary of changes:			
	0 - Initial version		

9.2.1 Introduction:

The VT message shall inform surrounding traffic and shore infrastructure about an electronic coupling between two or more vessels. Electronic coupling could be implemented by an assistant function providing distance and/or guiding line control or a comprehensive system coupling at least two vessels in a train formation.

The message can be used to indicate a train where a FV couples electronically to a LV without the notice of the leader (passive coupling) and a convoy coupled with the knowledge and acceptance of the LV (acknowledged coupling).

The message can be used to visualize a train formation in a VTS system or integrated navigation system on a vessel bridge e.g. by a dashed line for passive coupling and a continuous line for acknowledged coupling.

9.2.2 Additional information / usage notes:

A passively coupled train consists of two vessels where the sender of the message (source MMSI) does not equal the LV but a FV, the convoy state is set to "0" and the FV does not intend to sail in an acknowledged train. The typical application for a passive coupled train is an assistance system, typically providing distance and guiding line control.

When the follower intends to sail in an acknowledged train, he or she indicates this by sending convoy state "1" until the LVs accepts this state by adding the FV to the train formation and sending a VT message with convoy state "2".

An acknowledged coupled train consists of two or more vessels where the sender of the message (source MMSI) equals the LV and the convoy state is set to "2". In this case, the FVs shall not repeat the message until they intend to leave the train.

[1] ASM VT Message suggested to the Inland ECDIS Expert Group (IEEG)

Decoupling is indicated by the vessel leaving the train formation by sending a convoy state of “3” and the current train configuration. Decoupling by the LV is initiated by removing the FV from train configuration. In case the last FV is removed, the LV initiates a convoy state “3” message with the last follower.

A LV can decline a request by not accepting it (silence) or by issuing a convoy state “3” message containing the LV followed by a single FV that places the request.

Up to three vessels can be transmitted in a single-slot message and up to nine vessels can be transmitted in a two-slot message.

Number of train members	**2-3**	**4-9**
Number of bits used for a broadcast message	168	336
Number of slots used for a broadcast message	1	2
Number of spare bits in message n=	16	4

9.2.3 Structure:

	Parameter	Bit	Description
	Message ID	6	Identifier for Message 8; always 8
	Repeat Indicator	2	Used by the repeater to indicate how many times a message has been repeated. Default = 0; 3 = do not repeat anymore
	Source ID	30	MMSI number
	Spare	2	not used, should be set to zero, reserved for future use
Binary data	Application Identifier	16	DAC = ?, FI = ?
	Version indicator	3	The version number of the message default = 0, rest for future use
	Convoy state	3	0=passively coupled, 1= passively coupled and request for acknowledged coupling, 2= active acknowledged coupling, 3= decoupled and decoupling request in case of acknowledged coupling, rest not used (reserved for future)
	MMSI LV	30	MMSI number
	MMSI FV 1	30	MMSI number
	MMSI FV 2 (optional)	30	MMSI number, 0 = default = not used
	MMSI FV 3 (optional, 2-slot Message)	30	MMSI number, 0 = default = not used
	MMSI FV 4 (optional, 2-slot Message)	30	MMSI number, 0 = default = not used
	MMSI FV 5 (optional, 2-slot Message)	30	MMSI number, 0 = default = not used
	MMSI FV 6 (optional, 2-slot Message)	30	MMSI number, 0 = default = not used
	MMSI FV 7 (optional, 2-slot Message)	30	MMSI number, 0 = default = not used
	MMSI FV 8 (optional, 2-slot Message)	30	MMSI number, 0 = default = not used
	Spare (1 and 2-slot Message)	n	not used. Should be set to zero, reserved for future use
	Total	max 336	occupies 1 slot for a convoy of three ships, 2 slots for 9 ships

9.3 Annex C: RWS Application Form

NOVIMAR FULL-SCALE DEMONSTRATOR

Content RWS application form ‘permission experiments highly automated sailing’

Version 2 – 24th August 2020

On behalf of the NOVIMAR-consortium:

Henk van Laar

Bureau Telematica Binnenvaart

Details with regard to Vessel #1 – mps Annika

<u>Contact details owner vessel #1:</u>
XXXXXXXXXXX
XXXXXXXXXXX
XXXXXXXXXXX
<u>Responsible captain during experiment vessel #1:</u>
XXXXXXXXXXX
XXXXXXXXXXX
XXXXXXXXXXX
<u>Details of the vessel:</u>

Name	: mps Annika
ENI number	: (not available yet in view of the Annika being a new-build)
Length	: 135 meters
Beam	: 11,45 meters
Draft	: 1,5 meters
Air draught	: 6,5 meters
Displacement:	: 1.500 cubic meters
Country of registration	: Switzerland
Insured with	: SSA Overvliet
Number of nautical crew during demo	: 4

Details with regard to Vessel #2 – mvs Denford

<u>Contact details owner vessel #2:</u>
XXXXXXXXXXX
XXXXXXXXXXX
XXXXXXXXXXX
<u>Responsible captain during experiment vessel #2:</u>
XXXXXXXXXXX
XXXXXXXXXXX
XXXXXXXXXXX
<u>Details of the vessel:</u>

Name	: mvs Denford
ENI number	: 02338470
Length	: 110 meters
Beam	: 11,45 meters
Draft	: 3,5 meters
Air draught	: 10 meters
Tonnage	: 2.801 ton
Country of registration	: Luxemburg
Insurance	: TVM
Number of nautical crew during demo	: 4

Details of the experiment

Period	: November and December 2020
Duration	: The actual demonstration will cover 2 days
Location	: Haringvliet – Het Vuile Gat, with departure venue the Port of Willemstad

Number of nautical crew mps Annika	: 4
Number of passengers on board mps Annika	: between 40 and 80

Number of nautical crew mvs Denford	: 4
Number of passengers on board mvs Denford	: 10

In addition to the crew, passengers during the experiment on board of both vessels will include:

- Technical staff of Argonics and Innovative Navigation
- NOVIMAR-consortium representatives and organisers
- Relevant stakeholders (governmental, branch organisations and industry representatives)
- Press (trade journals and relevant general media)

Program & Planning:

- Day 1: Preparation i.e. internal testing (without visitors)
- Day 2: Public demonstration starting at 09:00 hours, ending at 17:00 hours

General information on the NOVIMAR project (https://novimar.eu)

The NOVIMAR project aims at adjusting the waterborne transportation such that it can make optimal use of the existing short-sea, sea-river and inland waterways, thus expanding the entire waterborne transport chain up and into the urban environment. The vessel train is foreseen as enabler for this transport system, providing opportunities for increased flexibility in cargo destinations, use of waterways and crew deployment. NOVIMAR has a variety of research topics in scope ensuring a balanced evaluation of the foreseen transport system. In addition, NOVIMAR will identify needed boundary conditions for the transport system and ongoing supporting developments in industry and other projects.

Full-scale demonstrator

As part of the NOVIMAR project, a full-scale demonstration of the Vessel Train concept is planned. The objective of this full-scale demonstration is to exhibit a working concept of the Vessel Train in real life conditions, and to show the working of a vessel train to the EU, interested authorities, industry representatives and other relevant stakeholders.

Ambition and background of the experiment

The goal of the NOVIMAR project is to implement a vessel train where multiple ships travel behind each other, supervised by a lead ship in front of the vessel train. The following vessels are navigated by an automatic control system that controls the rudder and the engines and keeps the ships on a path set by the lead vessel. They keep a certain distance to the ship directly in front by automatically adjusting the speed. The crew of the following vessels is ready to take over control whenever necessary.

Purpose and working method during the experiment

In this experiment, the vessel train control system will be tested on two full scale ships. On the lead ship, the control system will only have access to the rudder. On the following ship, rudder as well as engines will be accessed by the control system (see figure 1 on the next page covering the Vessel Train's system structure).

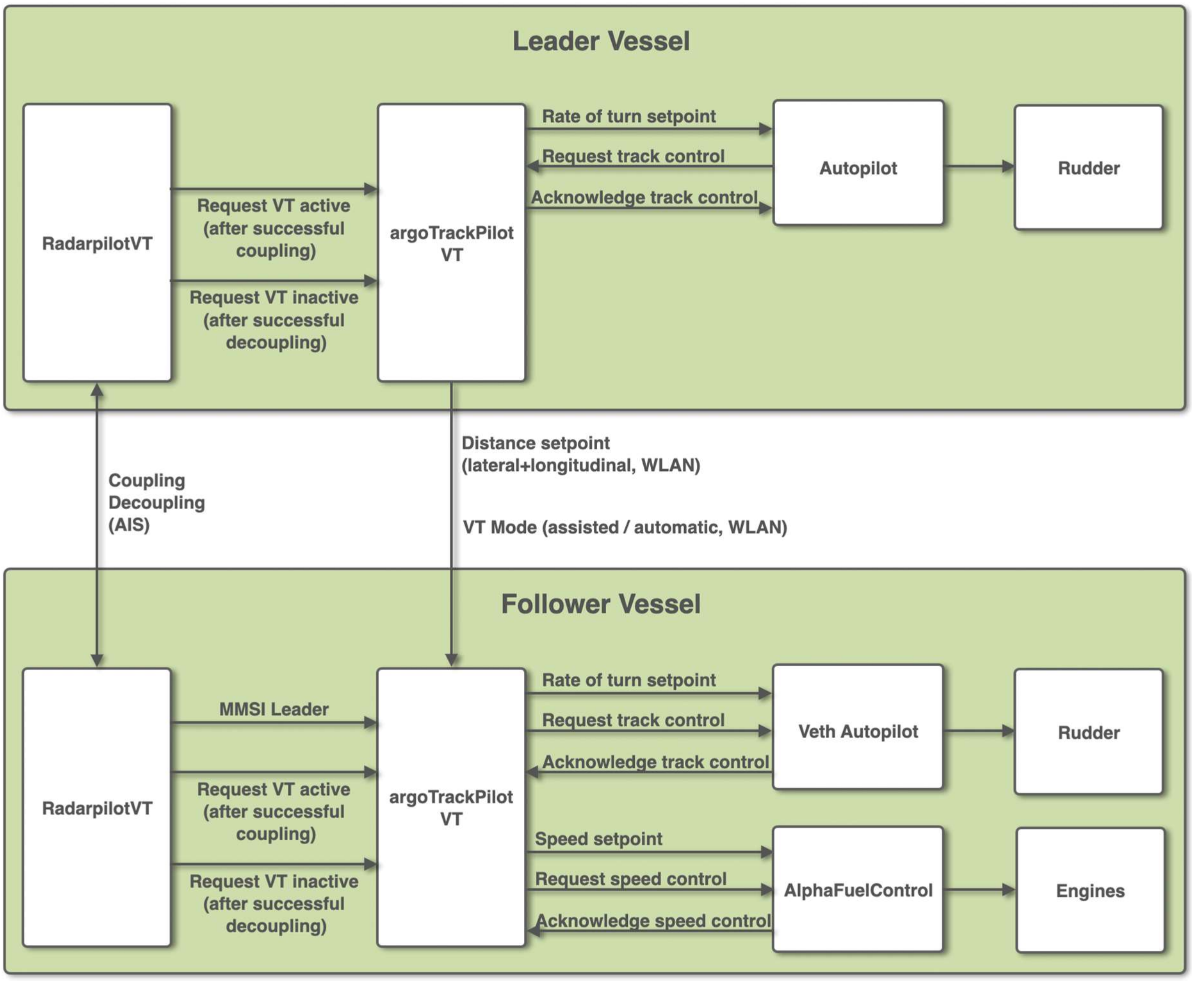

Figure 1: VT System structure

The automation level is 2 (Partial Automation) according to the definition of the CCNR. The crew on board of both ships will be ready to take over control of the ships at any time. The tests will include the following maneuvers:

- Coupling and decoupling of the vessel train
- Acceleration and deceleration maneuvers
- Turning maneuvers i.e. sailing through curves
- Track changes in order to avoid traffic

Table and Table summarize the procedures for coupling and decoupling a follower vessel to the LV. Each maneuver is initiated by radio communication. The actual coupling is achieved by selecting the LV in the RadarpilotVT ECDIS system (see figure 2 on page 8). The skipper of the LV then acknowledges the request using the ECDIS system as well. When the request is acknowledged by the LV, speed and track control is activated on the follower vessel.

Decoupling is done using the ECDIS system as well.

Step	Comm	Procedure of joining FV	Procedure of LV	Crew
1	Radio	Communicate arrival time and desired position in train to LV.		LV, FV
2	Radio		Waits LV for FV to arrive.	LV
3	WLAN	When the approaching vessel is close enough, the WLAN mesh gets active.	The joining vessel receives an IP address from the VT Leader.	
4		FV is positioned at the end of the VT.		FV
5	AIS	FV requests joining the train electronically by sending out an VT AIS ASM message.		FV
6	AIS		LV acknowledges the request by sending out a VT AIS ASM message.	LV
7		Track and speed control is switched on by VT control system.		FV
8	WLAN	VT relevant data is exchanged and processed	VT relevant data is exchanged and processed (lateral and longitudinal distance setpoint).	

Table 1: Coupling Procedure

Step	Comm	Procedure of leaving FV	Procedure of LV	Crew
1	Radio	Communicate wish to leave LV.		FV
2	AIS	FV requests leaving the train electronically by sending out an VT AIS ASM message		FV
3	AIS		LV acknowledges the request by sending out an VT AIS ASM message.	LV
4		Track and speed control are switched off by VT control system.		FV

Table 2: Decoupling Procedure

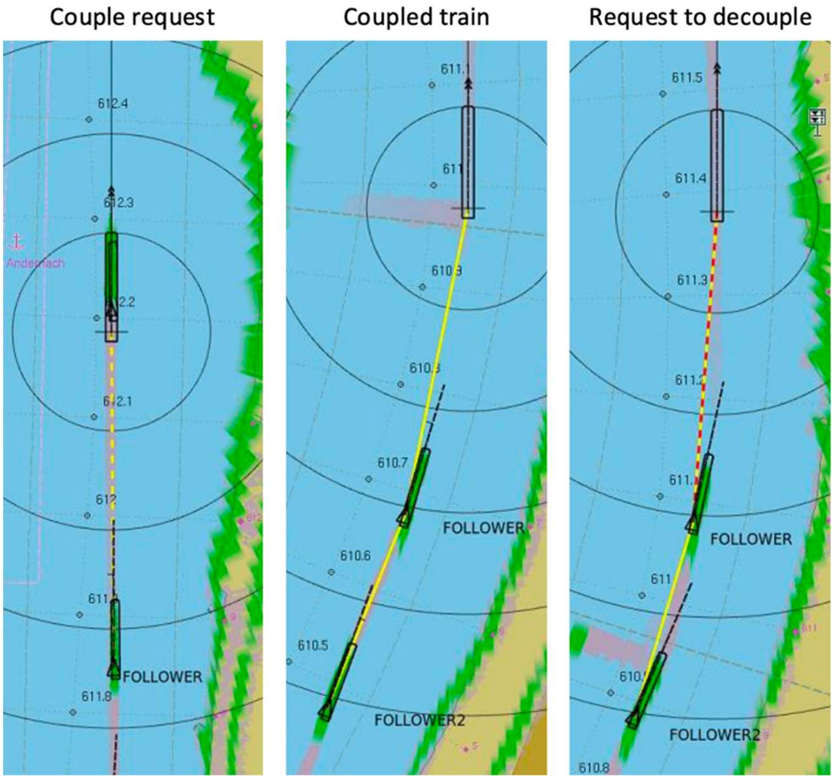

Figure 2: Coupling and decoupling in the RadarpilotVT ECDIS system

In case of an emergency the procedure to switch off the vessel train control system depends on the autopilot system installed on the ship. The type of autopilot on the leader vessel is unknown up to now but most autopilot systems use a dedicated button to activate track control (see figure 3 on the next page), i. e. the KOMPASS button in case of an Alphatron autopilot. To deactivate track control the skipper only needs to select AUTO or WEG mode by pressing the corresponding button. This deactivates all vessel train functions.

The follower vessel is equipped with a Veth autopilot system (see figure 4 on the next page). To switch off all vessel train functions in case of an emergency the skipper has two possibilities:

1. Switch to FOLLOW UP on the autopilot touch display
2. Use any control lever to set the rudder angle or engine speed. There is no need to push any button, all automatic control functions are switched off automatically.

Figure 3: Alphatron autopilot on leader vessel

Figure 4: AlphaFuelControl, argoTrackPilot VT and Veth autpilot on the follower vessel

The preliminary plan for the demonstration contains the following parts:

- **Coupling at zero speed:** The follower vessel is positioned 300 m to 500 m behind the leader vessel, close a predefined track. Coupling is carried out according to the procedures mentioned above. The leader vessel accelerates, the follower vessel accelerates accordingly, keeping a predefined distance of 200 m to 300 m.

- **Coupling at cruise speed:** The follower vessel follows the leader vessel at a distance between 300 m and 500 m close to a predefined track. Coupling is carried out according to the procedures mentioned above. The follower vessel adjusts its speed to keep the desired distance of 200 m to 300 m.

- **Varying the distance:** When the vessel train is coupled, and the follower vessel has reached the desired distance the desired distance is changed while the leader vessel is sailing at constant speed. The distance can be set to values between 150m and 400 m.

- **Varying speed:** When the vessel train is coupled and the follower vessel has reached the desired distance the leader vessel changes its speed to slow speed, waits until the follower vessel reaches the desired distance. It then accelerates to a speed higher than cruise speed and waits again for the follower vessel to reach the desired distance.

- **Varying lateral offset:** When the vessel train is coupled, and the follower vessel has reached the desired distance the leader vessel changes the lateral offset to the predefined track to a value up to 50 m. When both vessels reach the desired lateral offset, the offset is reduced to 0 m.

- **Switch between assisted and automatic guidance:** When the vessel train is coupled and the follower vessel has reached the desired distance the leader vessel switches to assisted guidance, the follower vessel now follows the track laid out by the leader vessel. The leader vessel is steered manually now. The leader vessel executes a maneuver to avoid an imaginary static object. When the avoidance maneuver is finished, the leader vessel switches back to automatic guidance, both ships return automatically to the predefined track.

- **Upstream stop maneuver:** The vessel train is sailing upstream. When the follower vessel has reached the desired distance of 300 m the leader vessel reduces speed down to a full stop. The follower vessel stops as well.

- **Decoupling at cruise speed:** When the vessel train is coupled, and the follower vessel has reached the desired distance the follower vessel requests to decouple. The leader vessel acknowledges, both ships continue with manual steering.

The order of the experiments will be determined depending on traffic and the most suitable location.

Training and required knowledge

On both vessels a boat master is required to perform the normal navigational tasks if the ships are not sailing automatically. No special training is required. If the ships are sailing automatically, the boat masters need to supervise the control system. The skipper on the lead ship performs changes to the desired track and speed if the traffic or the experiment plan requires it. There will be technical personnel from the technology providing companies (Argonics and Innovative Navigation) on board of both ships supporting the boat masters when sailing automatically.

Additionally, the skipper of the follower vessel has three years of experience of sailing on ships equipped with automatic track control. The skipper on the leader vessel will have time to familiarize with the track control system before the actual demonstration since the system will be installed several weeks earlier.

Previously performed tests or experiments and their outcomes

The vessel train control system has been tested successfully on 2 occasions at MARIN using 3 full mission bridge simulators. During tank tests at DST in Duisburg the vessel train control system was also tested successfully (https://novimar.eu/2020/02/14/scalemodeltests/). Furthermore, a test was executed successfully on the passenger vessel Geoffrey Chaucer in the beginning of 2020.

Risk assessment and visibility

The risk involved with this experiment, are limited to the level of what is normal i.e. acceptable in the day-to-day operations of sailing vessels on the inland waterways. The control system that will be tested, does not replace any part of the presently required tools for navigation and command and control of vessels. The NOVIMAR control system can be decoupled whenever necessary and crew will be in the wheelhouse at all times, in accordance to existing regulation. Furthermore, the waterway at the Haringvliet – Het Vuile Gat, is a well-known and frequently used stretch of water where sea-trials of newly build vessels are executed. The cargo will not contain any cargo. Furthermore, the vessels involved a normal surface ships and therefore highly visible.