Project acronym: NOVIMAR
Project full title: Novel Iwt and Maritime Transport Concepts
Grant agreement No. 723009
Coordinator: Netherlands Maritime Technology Foundation

NOVIMAR VESSELTRAIN

Deliverable D3.1
Navigational requirements and procedures of the vessel train

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723009

Duration:	48 months
Project Start:	01/06/2017
Project End:	31/05/2021

Deliverable data

Deliverable No	D3.1		
Deliverable Title	Navigational requirements and procedures of the vessel train		
Work Package no: title	WP3: Smart Navigation		
Task(s)	T3.1: Requirements & Procedures		
Dissemination level	Public	Deliverable type	Report
Lead beneficiary	DST		
Responsible author	Benjamin Friedhoff		
Co-authors	Thomas Guesnet, Matthias Tenzer, Felix Roettig, Rainer Kaiser, Jens Ley (DST) Maarten Flikkema, Dick ten Hove (MARIN) Alexander Lutz, Axel Lachmeyer (ARG) Sebastian Wagner (IN)		
Date of delivery	30-06-2018		
Approved	Name (partner)		Date [DD-MM-YYYY]
Peer reviewer 1	Steve Labeylie (CFT)		09-06-2018
Peer reviewer 2	Igor Bačkalov (BU)		09-06-2018
QA manager	Michael Goldan (NMTF)		17-08-2018

Document history

Version	Date	Description
0.1	22-05-2018	First draft circulated to the WP partners
0.5	27-05-2018	Extended draft circulated within WP3
1.0	31-05-2018	Final draft uploaded to EMDESK for review
2.0	16-06-2018	Revision uploaded for QA manager
3.0	25-07-2018	New structure after meeting 05-07-2018
3.1	21-08-2018	Final version after feedback from QA manager

The research leading to these results has received funding from the European Union Horizon 2020 Program under grant agreement n° 723009.

CONTENTS

List of symbols and abbreviations

AIS	Automatic Identification System
CCNR	Central Commission for the Navigation of the Rhine
DST	Development Centre for Ship Technology and Transport Systems
ECDIS	Electronic Chart Display and Information System
FV	Follower vessel
HAZID	Hazard identification study
HMI	Human-Machine Interface
IWT	Inland waterway transport
LV	Leader vessel
NOVIMAR	NOVel Iwt and MARitime transport concepts
SHS	Ship handling simulator
SSS	Short sea shipping
VT	Vessel train
WP	Work package

1 EXECUTIVE SUMMARY

The NOVIMAR project researches the vessel train (VT), a waterborne platooning concept featuring a manned leader ship and a number of followers which are virtually connected and follow at feasible distance by means of automatic control. The vessel train concept is a totally new approach for inland waterway and short sea transport. Thus, the definition of navigational requirements and procedures is crucial.

1.1 Problem definition

The vessel train (VT) could become a new waterborne transport system, which should fit into the current and well-developed system. To cite the objectives of the project, the ‘Project NOVIMAR strategic aim is to adjust waterborne transportation such that it can make optimal use of the existing short sea and inland waterways and vessels, while benefitting from a new system of waterborne transport operations that will expand the entire waterborne transport chain up and into the urban environment.’.

The VT is a service that has to be competitive with other means of transport. In order to be competitive, NOVIMAR has to show the economic and operational feasibility, while meeting safety requirements.

1.2 Technical approach and work plan

Task 3.1 “Requirements & Procedures” is the first task in WP 3 Smart Navigation, it started in month four of the project and the deliverable is submitted end of month thirteen. The task is strongly linked to decisions and results of several other tasks and work packages in NOVIMAR. Therefore, some of the procedures and definitions described in this deliverable may have to be reconsidered and adjusted to match the refining details of the VT later in the project.

In deliverable 1.1 the initial requirements were defined as starting points for the development of a model of a vessel train concept. In deliverable 2.1 the current situation of the working principles in inland waterway transport (IWT), short sea shipping (SSS) and sea-river transport are analysed and outlined. The present deliverable 3.1 resumes the requirements from the navigational point of view, defines the outline of the VT control system and describes the roadmap for the scenarios to be demonstrated in Task 3.5 and Task 3.6 as well as in the simulator campaigns of WP5.

1.3 Results

This report summarizes the navigational boundary conditions for the VT and as result the navigational requirements and procedures for the VT are derived. As next step, the concept for the VT control algorithms and hardware is specified. The Radarpilot720° of project partner Innovative Navigation and TrackPilot developed outside of NOVIMAR by Argonics were identified as a well-suited basis for the implementation of the VT functionalities. Finally, a roadmap for the various demonstrations foreseen within NOVIMAR is proposed. Not only the use of a ship handling simulator, scaled model tests and full scale demonstrations as part of WP3 but also the tests at DST’s simulator planned with a focus on the human factor in WP 5 are considered. The interrelation and focuses of these demonstrations were specified during the work for this deliverable. A proposal for the corresponding scenarios is included.

2 SYSTEM REQUIREMENTS AND PROCEDURES

2.1 Task objectives

The following extract from the proposal describes the work performed in the preparation of this deliverable.

The task objectives are:

To determine detailed system requirements, procedures and assumptions for the VT-developments and the scenarios to be demonstrated in T3.5 and T3.6.

In order for the VT to work, certain requirements and procedures need to be specified in detail. These include coupling/uncoupling and manoeuvring requirements etc. and the above defined scenarios for demonstrations.

Sub-task T3.1.1: **Define the navigation and control requirements** to fit within the VT-concept regarding safety, minimum distance to other traffic or objects, stopping, manoeuvring, etc..

Sub-task T3.1.2: Detail **scenarios to prepare control systems and demonstrations**: vessel selection (size, manoeuvrability and propulsion system), number of ships in the VT and location to execute manoeuvres.

Sub-task T3.1.3: Define **standard procedures** such as coupling/uncoupling of a vessel from the train.

Sub-task T3.1.4: Define **complexities outside the scenarios**: passing locks, combining vessel sizes and types.

Sub-task T3.1.5: Prepare the task deliverable

Role of the Partners

DST (leader) with MARIN and VML define/detail scenarios and VT-nautical and hydrodynamic issues.

ARG with IN define/detail navigation control requirements and procedures including on-board equipment.

VIA and IN contribute to T3.1.2 with inputs on Danube navigation and links to River Information Services.

Input/output relations

Task T3.1 receives input from task T1.1, the NOVIMAR proposal and external sources.

Task T3.1 provides output to tasks T2.3, T3.2, T3.3, T3.4, T3.5, T3.6, T4.4, T5.1 and T5.2.

2.2 Define the navigation and control requirements

Actors are in principle the Lead Vessel (LV), the Follower Vessel (FV) and a shore-based control centre (CC). The LV is manned; the FV could be operating with reduced crew or even be unmanned.

As result of the business cases that have been defined and provided to WP3, feasibility estimation is shown in the table below.

Table 1. Feasibility estimation

Crew level FV	Type	Feasibility	Remarks
Complete crew	Retrofit		Only feasible if operational time can be increased (IWT)
	New		
Reduced crew	Retrofit		Additional investments for equipment depends on absolute crew level
	New		As retrofit + extra cargo capacity
No crew (remote controlled)	Retrofit		Too high additional costs
	New		Reduction of remote operating costs compared to outside VT
No crew (autonomous)	New/retrofit		No gain being part of VT -> out of scope

Based on Table 1the expected optimum is the reduced crew variant. Within this spectrum the most promising one is the situation with at least one crew member that is present to handle emergency situations to meet the safety requirements, but during regular sailing has no role. This variant seems to have the best cost/benefit relation. For WP3 it does not matter whether it is a retrofit or new built variant. WP3 investigates what the control requirements are for this variant and develops it. Later in the project additional research can be done regarding the unmanned, remotely supervised variant, which is only feasible for newly built vessels.

Referring to the operation with "reduced crew", it is most important that the crew of the FV shall not be called upon the bridge to perform **common navigation related tasks**.

Role of the lead vessel

The LV sets out a sail plan and provides the FV's with the necessary data to follow its "tracks". It is responsible for communication with outside parties and for the overall VT behaviour within the waterways' infrastructures and traffic and takes preventive and/or curative action within the limits of its authority and technological ability, for example reducing speed, stopping, or adjusting the heading. The boat master responsibility prevails, assistance systems are available. The LV has no authority over the FV's own systems, e.g. cannot restart engines and generators, activate fire-fighting systems or ballast pumps.

Role of the follower vessel(s)

The FV follows the sail plan set out by the LV and remains responsible for navigating by automated regulating of distance and position with respect to the LV or FV ahead. For this, it is necessary to adjust engine revolutions (power) and activating manoeuvring devices (rudder, propellers, bow thruster). The VT control system sets the parameters for the part of the VT control system that is responsible for keeping track and distance of the FV. The FV is responsible for keeping all own vessel systems up and running, solve emerging problems and take appropriate action following LV instructions or own decisions.

The FV is manned by at least one crew member. The available assistance systems on board of the FV navigate under normal operation conditions, following LV instructions. The crew is called to act only to solve whatever on-board problems occur as well as acts in emergency situations. For example, the ship takes water (activate pump), there is a fire (activates fire-fighting system). The crew also navigates the FV to connect with the VT, and navigates the FV out of the VT towards the final destination

Role of the control centre

The control centre (CC) could be a service centre for ship owners/operators or a facility established by a large owner/operator, helping to organize the assembly or voyage optimisation of the VT.

2.2.1 NAVIGATIONAL REQUIREMENTS

Referring to the operation with “reduced crew”, it is most important that the crew of the FV shall not be called upon the bridge to perform **common navigation related tasks**. Once “hooked” to the VT, the boat master of the FV will be off duty and his/her presence not required at the helm of the vessel. Without any activity of the FV crew, the following actions are continuously performed by the assisting systems available on the FV:

- Track keeping as defined by LV, this includes narrow passages such as bridges
- Distance keeping to LV, or the FV in front
- In case of necessity, initiation of stopping manoeuvre

The non-interrupted duration of “common navigation”, without any action of the boatmaster could be several hours per day, in the best case during the complete shift.

Once coupled to the VT, action of the boat master is required only in case of:

- Approaching the destination port, leaving the VT
- In an emergency manoeuver
- Any malfunction on board
- Passing locks

Referring to recent discussions at CCNR level[1], the required level of automated navigation on board of the follower vessel should be “Conditional automation: the sustained context-specific performance by a navigation automation system of all dynamic navigation tasks, including collision avoidance, with the expectation that the human helmsman will be receptive to requests to intervene and to system failures and will respond appropriate navigation tasks, including collision avoidance”. This is the level of automatization that could have an influence on crew requirements and could justify certain reductions.

[1] „Draft definitions on various forms of automated navigation by the Central Commission for the navigation on the Rhine”

2.3 REQUIREMENTS FOR THE VESSEL TRAIN ONBOARD-SYSTEM

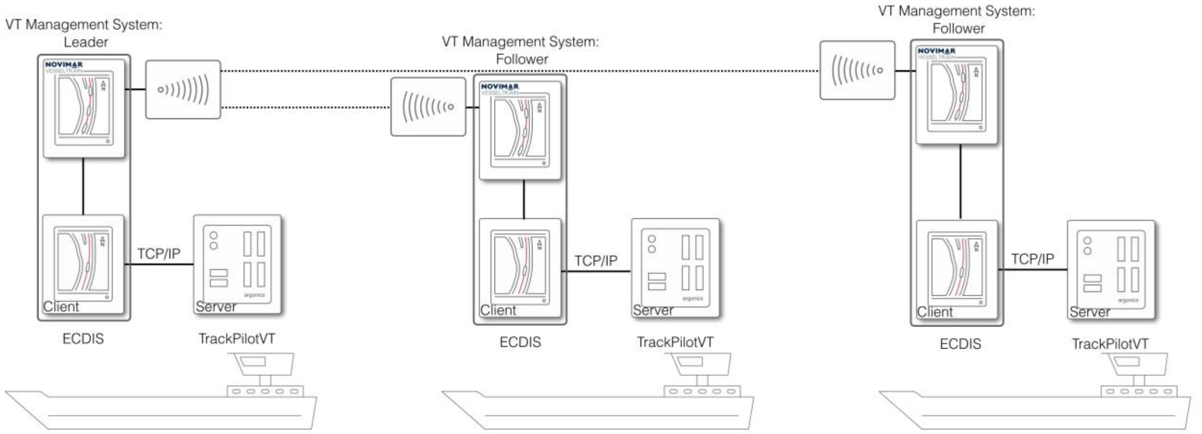

Figure 1: VT Control system

2.3.1 General requirements

To gain safety, flexibility, and keep the system architecture comprehensible, the command module equipment shall be identical on all VT units. A logical consequence is that any equipped vessel will be able to operate as leader vessel or as follower vessel from technical point of view. The equipment shall make use of existing sensors and actuators. During the project it is to be evaluated, if the standard equipment is sufficient for running the VT, or which additional equipment is needed like e.g. bow-thruster control, additional GPS systems or compass units. Compared to standard equipment, we expect at least Inland-AIS and a GPS compass to be mandatory and in cases bow-thrusters to improve stopping capabilities.

Additional communication devices to link the VT members will be mandatory. The technology in use for these communication devices will highly depend on the amount of data traffic exchanged between the VT units. The design approach therefore will narrow down communication bandwidth. As a consequence the single VT unit will need to have artificial intelligence (AI) to a certain extent to operate the VT member with a minimum communication exchange to the VT leader. However this AI of a VT member shall always react predictably, so the VT as a whole will react predictably and reliably to be manageable for the VT operator during normal operation.

In hazard situations, where the AI is not able to control the vessel in a predictable way, an emergency manoeuvre is raised and a human on board (or remote) will have to intervene. Research of remote controlled vessels is not part of the work done in WP3. However, existing remote controlled vessels or even autonomous vessels could be easily included in the system.

As result of model tests performed in the scope of WP3, it appears also that the distance between two vessels in a VT should not be too close. At a distance of about 100 m or approximately one ship length, negative hydrodynamic influences of the LV are much reduced and course- and position-keeping will be easier for the FVs. Maintaining this minimum distance to vessels ahead is also common practice in inland waterway navigation today.

The distance between the VT vessels depend on the dynamics of the VT members and the technology used to link the vessel train units. Furthermore a VT maximum length might be necessary to be defined, so that a LV operator is still capable of sailing the train safely. WP3 will evaluate how the distance between a FV and the LV or a FV and another FV from a control point of view should be set. The distances kept as good practice in navigation should be considered. However this topic is part of the research done in the work package.

2.3.2 VT operation modes

The vessel train control and command module will provide two different operation modes to operate the vessel train:

- In assisted guidance, the VT follower will follow the path of the VT leader vessel, thus giving the operator the freedom to manually steer the VT around stationary objects (Figure 2). In assisted guidance mode the VT operator sails the leader vessel as if it was the vessel with the slowest dynamics in the train. This implies a very good knowledge about the reaction of each vessel in the train.

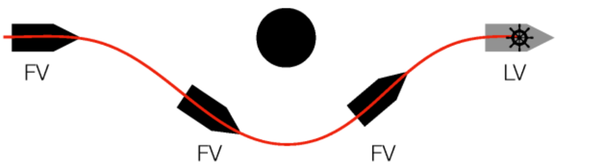

Figure 2: Operation mode “assisted guidance”

- In automatic guidance, the VT follows a guiding line as a whole. This mode assists the VT operator in handling of encountering traffic. He will have the additional freedom to influence the lateral offset to the guiding line (Figure 3) which is applied to all followers immediately. Means will be provided to automatically adjust the lateral offset individually on the follower vessels, if the VT relevant fairway is not wide enough.

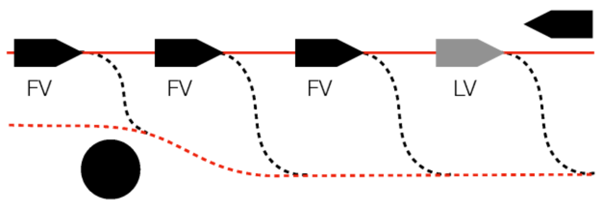

Figure 3: Operation mode “automatic guidance”

2.3.3 Requirements for the display and command module

To benefit from the central system role of a chart based navigation system, the command module is integrated in an Inland ECDIS navigation system. For short sea going vessels, we expect the presence of an Inland ECDIS system on the navigation bridge, as e.g. radar resolution is much more ambitious in respect to target separation. WP3 will not analyse the option of adding the command module within a type approved chart radar system, as this is not a technical question but rather a question of regulations. These regulatory issues will be partly covered by WP 5 but will also need to be continued beyond NOVIMAR. The display module of a single vessel shall provide information about the vessel train positions and surrounding traffic, it therefore provides a visual feedback of the positions of all members of the vessel train and the leader vessel as overlay in the navigation system. It shall present the current radar image and AIS data according to the Inland ECIDS standard to provide highest safety standards. The system displays the guiding line when the vessel is guided automatically. To increase safety and assist the vessel train operator, the command module implements a collision avoidance functionality which triggers a warning to the crew in case of an imminent collision.

The display module shall show the current status of the own ship equipment as well as the status of the VT related equipment and the safety status of the other vessels, if applicable. The status will include:

- Automatic Guidance active (System state OK)
- Assisted Guidance active (System state OK)
- System errors (communication error, internal system error – e.g. measurement or actuator system unreliable, control system error, end of guiding line).
- If a ship requires supervision of safety related functions, the status of these functions is interfaced and mapped to a VT safety related alert. (e.g. fire detection system, cargo temperature, etc.)

VT specific alerting shall be available. If in a hazardous situation the VT operator or a crew member on a follower vessel decides to wake up the crew on the other vessels, an alert function shall be provided to do so. The display module shall provide means to acknowledge alerts by human interaction. Furthermore, in certain situations, it is necessary to automatically alert the crew of the own ship. This comes true when the communication link to the other vessels is down, the system status of one of the predecessor vessels is in error state, the system status of the own system is in error state and for the leader vessel when an imminent collision of one of the follower vessels is detected. Furthermore it is evaluated if certain information from the controller is necessary for the operator of the VT to sail the train during normal operation. Therefore, VT related system warnings shall be exchangeable (e.g. max engine power reached).

The VT display module shall provide means to assist the VT operator in coupling and decoupling a VT follower. It shall provide means to handle electronical request of membership in the train, to acknowledge or reject a request and to release membership again.

2.3.4 Requirements for the Control Module

The objective of the VT control system is to follow a desired path (lateral control) while keeping a desired distance to the next vessel (longitudinal control) within the VT.

Longitudinal control

Minimum distance: The minimum distance between the vessels within a VT is such that an emergency manoeuvre of any vessel within the VT will not lead to a collision within the VT. This requirement will be addressed under the assumption that the stopping capability of all involved vessels is known and under the assumption that the follower vessel does not receive dedicated information about the emergency stopping. The actual minimum distance consists of two parts: One which depends on the difference of the stopping capabilities of the two vessels and another which depends on the longitudinal control system.

Stopping manoeuvre: The automatic stopping up to a speed through water of zero is possible. The automatic stopping of vessels going downstream may involve the use of bow thrusters in order to keep the lateral distance within the specified limits. This greatly increases the complexity of the control system. A technical solution to stopping (speed against ground = 0) while going downstream or at stream speed of zero may require further research. The detailed needs will be determined until midterm at M24.

Longitudinal deviation from setpoint under normal conditions (longitudinal velocity > 5km/h, longitudinal acceleration 0, Rhine between km 400 and 980): Less than 0.5 ship lengths (95% of the time)

Lateral control

Static objects listed in the electronic nautical chart (ENC) such as bridge pillars, buoys etc. are avoided by the track selected by the LV and static objects which are not listed in the ENC are avoided by intervention on board the LV.

The meeting and passing of other vessels are possible by intervention on board the LV.

Lateral deviation from set point under normal conditions (longitudinal velocity > 5km/h, longitudinal acceleration 0, Rhine between km 400 and 980): Less than 10m (95% of the time).

2.4 DETAIL SCENARIOS TO PREPARE CONTROL SYSTEMS AND DEMONSTRATIONS

The development plan of the vessel train concept includes various tests and demonstrations with different methods and tools, used with an increased level of technology readiness:

- Manoeuvring simulations
- Fast-time manoeuvring simulations
- Full mission bridge simulations
- Towing tank tests
- Full scale demonstration

Figure 4 shows the planned sequence of the step-by-step examination of the VT concept on the basis of the methods mentioned.

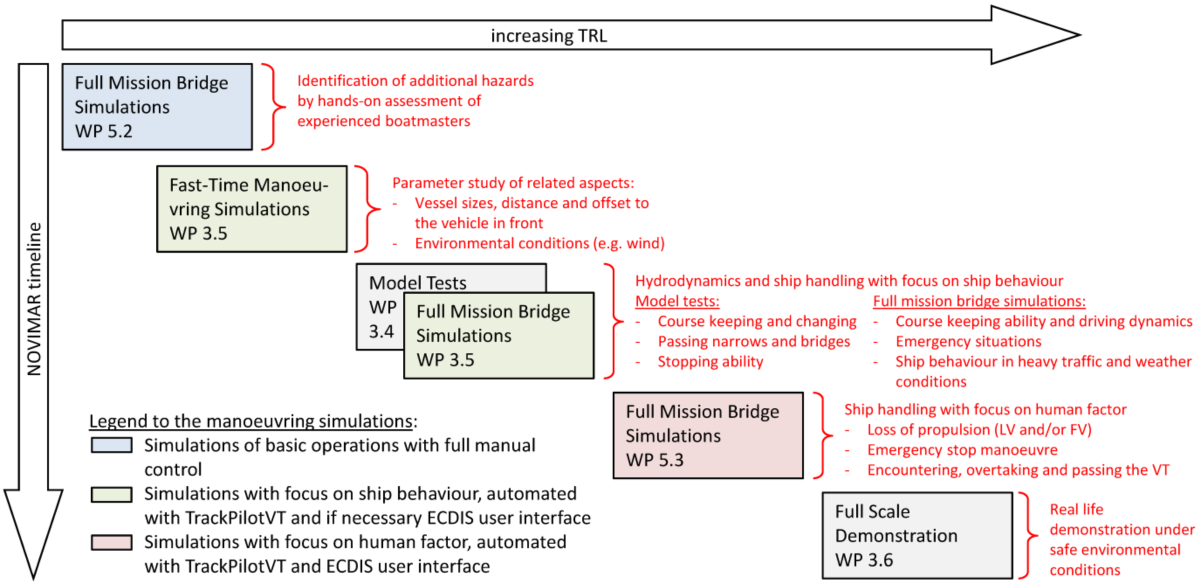

Figure 4: Description and procedure of the research methods

According to the time schedule of the NOVIMAR project, the demonstrations on simulators will be performed within 2019 and the full scale demonstrations will start in 2020.

The simulations with manually steered vessels can be carried out without any prerequisites. For later automated simulations and model tests, the TrackPilotVT system must be available for each vessel. This system is usually controlled by the ECDIS system (RadarPilot720°). Initially, the TrackPilotVT can also be controlled from outside, but a complete ECDIS system should also be available on all vessels involved for advanced simulations and the large-scale demonstration. Given the limited number of available devices all demonstrations should be performed on up to three different vessels.

For each of the planned demonstrations a scenario, for example a sequence of situations and boundary conditions, has been elaborated. They are assigned to different TRLs of the vessel train control system and should be applied in the proposed order to develop and test the system with increasing complexity and avoid redundant tests.

A long list of situations was derived from the hazard identification study within WP 5. Many of these situations share the same requirements and reactions of the control system. Therefore, the long list was reduced to a few basic situations and discussed regarding the best suited time and tool for the demonstration. The results are summarized in Table 2 below.

Table 2: Conditions and situations selected for different demonstrations

Case: Navigation under normal conditions	SHS Non-auto-mated	Fast time SHS	Model tests	SHS focus on ship behaviour	SHS focus on human factor	Full scale demonstration
Vessels with differing size, speed and manoeuvring capabilities	X	X				
VT (two or more vessels): Straight course, bend, narrow passage, bridge passage	X	X	X	X		X
Coupling and decoupling of FV to the LV	X			X		X
Encountering traffic		X		X	X	
Passing vessels		X		X	X	
Stopping		X	X	X	X	X
Case: HAZID (Emergency and handling of risk)						
Stopping of the VT as emergency			X	X	X	
Loss of propulsion of LV					X	
Loss of propulsion of FV					X	

At least two vessels with crew are required to perform full scale tests under realistic operation conditions. The test sector of the inland waterway should include some of the more difficult operation conditions, such as current, shallow water, river bends and bridge passages.

The demonstrators have to be equipped with all necessary devices operating as a vessel train. One of the vessels will be the leading vessel and human operated. The other will follow as a participant of the vessel train, controlled by the TrackPilotVT. The operation of the follower will be surveyed by the vessel crew who will be able to interfere at any time.

2.5 DEFINE STANDARD PROCEDURES

Standard procedures have to be defined for the tasks referred to as “common navigation tasks”. The standard procedures have to be able to perform continuously and without human intervention the following tasks:

- Avoiding traffic, traffic with other IWT vessels may be encountering, passing or even crossing.
- Passing bridges, this is a special case of track-keeping, as the lateral control has to be maintained with much less tolerance. A precise passing of the narrow bridge requires a good knowledge of the local conditions,
- Navigating narrow, shallow and/or bendy waterways
- Self-Check, of the VT system, supervision by leader vessel

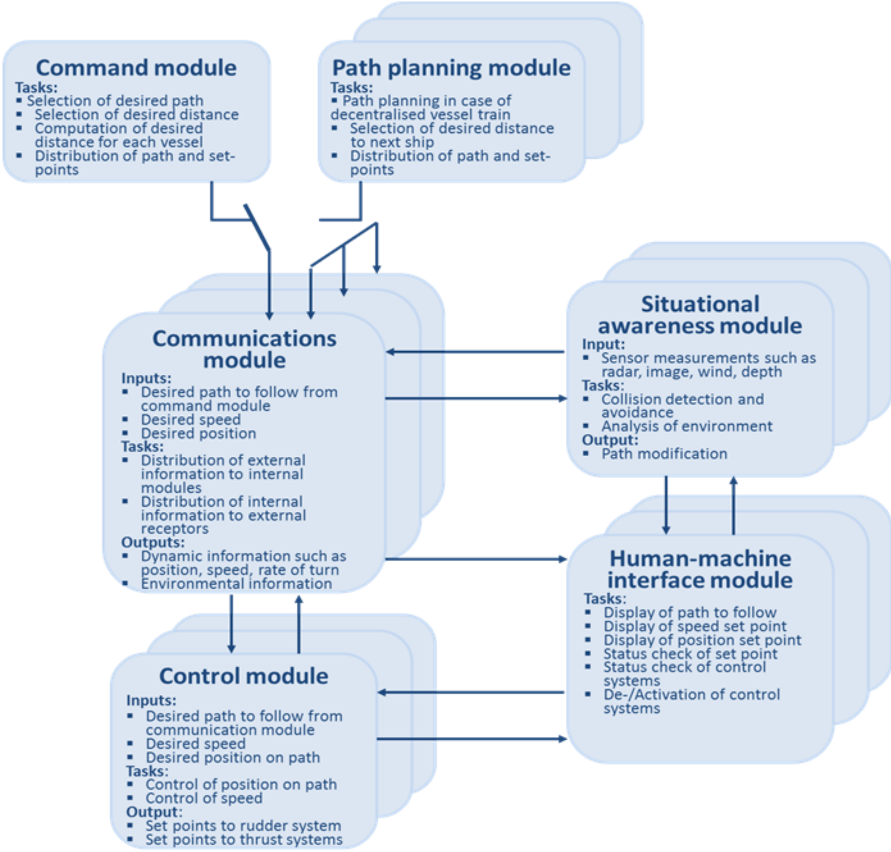

Figure 5: Modular architecture for handling of standard procedures

A modular architecture, as outlined in Figure 5, is most suitable for handling these complex requirements.

2.6 DEFINE COMPLEXITIES OUTSIDE THE SCENARIOS

The investigation of special operations from Deliverable 1.1, if they are not part of "common navigation tasks", is discussed in the following Table 3. In the event of malfunctions, it is assumed that either the crew on board will take over control of the ship or the ship will be remote-controlled from shore via a control centre. This means that decisions on emergency situations are always made by qualified persons.

Table 3: Dealing with "Special Operations" from Deliverable 1.1

Special Operation	Further handling of this task
a. Docking/undocking at terminal, loading & unloading cargo	Part of the transport system model in WP 2 and standard operation of the vessels outside the VT, no relevance for smart navigation or safety issues and human skills
b. Joining/leaving a train	Part of ship handling simulations in WP 5.2, WP 3.5 and WP 5.3 and the full scale demonstration in WP 3.6
c. Passing locks	Part of the transport system model in WP 2. The requirement is that methods have to be described to handle this situation with a reduced crew.
d. Loss of control	Part of ship handling simulations in WP 3.5 and WP 5.3
e. Anchoring in case of a calamity	No automatic decisions of the VT system are included. Emergency manoeuvres are considered in WP 5.3.
f. Countering calamities underway, including emergency manoeuvres	No automatic decisions of the VT system are included. Emergency manoeuvres are considered in WP 5.3.
g. Embarking & disembarking vessels	Crew embarking & disembarking vessel during navigation at normal speed remains difficult to handle in case of reduced crew. Should not be part of VT operation concepts.

The assembly of the VT as combination of vessel sizes and types will be subject to some restrictions, as the VT should be navigating as a well-fitting combination of vessel properties in terms of:

- Port of origin, port of destination
- Draught and air draught of the vessel
- Speed and manoeuvrability

An exchange platform will have to be created in the scope of NOVIMAR to make these vessel data available to the LV. In the form of an exchange system, offer and demand can then be matched in order to make a favourable combination of the VT possible.

3 CONCLUSIONS AND RECOMMENDATIONS

The NOVIMAR project researches the vessel train, a waterborne platooning concept featuring a manned leader ship and a number of follower ships that follow at some distance by automatic control. The vessel train concept is a totally new approach for inland waterway and short sea transport. Thus, the setting of requirements is crucial. In task 3.1 the navigational requirements and procedures of the VT have been assessed and are summarized within this report. This includes the analysis of the existing fleet and waterway infrastructure and the regulatory framework. The concept of the VT controller and the HMI were outlined.

In current nautical practice of IWT, boatmasters keep a distance of about one ship length. For safety reasons it seems advisable to use at least this distance in the VT. To decelerate a ship quickly in an emergency situation, the propulsion has to be reversed. This is far more complex than braking a truck and strongly depends on the equipment of each ship. Inland vessels have to prove a stopping capacity for a maximum stopping distance of 350 or 305 m without current depending on the ship size. Seagoing ships may require even up to 20 ship lengths. While a helmsman can combine stopping with changing the course to avoid a collision, this is extremely challenging for an automated control system.

Vessel trains with several following vessels may have a great total length and should not be crossed by other traffic. This is a simple safety rules that was in older times applied for towed barge convoys. The leading vessel will communicate this specific property to the surrounding traffic.

Fuel consumption of the transport is not reduced by platooning on waterways directly. However, energy efficiency can be improved by an optimized speed and track choice according to the waterway conditions. The largest savings can be achieved by slow steaming, which becomes viable as soon as personal costs are reduced by VT automation.

The complex VT concept needs to be developed in an iterative manner taking into account numerous different aspects. This requires proper coordination of the work performed in the different work packages of NOVIMAR. Several tools like full mission bridge simulators, scaled model tests and a full scale demonstration are foreseen at different technology readiness levels. The sequence and objectives of these demonstrations have been aligned in task 3.1 and are reported here. More details will be elaborated in the coming tasks, with some already started.

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5 ANNEXES

5.1 Annex A: Public summary

The NOVIMAR project researches the vessel train (VT), a waterborne platooning concept as a new transport system for inland waterway and short sea transport. The VT is a service that has to be competitive with other means of transport. In order to be competitive, NOVIMAR has to show the economic and operational feasibility, while meeting safety requirements. In task T3.1 of WP3 the detailed system requirements were determined and procedures and assumptions for the VT-development were defined. In addition, a roadmap for the scenarios to be demonstrated in T3.5 and T3.6 at different TRLs was set up.

The main technical and nautical requirements for the new system were worked out as one of the first steps in the work package WP3 of the research project. For the economic viability cost savings are essential. Referring to the operation with “reduced crew”, it is most important that the crew of the follower vessels (FV) shall not be called upon the bridge to perform common navigation related tasks. Only one crew member should be present to handle emergency situations to meet the safety requirements, but during regular sailing has no role. Once “hooked” to the vessel train, the boat master of the FV will be off duty and his/her presence not required at the helm of the vessel. Without any activity of the FV crew, the following actions are continuously performed by the assisting systems available on the FV:

- Track keeping as defined by leading vessel
- Track keeping as defined by LV, this includes narrow passages as bridges
- Distance keeping to LV, or the FV in front
- In case of necessity, initiation of stopping manoeuvre

Once coupled to the VT, action of the boat master of the FV is required only in case of:

- Approaching the destination port, leaving the VT
- In an emergency manoeuver
- Any malfunction on board
- Passing locks

Referring to recent discussions on CCNR level, the required level of automated navigation on board of the follower vessel should be “Conditional automation: the sustained context-specific performance by a navigation automation system of all dynamic navigation tasks, including collision avoidance, with the expectation that the human helmsman will be receptive to requests to intervene and to system failures and will respond appropriate navigation tasks, including collision avoidance”. This is the level of automatization that could have an influence on crew requirements and could justify certain reductions.

Name of responsible partner: Development Centre for Ship Technology and Transport Systems

Name of responsible person: Benjamin Friedhoff

Contact info: friedhoff@dst-org.de

5.2 Annex B: Fleet, Waterways and Regulations

European inland waterways

Nowadays approximately 19 000 vessels including passenger ships and lighters operate on the European network of inland waterways with its total length of almost 40 000 kilometres. These waterways are divided into navigable rivers, which may be free flowing or regulated with weirs and locks, lakes and artificial canals. The inland waterway network in Europe is categorised by the European Conference of Ministers of Transport (French: Conférence européenne des ministres des Transports, CEMT). These CEMT classes for large navigable waterways range from I to VII with increasing size. Class I to III are considered to be of minor or regional importance while class IV to VII allow larger vessels and international importance. The following **Table 4** gives a simplified overview of the waterway classes and corresponding vessels. Class I to III differ slightly for waterways east of Elbe. Figure 6 shows the categorised inland waterway network.

Table 4: Classification of European inland waterways

	Motor vessels				Pushed convoys				Height under bridges
Class	Length [m]	Width [m]	Draught [m]	Capacity [t]	Length [m]	Width [m]	Draught [m]	Capacity [t]	[m]
I	38.5	5.05	1.8 – 2.2	250 – 400					4.0
II	50 – 55	6.60	2.5	400 – 650					4.0 – 5.0
III	67 – 80	8.20	2.5	650 – 1000					4.0 – 5.0
IV	80 – 85	9.50	2.5	1000 – 1500	85	9.5	2.5 – 2.8	1250 - 1450	5.25
Va	95 – 110	11.40	2.5 – 2.8	1500 – 3000	95	11.4	2.5 – 4.5	1600 – 3000	5.25
Vb					172	11.4	2.5 – 4.5	3200 – 6000	5.25
VIa					95	22.8	2.5 – 4.5	3200 – 6000	7.0
VIb	140	15.0			185	22.8	2.5 – 4.5	6400 – 12000	7.0
VIc					270 195	22.8 33.0	2.5 – 4.5	9600 – 18000	9.1
VII					285	33.0	2.5 – 4.5	14500 – 27000	9.1

Germany, the Netherlands and Belgium are very well connected by the Rhine. The Rhine itself is a class VI waterway, the main tributary rivers are still class V waterways. Connecting waterways in South Germany to France are class I waterways. The connection from Antwerp to the Rhine via the Scheldt-Rhine canal is also a class V waterway. Inland navigation in Romania and Bulgaria benefits from the Danube, which is a class VII waterway in this region. The rest of the Danube almost up to Regensburg in Germany is a class VI waterway. However, there are several sections with water depths and bridge heights smaller than the values given in Table 4 limiting the use in IWT with large ships.

Figure 6: European inland waterways network (modified/legend enlarged from [1]**).**

- Fleet

The analysis of the fleet is important for the decision whether the vessel train concept can be integrated into the current system as foreseen or if new specific or substantially retrofitted ships are needed. New build vessels can be designed specifically for the VT concept, thus can be optimised for the operation in a VT and be more competitive. However, new vessels are a big investment and the implementation of the VT will rather be a smooth transition than a sudden introduction. Therefore, it should also be possible to use the VT concept in the current fleet. Thus, the existing fleet with its extreme diversity has to be considered. Vessel trains may be limited to a subset of the fleet fulfilling certain requirements. However, it should be avoided to exclude prevalent ship types. The characteristics and distinctive features need to be known and are presented in the following pages.

Short sea, small air-draught sea-river and river-sea vessels have to be considered and are obviously different from vessels operating on inland waterways. Sea-river vessels are ships that are built, certified and equipped according to the international regulations for sea-going ships. To navigate in suitable inland waterways these vessels have to fulfil corresponding rules additionally and to match the boundary conditions in general dimensions. Besides draught and lock sizes the most important limitation in most regions is the air draught to allow passing under bridges and overhead cables. Depending on the area of operation, requirements for ships navigating on inland waterways or at sea may differ significantly. Vessels linking these areas have to fulfil both. Crewing requirements, boatmaster certificates and exhaust gas emission limits also are different.

Sea-river transport is only possible on inland waterways of sufficient size and with access to the sea. According to the European River-Sea-Transport Union (ERSTU) [2], in Europe the following waterways are suited for sea-river transports:

- Rhine (Netherlands, Germany)
- Thames, Humber, Forth (United Kingdom)
- Albert-Canal-Route (Belgium)
- Seine to Paris, Rhone to Lyon (France)
- Guadalquivir to Seville (Spain)
- Göta Alv, Trollhättan and Södertälje Canal (Sweden)
- Saimaa Canal and Finnish Lakeland (Finland)
- Lower Danube (Romania)
- Sea of Azov and Black Sea, Caspian Sea with connected rivers

To achieve the goals of greenhouse gas emissions by transport and to shift freight from the road to rail and maritime transport the European Union promotes Short Sea Shipping (SSS). In recent years short sea shipping promotion centres (SPC) were established in most EU countries with sea ports. However, today data for SSS is still not as extensive as for inland navigation and even the terminology is often not consistent. Maritime, short sea, river-sea and sea-river shipping and/or ship designs are often separated from each other differently. Additionally, the definition of SSS can vary locally. To clarify the meaning of SSS in the context presented herein, the following EU definition is used:

“Short Sea Shipping means the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports and ports situated in non-European countries having a coastline on the enclosed seas bordering Europe. Short sea shipping includes domestic and international maritime transport, including feeder services along the coast, to and from the islands, rivers and lakes. The concept of short sea shipping also extends to maritime transport between the Member States of the Union and Norway and Iceland and other States on the Baltic Sea, the Black Sea and the Mediterranean.” [3].

The manifold boundary conditions of the waterways like water depth, width, lock size and bridge height have caused a huge variety of vessels in the existing fleet. This is increased by the extreme longevity of the vessels, which may be lengthened or even widened within their life span. The average age of German cargo vessels today is 45 years (see [4]). Serial production of inland ships is virtually non-existent. The growing number of coupled convoys adds to the complexity of the fleet. Several national and international databases (like the German waterway authorities, the IVR Ships Information System and the European hull database) exist and try to categorise the fleet with slightly different criteria and deviating numbers. An exemplary overview of the vessel size distribution per country is given in Table 5.

Table 5: Fleet structure of self-propelled barges with CEMT classes per country [Source: Eurostat and CCNR]

	Total*	< 250 t	250-399 t	400-649 t	650-999 t	1000-1499	1500-2999	>3000 t
			CEMT I	CEMT II	CEMT III	CEMT IV	CEMT V	CEMT
Rhine								
Belgium	874	32	203	99	130	244	203	111
Netherlands	3.703	336	297	556	778	768	716	252
Germany	1.168	27	51	44	190	514	436	22
Luxembourg	nD	nD	5	3	3	10	8	nD
Switzerland	13	nD	1	nD	1	22	61	5
Danube								
Austria	nD	1	2	2	15	8	6	nD
Bulgaria	31	0	1	0	0	16	7	0
Croatia	19	2	3	nD	2	5	nD	nD
Slovakia	31	3	0	1	2	8	6	3
Hungary	70	5	10	18	24	9	6	0
Romania	107	0	0	0	0	0	5	0
France								
France	804	3	430	124	141	118	74	16
*Due to different sources and time of data the total numbers may not fit sum of detailed numbers.								

This structure shows the huge variety of ship sizes, which is characteristic for IWT. There is no dominant size class. Even ships with the same principal dimensions often have very different engine power and draught. Hence, a VT should not be limited to similar ships. Especially in confined waterways the different hydrodynamics lead to different speeds for safe and easy navigation.

Within WP2 relevant vessels were selected for the first case studies. Their general particulars are listed in Table 6 and Table 7.

Table 6: Selection of typical IWT ships

IWT class	Length [m]	Width [m]	Draught [m]	Air draught [m]	Tonnage [t]	Installed Power [hP]
Class II (Kempenaar)	50-55	6.60	2.50	3.70-4.70	400-650	350-500
Class IV	85.0	9.50	2.50	4.50-6.70	100-1,500	1.200
Class V	110	11.40	2.50-4.50	4.95 - 6.70 - 8.80	1,500-3,000	1.500

Table 7: Data of representative sea-river and short sea container ships

Vessel name	Length [m]	Width [m]	Draught [m]	Air draught [m]	Tonnage [tonne][1]	Design Speed [knots]	Installed Power [kW]
Lady Anna	88	13.35	4.90	n/a	3000	10	749
Pachuca	139.81	19.64	7.30		9235	17.2	7200
Maike D	133.24	18.70	8.40		7944	23.6	nD
Arklow River	84.98	14.00	5.68		4530	12.0	1800

Where possible, it will be tried to cover similar ships and corresponding compositions of the VT in the demonstrations. If matching vessels are not available, it will be ensured that the corresponding differences (speed, size, manoeuvring capability etc.) are covered.

Regulations for safe navigation in IWT

In this chapter current regulations on inland waterways are summarized and assessed regarding their relevance for the VT concept.

- **Speed**

For every VT and according to the environmental conditions the sailing speed must be selected so that every vessel in the VT can follow. The European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN) prescribes in §5.06 for every vessel a minimum velocity of 13 km/h against water (see [5]). This speed requirement will have to be fulfilled for all vessels participating in a VT.

- **Distance, stopping and turning**

To ensure a safe and economic operation, a carefully defined distance is essential. This is not only needed in cases of emergency, but rather for normal stopping to avoid collisions. The stopping capacity is also checked in the navigational test and depends on the type and size of vessel (see ES-TRIN instruction ESI-II-3). The allowable stopping distance under standard conditions sailing downstream must be smaller than 550 m or 480 m, depending on the size of the vessel/convoy and therefore this has to be considered when calculating a suitable distance between ships.

Nowadays, the turning capacity is checked during the navigational test. Depending on the type of vessel the turning speed and the maximum time to reach it at shallow and deep water are prescribed (see ES-TRIN ESI-II-4). Depending on the water level, the evasive manoeuvre requires different times and space.

In addition, there are regulations for the distance between vessels marked with two or three blue cones transporting ADN products, RheinSchPV §6.17 (see [6]). While sailing parallel with such a vessel a distance of 50 m is required.

- **Encountering**

Encountering traffic on the river Rhine is organized by §6.04, §6.05 and §9.04 of the RheinSchPV. In most river sections the vessel sailing upstream is allowed to choose if the encountering side is port or starboard (blue sign regulation, see Figure 7). But there are exceptions where the downstream sailing vessels may choose the side of encountering.

Figure 7: Vessels passing on starboard and showing the blue sign

- **Local regulations**

On some waterways local regulations are relevant. For example on the river Rhine there are locations where encountering traffic of pushed convoys with L > 186.5 m and B > 22.90 m and vessels larger than 110 m is not allowed (RheinSchPV §9.09). Another example is the maximum width of a vessel between Bingen (Rkm 528.5) and St. Goar (Rkm 556.0) which is restricted to 17.7 m (RheinSchPV §11.01).

- **Regulations for towed convoys**

On the river Danube, DonauSchPV § 6.15, it is not allowed to enter the gaps of a towed convoy. This is a simple safety rules that was in older times applied for towed barge convoys.

- **Operational modes; working and resting**

There are very different conditions on how working time of the crew members are distributed. A main topic is the operational mode of the vessel. On the river Rhine there are the operational modes A1, A2 and B. In combination with the equipment standard (S1/S2) and the type and size of the vessel, they define the crewing requirements. Operational mode B is 24 h continuous operation. In mode A1 the operational time of the vessel is 14 h and in mode A2 the operational time is 18 h. In addition, there is a night rest between 22:00 and 6:00 for operational mode A1 and from 23:00 to 5:00 in mode A2 (RheinSchPersV §3.10). For vessels with tachograph, the night rest could be moved forward or backward.

The maximal working time is 14 h per 24 h, 84 h in seven days and 48 h per week as average in twelve months (e. g. BinSchArbZV §4). Working time at night, between 23:00 and 5:00 is restricted to 42 h in seven days. Because of the individual working time of a crew member the rest time is also individual. Within 24 h a minimal rest period of 10 h is required and an uninterrupted rest of 6 h must be included. In addition, 84 h rest are required in seven days (BinSchArbZV §6). In addition the limits for noise nuisance differ between operation and rest.

- **Land-based traffic surveillance**

On the river Rhine between Oberwesel (Rkm 548.50) and St. Goar (Rkm 555.43) a land-based traffic surveillance exists. The river is divided into parts and with traffic lights the encountering traffic is signalled. The explanation of the signals and the prescribed behaviour, depending on type of vessel, is given in ReinSchPV §12.01 - §12.03. In current regulation the vessels are categorised in convoy or single vessel with a length upper or lower 110 m.

- **AIS / ECDIS**

Two years after the implementation of the mandatory installation of inland AIS devices and electronic chart display systems on the river Rhine effective from 01. December 2014, the CCNR conducted an online survey to get feedback from groups like boatmasters, waterway authorities or enforcement and police authorities which are affected by the consequences (https://www.ccr-zkr.org/files/documents/ris/enq_Ais_e.pdf). The aim was to improve the safe navigation of the Rhine. More than half of the boatmasters reported problems with the AIS device and one third of the boatmasters reported problems with the electronic chart display. The reasons differ, but as a result, the AIS signal or the electronic chart display had wrong information or did not work properly. These technical problems in combination with the voluntary connection of the blue sign, i. e. the blue board and flashing white light used by the ships for special manoeuvres or passing on starboard side, with the AIS device add to confusion in handling encountering traffic situations. At the same time the systems may lead to reduced visual observation and to less VHF communication.

Regulations for safe navigation of seagoing and short sea vessels

Current international rules on construction, operation and navigation of seagoing vessels do not cover the operation of unmanned ships or ships operating in a VT. Moreover, the construction, operation and navigation of seagoing vessels is controlled and supervised by different international and national regulatory bodies compared to responsible regulatory bodies for inland vessels. Thus, a study on relevant rules and regulations for seagoing ships was carried out as well.

An overview of relevant institutions and associations and their relevant publications is given and followed by a detailed discussion of rules that may affect the VT concept or need to be adopted.

The International Maritime Organization (IMO) is a specialized agency of the United Nations (UN) which is responsible for measures to improve the safety and security of international shipping and to prevent pollution from ships.

The most relevant international conventions with respect to the VT concept including sea going vessels are found to be:

- International Convention for the Safety of Life at Sea (**SOLAS**), Chapter V – Safety of Navigation
- International Regulations for Preventing Collisions at Sea 1972 (**COLREG**), Rules 1 - 40
- International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978 (STWC)

- IMO Resolution A708(17) – Navigation Bridge Visibility and Functions
- IMO MSC/Circular.1053 – Explanatory Notes to the Standards for Ship Manoeuvrability

Another international regulation body is the international Association of Classification Societies (IACS) that aims on the harmonisation of existing rules and guidelines of member societies (e. g. DNV GL, Lloyds Register, Bureau Veritas etc.). To achieve this goal, so called *Common Structural Rules* (CSR), *Unified Requirements* and *Recommendations* are published. The corresponding publications predominantly address technical issues and requirements related to the ship design. However, the required manoeuvring characteristics (stopping, turning, course keeping etc.) of ships are also addressed.

A stronger link to navigational requirements is found in national regulations of the flag states. These regulations need to comply with *International Regulations for Preventing Collisions at Sea* (COLREG) and refer to specific *IMO Resolutions*. Traffic in restricted fairways, interactions between ships in terms of overtaking and encountering and navigational requirements are addressed and adapted to particular national maritime waterways. Therefore, changing national regulations with respect to navigational issues most likely requires a previous change of international rules and regulation by the IMO.

Two examples of national traffic regulations for seagoing ships are given here:

- German Traffic Regulations for Navigable Maritime Waterways (SeeSchStrO) published by the Federal Maritime and Hydrographic Agency, Germany.
- The Merchant Shipping (Distress Signals and Prevention of Collisions) Regulations 1996 published by Maritime and Coastguard Agency, UK.

- **Minimum distances between seagoing ships**

The German Traffic Regulations for Navigable Maritime Waterways defines minimum distance for the Kiel Canal in Germany. The Kiel Canal represents a realistic operational area for VTs including seagoing vessels and mixed VTs with seagoing vessels and inland vessels.

“(1) At locations other than the sidings and locks forming part of the Kiel Canal – except for stretches of water extending for a length of 1000 metres in front of, and 2000 metres behind, the limits of sidings:

- *vessels of vessel categories 1, 2, and 3 shall keep a distance of not less than 600 metres*
- *vessels of vessel categories 4 and above shall keep a distance of not less than 1000 metres from any vessel navigating in front of them,*

unless they are in an overtaking situation as described in Section 23(4) or (5) above.

(2) The minimum safe distance to be kept from vessels of less than 20 metres in length may be less than that prescribed in the foregoing paragraph.”

Vessel categories 1, 2, 3 define the ship lengths up to 55 m, 85 m and 140 m, respectively. The category 4 represents ship lengths up to 160 m. VT operation has to find a way how to handle these requirements and/or to obtain derogation from the existing rules.

The German Traffic Regulations for Navigable Maritime Waterways defines common Sailing Rules in Part Four:

“The overtaking vessel, acting in compliance with the provisions of Rule 9(e) and Rule 13 of the International Regulations for Preventing Collisions at Sea, 1972, as amended, shall slacken her speed so much, respectively, shall give the vessel being overtaken such a wide berth that no dangerous suction or wash can develop and that no vessel proceeding in the opposite direction will be put at any risk for the entire duration of the overtaking process. The vessel being overtaken shall facilitate the overtaking vessel’s action to the greatest possible extent.”

“Where, in a fairway, safe overtaking may only be done with the active co-operation of the vessel to be overtaken, no overtaking shall be permitted unless the vessel to be overtaken has given her unambiguous consent upon the request or the indication by the overtaking vessel of her intention to overtake. In derogation of the provisions of Rule 9(e)(i) of the International Regulations for Preventing Collisions at Sea, 1972, as amended, the overtaking vessel may indicate her intention to overtake via VHF radiotelephony to the vessel to be overtaken in the following circumstances:

1. *All participants in the communication process are unambiguously identified by all other participants.*
2. *An unambiguous understanding and agreement can be achieved through VHF radiotelephony.*
3. *…”*

These rules raise the questions, whether the leading vessel and its crew is allowed to represent all participating vessels and if so, is the leader able to judge that the overtaking process is safe for all involved vessels.

- **Right of way of ships in a fairway**

The German Traffic Regulations for Navigable Maritime Waterways defines the rights of way of ships in a fairway. A fairway

“…denotes those parts of navigable waters that are marked or delimited by any one or more of the visual signs described under Items B.11 through B.13 of Annex I to the present Ordinance or, when they are not so marked or delimited, those parts of such waters <u>that are designated for the through passage of vessels to or from inland waterways</u>; any such fairway shall be deemed a “narrow channel” in terms of the International Regulations for Preventing Collisions at Sea, 1972, as amended;

(2) A vessel proceeding along the course of the fairway channel, irrespective of whether or not she can safely navigate only within the fairway channel, shall have the right of way over vessels

1. *entering that fairway,*
2. *crossing that fairway,*

3. *making turns in that fairway*
4. *leaving their anchoring or mooring grounds*

…

(4) A vessel navigating in a fairway, whether or not she is actually proceeding along the course of the fairway channel, shall have the right of way over vessels entering that fairway from a fairway branching off or joining it.

These rules are reflecting good practice in safe navigation and should be taken into account by the operation methods of a VT.

- **Stopping capability**

An indication of the stopping distances of seagoing ships is given by Lloyd's Register Rules and Regulations, *Rules and Regulations for the Classification of Ships, July 2016 - Part 5 Main and Auxiliary Machinery - Chapter 1 General Requirements for the Design and Construction of Machinery - Section 5 Trials:*

"The stopping distance achieved when ship is initially proceeding ahead with a speed of at least 90 per cent of the ship's speed corresponding to 85 per cent of the maximum rated propulsion power should not exceed 15 ship lengths after the astern order has been given. However, if the displacement of the ship makes this criterion impracticable then in no case should the stopping distance exceed 20 ship lengths."

Even if the ship's speed of a vessel, that is part of a VT, can be assumed to be less than the speed that is addressed by the rule, the permissible stopping distance is high compared to the probable distance between ships or rather compared to the maximum permissible stopping distance of inland vessels (305 – 550 m).

- **Linking inland and maritime waterways**

Generally, inland vessels are not allowed to navigate outside of the inland waterways. Some exceptions are defined by local authorities and requirements from classification societies. The United Nations Economic Commission for Europe (UNECE) tried to standardise the requirements for vessels operating in estuaries and areas with moderate waves regarding strength, stability and freeboard by the definition of zones 1, 2 and 3. Zone 1 implies significant wave heights (with the unconventional definition of H1/10 instead of H1/3) of up to 2.0 m while zones 2 and 3 are limited by 1.2 and 0.6 m, respectively. An excellent and more detailed overview of the non-uniform status quo of river-sea solutions is given by Vantorre et al. [7]. Today the number of inland vessels certified to operate in these areas and even the number and size of the areas where their navigation is allowed are very limited.