

## **Innovative Manoeuvring Support - From Today's Shipboard Organisational Structures to Shore-Controlled Autonomous Ships**

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On ships with high safety level and a high portion of manoeuvring activities within ships operation the shipboard tasks and procedures have been changed to high back-up procedures as in air planes. For port manoeuvres e.g. the system of pilot/co-pilot was introduced on ferries in a sense that one officer is operating and the other is monitoring and checking the safe performance. In cruise-liner operation there are even new structures replacing the traditional rank-based system with a flexible system based on job functions. The main purpose for this change is to create a safety net around the person conning the vessel, in order to detect and manage any human errors before they lead to negative consequences. Each operation is cross checked before execution by one or two persons depending on circumstances. The consequence is higher costs for double personnel on the one hand and the need for a technology to guarantee that the checking officer is able to monitor what the conning officer is doing on the other hand. This is hard to do if one officer is working out in the wing and the other one is inside the bridge. This opens up chances for the application of the new “Fast-Time Manoeuvring Simulation Technology” (FTS) developed at the Institute for Innovative Ship Simulation and Maritime Systems (ISSIMS). It calculates within one second of computing time up to 1000 seconds of manoeuvring time by a very complex ship-dynamic simulation model for rudder, engine and thruster manoeuvres. This enables the online prediction of all manoeuvres carried out by the conning officer for the observing officer, too. So it is easy for both officers to see whether the manoeuvring actions have at least the correct tendency and even more the effectiveness of the manoeuvres can be improved. This new type of support is called Simulation-Augmented Manoeuvring Design and Monitoring (SAMMON) – it allows not only overlooking the next manoeuvring segment ahead but also for the following or even for series of manoeuvring segments.

Currently, this technology is used within two new research projects:

The Project COSINUS (Co-operative Ship Operation in Integrated Maritime Traffic Systems) sets out for implementing the FTS technology into integrated ship bridges and to also communicate the manoeuvre plans and display it to VTS centres and

Within the European project MUNIN (Maritime Unmanned Navigation through Intelligence in Networks) this technology will be used to investigate if it is possible to steer autonomous ships where the information for manoeuvring the ship will be delayed due to the communication links.

For practical application and testing, the new technology was interfaced to the ship-handling simulator (SHS) at Maritime Simulation Centre Warnemuende (MSCW). During the research activities it became obvious that the new FTS technology has also great potential for teaching and learning in the maritime education both for lecturing and simulator training in briefing and debriefing sessions of exercises.

## KEYWORDS

- Simulation-augmented manoeuvring
- Fast-time simulation, FTS
- Dynamic prediction methods
- Manoeuvre planning
- Simulation Augmented Manoeuvring Design and Monitoring, SAMMON
- Institute for Innovative Ship Simulation and Maritime Systems, ISSIMS

## 1. INTRODUCTION

During the previous INSLC 17 conference in 2012 [7] a fast-time simulation tool box was introduced to simulate the ships motion with complex dynamic models and to display the ships track immediately for the intended or actual rudder or engine manoeuvre in the ECDIS. These “Simulation-Augmented Manoeuvring Design and Monitoring” - SAMMON tool box will allow for a new type of design of a manoeuvring plan as enhancement exceeding the common pure way-point planning – and it will play an important role in future education and training in simulators for ship handling.

Also during this INSLC 17 conference new concepts were presented for innovative organisational structures specifically for bridge management [8].

This paper presents the potential of the new method specifically for the support of manoeuvring of ships both for the new manning concept and even for shore-based support or moreover for autonomous ships. Manoeuvring of ships is and will be a human-centred process despite of expected further technological developments. Most important elements of this process are the human itself and the technical equipment to support its task. However, most of the work is to be done manually because even today nearly no automation support is available for complex manoeuvres. Up to now there was nearly no electronic tool to demonstrate manoeuvring characteristics efficiently or moreover to design a manoeuvring plan effectively.

However, due to the new demands there is a need to prepare harbour approaches with complete berth plans specifically in companies with high safety standards like cruise liners. These plans are necessary to agree on a concept within the bridge team and also for the discussion and briefing with the pilot. For increasing the safety and efficiency for manoeuvring real ships, the method of Fast-Time Simulation will be used in future – even with standard computers it can be achieved to simulate in 1 second computing time a manoeuvre lasting about to 20 minutes using innovative simulation methods. These Fast-Time Simulation tools were initiated in research activities at the Maritime Simulation Centre Warnemuende (MSCW) which is part of the Department of Maritime Studies of Hochschule Wismar, University of Applied Sciences - Technology, Business and Design in Germany. They have been further developed by the start-up company Innovative Ship Simulation and Maritime Systems (ISSIMS GmbH [6]).

A brief overview is given for the modules of the FTS tools and its potential application:

- SAMMON is the brand name of the innovative system for “Simulation Augmented Manoeuvring Design & Monitoring”. It is made for both:
  - o Application in maritime education and training to support lecturing for ship handling to demonstrate and explain more easily manoeuvring technology details and to prepare more specifically manoeuvring training in ship-handling simulators (SHS) environment and

- Application on-board to assist manoeuvring of real ships e.g. to prepare manoeuvring plans for challenging harbour approaches with complex manoeuvres up to the final berthing/unberthing of ships, to assist the steering by multiple prediction during the manoeuvring process and even to give support for analysing the result,
- And SAMMON contains the following modules:
  - Manoeuvring Design & Planning Module to design ships-manoevring concepts as “manoeuvring plan” for harbour approach and berthing manoeuvres (steered by virtual handles on screen by the mariner)
  - Manoeuvring Monitoring & Multiple Dynamic-Prediction Module: monitoring of ships manoeuvres during simulator exercises or manoeuvres on a real ship using bridges handles, display of manoeuvring plan and predicted manoeuvres in parallel. It calculates various prediction tracks for full ships-dynamic simulation and simplified curved-headline presentation as look ahead for future ships motion.
  - Manoeuvring Simulation Trial & Training Module: ship handling simulation on laptop display to check and train the manoeuvring concept (providing the same functions as monitoring tool; steered by virtual handles on screen)
- SIMOPT is a simulation-optimiser software module based on FTS for optimising standard manoeuvres and modifying ship math model parameters both for simulator ships and for on board application of the SAMMON system.
- SIMDAT is a software module for analysing simulation results both from simulations in SHS or SIMOPT and from real ship trials: the data for manoeuvring characteristics can be automatically retrieved and comfortable graphic tools are available for displaying, comparing and assessing the results.

The SIMOPT and SIMDAT modules were described in earlier papers ([1] for tuning of simulator-ship model parameters and also the modules for Multiple Dynamic Prediction & Control [2] for the on board use as steering assistance tool. In this paper, the focus will be laid on the potential of the SAMMON software supporting ship operations aboard and ashore.

## 2. FUNCTION-BASED BRIDGE ORGANISATION

The concept of Function-Based Bridge Organisation was introduced by Hans Hederstrom at the INSLC Conference in 2012 [8]. Acknowledging that all humans may make errors, the function-based bridge organization introduces organizational countermeasures to detect and manage human error before it leads to any negative consequence. It can help to remove hierarchical barriers and enhance teamwork and communication, if a traditional rank-based system has been replaced by a function-based bridge organization.

The function-based bridge organization does not diminish the authority of the Master. The Master assigns officers to the particular functions based on watch-keeper competence and experience with the upcoming operation, making it a very adaptable system.

The system builds on the airline concept by introducing Navigator and Co-Navigator functions. The Navigator who is conning the ship is required to communicate intentions and orders to the Co-Navigator. This means that no course changes or engine orders will be carried out without a confirmation from the Co-Navigator. These new protocols also require a double watch-keeping system with a minimum of two bridge officers on watch at all times the ship is at sea.

For ships with a single watch-keeping officer and a lookout on watch, the system may be somewhat more difficult to introduce. However, with trained and engaged lookouts there are definitely ad-

vantages to gain. When the Captain joins the bridge team, there is no problem to use the function based system. The best way to apply the system in this situation would be if the Captain takes on the function as Co-Navigator, leaving the watch officer to continue conning the ship. The following definitions were given.

## **2.1 FUNCTIONAL POSITIONS**

The following assigned tasks are included in these procedures (only extracted items specifically for manoeuvring aspects):

### **Operations Director**

- Overview of the entire bridge operation, ensuring that it is, at all times, carried out in accordance with these procedures.
- Provides guidance and suggestions to other members of the bridge team as necessary or appropriate.
- Direct monitoring of both the Navigator and Co-Navigator, ensuring that safe passage is maintained and that no internal or external influences are permitted to distract them from their primary tasks.
- If the Operations Director has the charge, s/he can assume any of the other functions at any time.
- Monitors workload and transfers tasks between functions as circumstances dictate.
- Unless directed otherwise by the officer with the charge, will conduct the Pilot exchange briefing.
- Responsible for checklist completion in Yellow and Red manning.
- If the Operations Director takes the conn, then the position of Operations Director must be re-established as soon as possible.

### **Navigator**

- Responsible for conning, navigating the ship following the approved passage plan and collision avoidance.
- Ensure that the bridge team (including the Pilot) is aware of planned actions and intentions by “Thinking Aloud”.
- If a pilot has the conn, the Navigator should ensure the Pilot’s intentions and planned actions are understood in advance by all bridge team members and agreed upon by the Navigator.
- If s/he has the charge, the Navigator is responsible for taking back the conn from the Pilot whenever s/he determines that doing so is necessary or appropriate for the safe navigation of the vessel.
- The Navigator should always foster a climate that encourages other members of the bridge team to challenge the Navigator if warranted.

### **Co-Navigator**

- Monitors and cross checks the actions of the Navigator.
- Supports, challenges, and recommends actions to the Navigator.
- Notifies the Master or Second in Command whenever s/he has reason to believe that the Navigator has taken or plans to take any action that violates the Master’s orders or is inconsistent with the safe navigation of the vessel.
- Monitors and cross checks the ship's position against the passage plan using real time navigation methods.

- Monitors traffic and collision avoidance.
- Unless directed otherwise by the officer with the charge, is responsible for external VHF (may be delegated to the Pilot) and liaison with the ECR.

#### **Administrator**

- Responsible for fixing the ship's position when paper charts are in use.
- Responsible for alarm management and actions. Alarms to be identified as either urgent or non-urgent alarm.
- Responsible for internal communications as directed.
- Responsible for logbook entries, checklist management and status board.
- Ancillary tasks as assigned.

#### **Lookout**

- Maintains all around lookout by sight and by hearing, reporting all sightings and/or sound signals to the Navigator, unless otherwise directed.
- Maintains awareness of planned intentions and reports any necessary clearances before an alteration of course.
- Must be able to give full attention to the keeping of a proper lookout, and no other duties shall be undertaken or assigned which could interfere with the task.
- Be available to interchange duties with the Helmsman. The duties of the Lookout and the Helmsman are separate. The Helmsman shall not be considered the Lookout while steering.

#### **Helmsman**

- Acknowledge and execute steering orders given by the person with the conn.
- Advise the person with the conn of any steering concerns.

## **2.2 THE CAPTAIN AS A LEADER INSTEAD OF AN OPERATOR**

It is up to the Captain to decide who should fulfil any of the four functions. A Risk Factors Table and a Risk Analysis and Bridge Manning Level Table have been developed to assist the Captain in deciding what manning level to set. Those manning levels are to be seen in Fig. 1. The philosophy behind the system encourages the Captain to assume the role of Operations Director, acting as a leader while the team undertakes the operation.

By delegating the operational tasks, he demonstrates trust in his team. This has many positive effects, such as:

- enhanced learning;
- readiness to actively participate in problem solving;
- enthusiasm and motivation to work; and
- an engaged team directly leading to increased safety and efficiency.

As officers are allowed to conduct the vessel, they will be better prepared for their promotion when time comes. This will normally also increase job satisfaction, which facilitates officers' retention rate.

Within this paper some elements are presented on how the communication within the bridge team can be supported by the Fast Time Simulation Modules of the SAMMON System.

### Required Functions at Each Bridge Manning Level

		Bridge Functions					
		Navigator	Co-Navigator	Administrator	Operations Director	Lookout	Helmsman
Bridge Manning Level	Green	Yes	Yes		No	Yes	As required
	Yellow	Yes	Yes		Yes	Yes	Yes
	Red	Yes	Yes	Yes	Yes	Yes	Yes

Green Manning: Minimum bridge manning required underway.

		Bridge Functions					
		Navigator	Co-Navigator	Administrator	Operations Director	Lookout	Helmsman
Bridge Manning Level	Green	Yes	Yes		No	Yes	As required

In Green Manning there is one officer assigned two functions (Co-Navigator and Administrator). His/her title is Co-Navigator.

Yellow Manning: Used in situations where indicated by the Risk Analysis and Bridge Manning Level Table.

		Bridge Functions					
		Navigator	Co-Navigator	Administrator	Operations Director	Lookout	Helmsman
Bridge Manning Level	Yellow	Yes	Yes		Yes	Yes	Yes

In Yellow Manning one officer is assigned two functions, Co-Navigator and Administrator. His/her title is Co-Navigator. Compared to Green Manning, the bridge team is strengthened by the Operations Director and another AB ready to assume function of helmsman at any time if required.

Red Manning: Always used for arrivals and departures and for all situations indicated by the Risk Analysis and Bridge Manning Level Table, or as deemed necessary by the Master.

		Bridge Functions					
		Navigator	Co-Navigator	Administrator	Operations Director	Lookout	Helmsman
Bridge Manning Level	Red	Yes	Yes	Yes	Yes	Yes	Yes

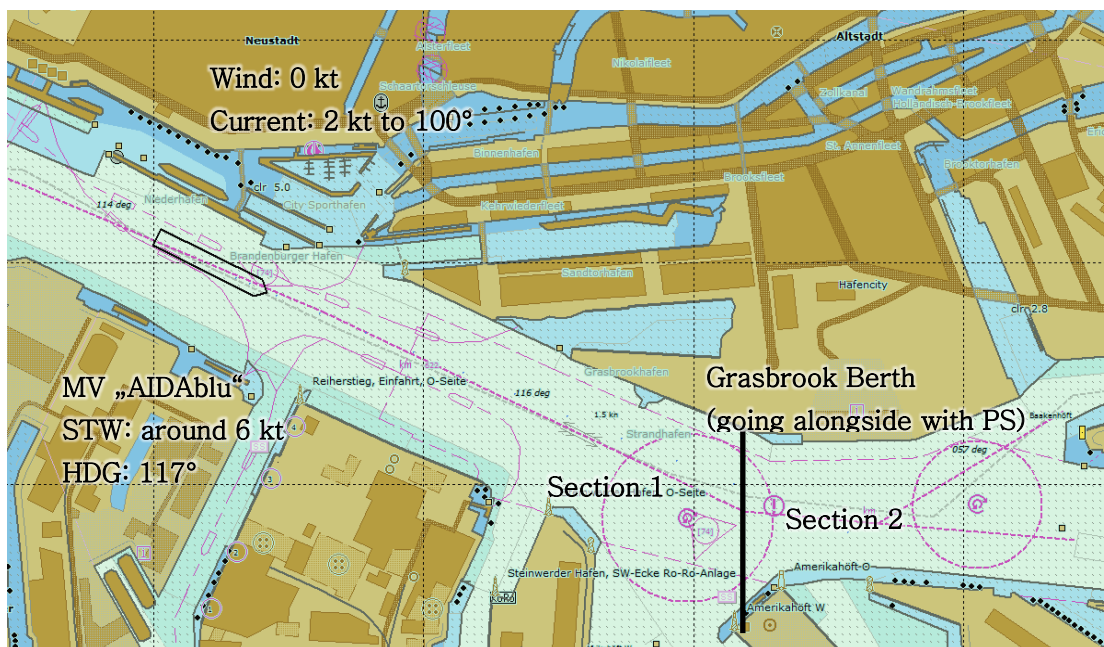
The Master must be on the bridge, assume one of the functions and take the charge. In Red Manning the bridge must be in closed condition.

**Fig. 1: Required Functions and Manning Concept for Functional Approach for Bridge Operation**

### 3. SIMULATION-AUGMENTED SUPPORT FOR SHIPMANOEUVRING PROCEDURES

#### 3.1 PRE-PLANNING WITH “MANOEUVRE PLANNING & DESIGN MODULE“

As an example for creating a berth plan and briefing the navigational officer, a berthing scenario is chosen for a harbour area - the starting situation and the environmental conditions within this area on a sea chart is to be seen in Fig. 2. The objective is to berth the ship with port side alongside Grasbrook Berth at Hamburg Port.



**Fig. 2: Exercise area and environmental conditions in Port of Hamburg for berthing scenario, divided into two sections for planning the manoeuvres**

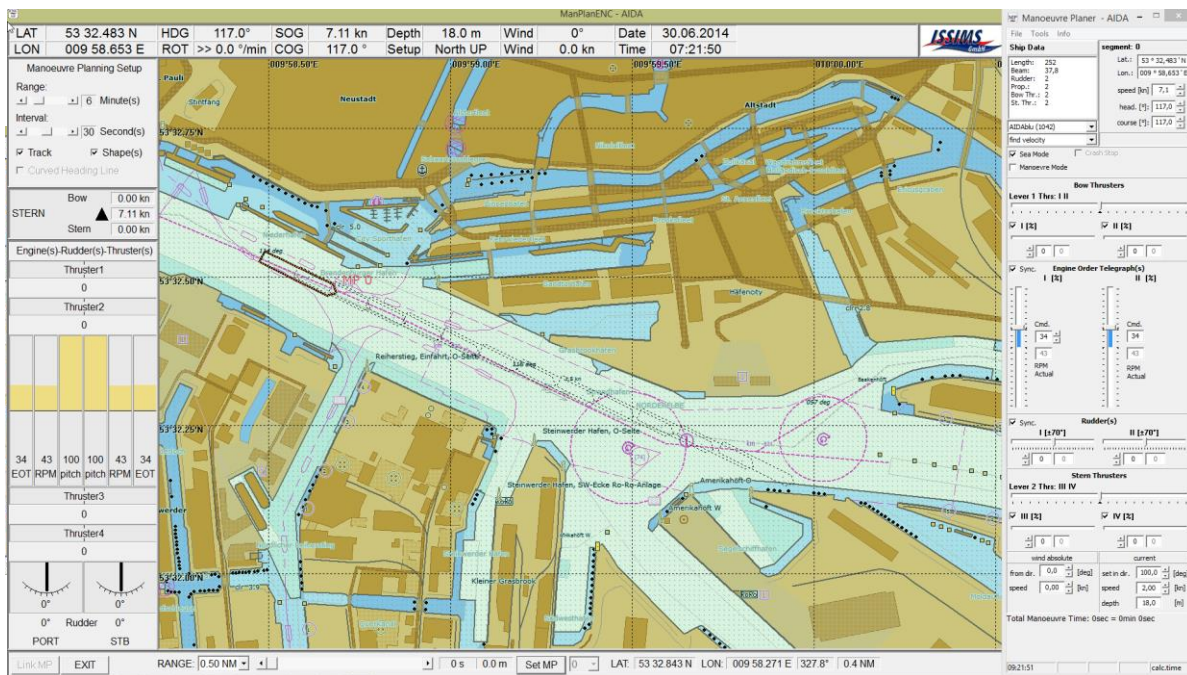
The respective harbour area is being divided into two manoeuvring sections following a specific aim:

1. Section 1: At the end of this section the speed over ground (SOG) should be around 3 kn and the heading slightly towards southeast as preparation for section 2.
2. Section 2: A state should be reached, where the ship can be held in the current at a position with constant heading and no speed. Then, the ship can then crab towards the berthing place mainly by means of thrusters. The current can be used as an additional supporting aid to go alongside.

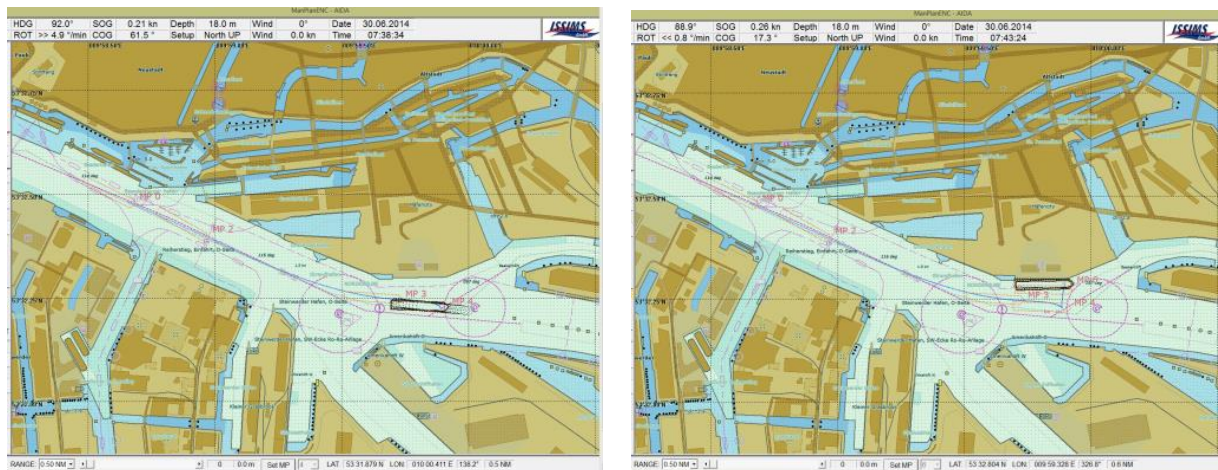
In a conventional briefing only these rough indications of the manoeuvring status can be used to develop a potential strategy for berthing the ship. The manoeuvres and setting of engines, rudders and thrusters cannot be discussed in detail because no specific manoeuvring characteristics are available for the specific situations.



With the new fast-time simulation there is the chance for designing a manoeuvre plan as a detailed strategy with the specific settings at distinguished positions called the Manoeuvring Points (MP). In the following, the course of actions is described in a series of figures to make a full manoeuvring plan by means of the control actions at the manoeuvring points, MP. In Fig. 3 the initial position is to be seen where the instructor has set the ship in the centre of the fairway. The prediction already shows that the ship would drift slightly to port side due to the set handle positions. It can be learned that therefore the rudders have to be put slightly to starboard at the very beginning in order to follow the straight track until the next MP 1. At MP 2 the rudders are set amidships again and both propulsion units are used to slow down and to steer the ship: the starboard engine is kept at 34 %, resp. 43 rpm to allow for a certain rudder effectiveness for steering control, whilst at MP 3 the portside engine is set backwards in order to achieve about 3 kn SOG at the end of section 1.



**Fig. 3: MP0: Initial position: The prediction already shows that the ship would drift slightly to portside due to the set handle positions.**





**Fig. 4: Final part of the manoeuvring plan: Left MP4 - The vessel is stopped and the heading is chosen in that way, that all handles can be set in zero position. Right: MP5 / MP6: the ship is already brought to the berth**

In

Fig. 4 left side, the ship is stopped at MP4: The vessel's heading is chosen in that way, that all handles can be set in zero position, holding the ship with a minimum speed almost at the same position. At this moment, bow and stern thrusters can be applied to bring the ship safely to its berth. In the right figure the ship is already brought to the berth. The crabbing by means of bow and stern thrusters needs a further MP in order to reduce the transversal speed shortly before berthing.

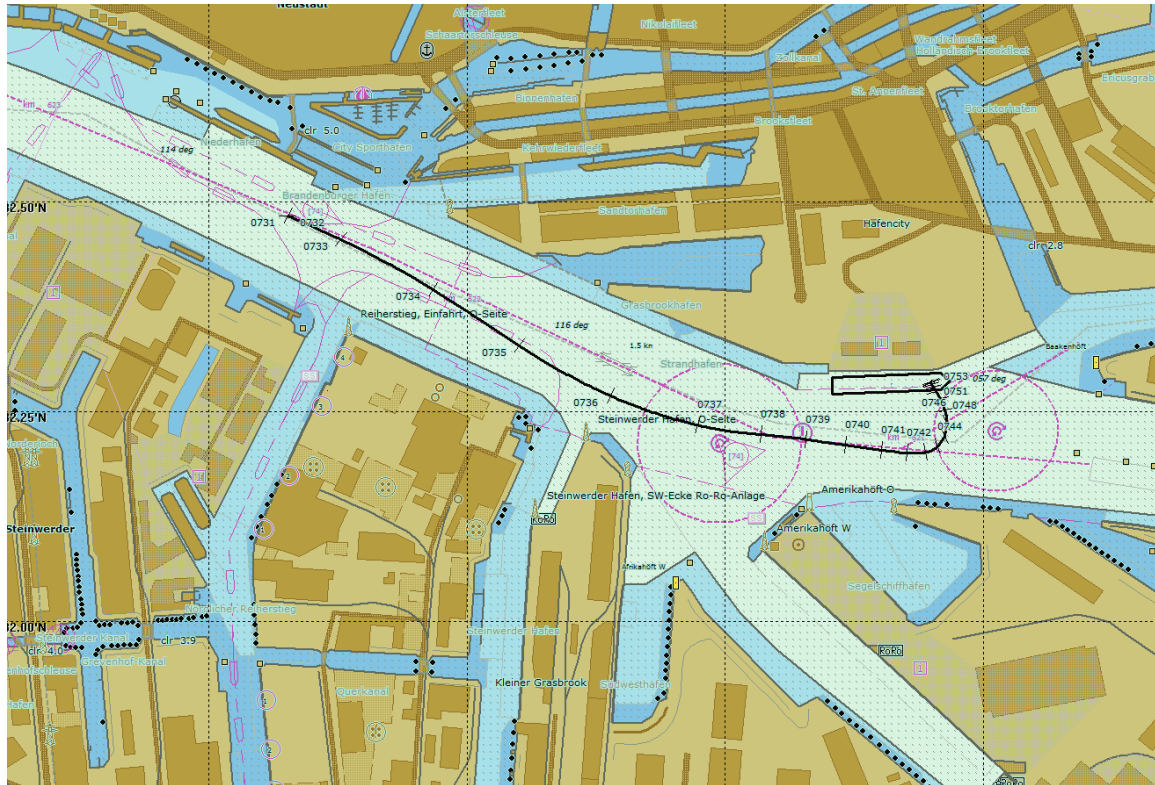
The complete manoeuvring plan can be saved to be used for the training or to be loaded again for editing the plan for an optimisation to achieve a better performance e.g. to do the whole manoeuvre in less time. For an in-depth discussion at the separate manoeuvring points and sections, there is the possibility to save the specific conditions as situation files. These situation files can be useful for discussing strategies during the planning at different places where new challenges will come up as well as for the debriefing sessions. In

Fig. 4 at the right corner at the bottom the time is to be seen for the complete series of segments: the total manoeuvre time is about 17,5 minutes for this version of the plan.

## **4. SIMULATION AUGMENTED SUPPORT FOR EXECUTION OF MANOEUVRE**

### **4.1 BERTHING EXERCISE WITH CONVENTIONAL PREPARATION AND USE OF SHIP-HANDLING SIMULATOR**

For comparing the effectiveness of the simulation-augmented support tools a simulator test was made with trainees who have no support and trainees who have the full support. The result of this attempt by an experienced trainee who has no specific preparation for the exercise is seen for the ships track in Fig. 5. The ship is set at the starting position and the task is to manoeuvre it to the berth with no Fast Time Simulation (FTS) aid at all.



**Fig. 5: result of manoeuvring training in ship handling simulator for a trainee with conventional preparation and no support by fast time simulation (Total Manoeuvring Time about 20 min)**

#### **4.2 BERTHING MAKING USE OF SIMULATION-AUGMENTED SUPPORT IN SHS AND WITH SAMMON MONITORING AND TRAINING TOOL**

During the exercise it is possible to take advantage from the multiple predictions for the manoeuvres. In Fig. 6 the setup is to be seen where a students can bring his own laptop onto the simulator bridge (where he has already developed the manoeuvring plan), the prediction is controlled via the bridge handles. The same laptop with the monitoring tool can also be placed at the instructor station. Alternatively the execution of an exercise can also be trained using the trail & training tool which is available on the same laptop for pre training. The ships motion is then controlled via the same virtual handle panel on the screen as in the planning tool.



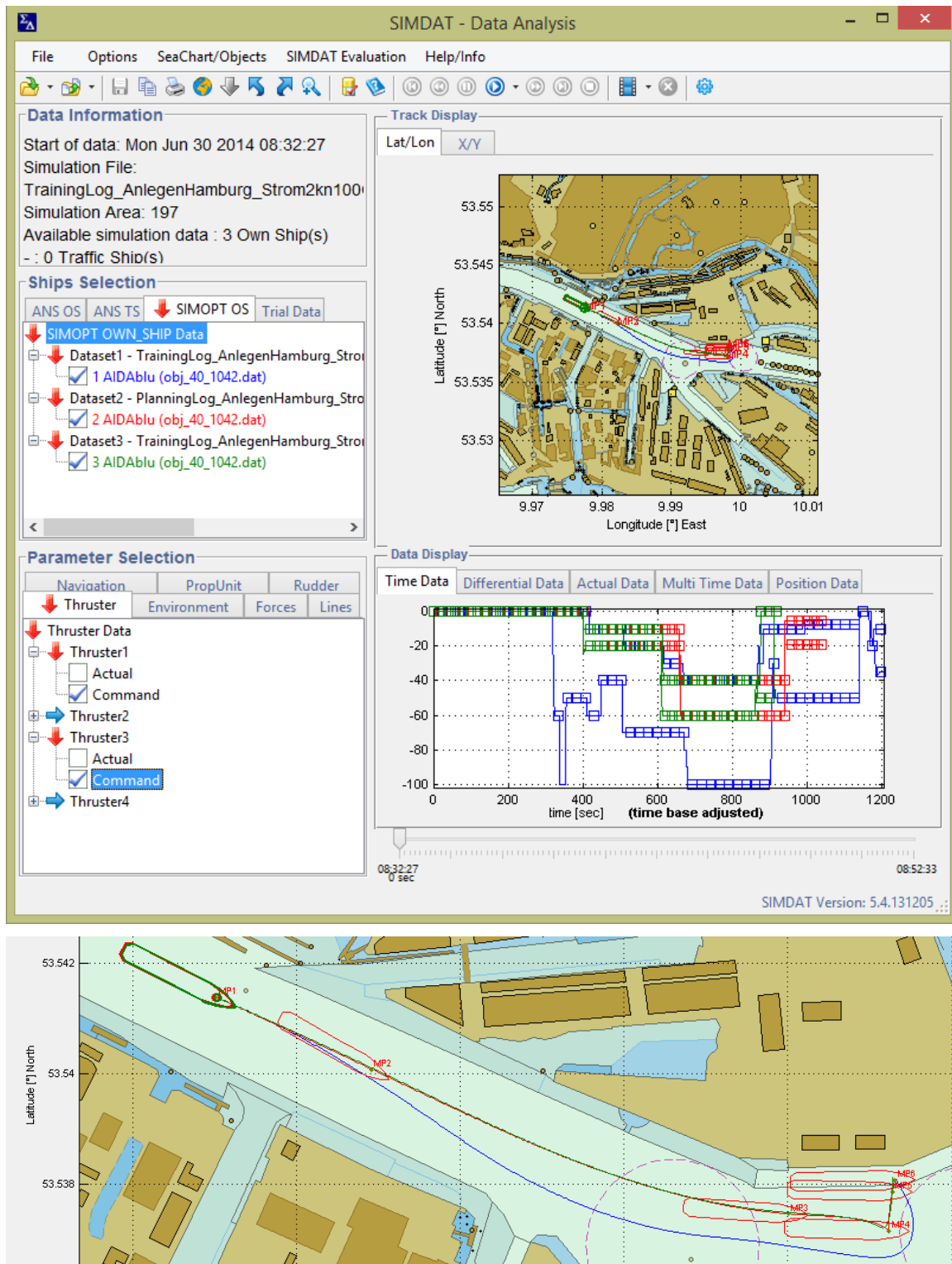
**Fig. 6: Portable setup for prediction display on ECDIS in Monitoring Tool on students laptop on bridge 1 of ship-handling simulator of MSCW – the prediction is controlled by the bridge handles. The dynamic prediction shows the future manoeuvring track whereas on the radar screen the static path prediction shows still a straight line according to the initial conditions of the ship-handling simulator of MSCW.**

In Fig. 7 a comparison is made between the two simulator results of the trainees with different level of preparation and the manoeuvring plan of the second trainee. The achievements of the better prepared trainee are obvious – the planned manoeuvre is very close to the executed track and the actions of the controls has been done also nearly in accordance with the planned procedures. It is obvious that there is not just a reduction of manoeuvring time when applying the Fast-Time Simulation tool in briefing and training; the thruster diagrams show also that a well prepared manoeuvre can minimize the use of propulsion units and therefore be more efficient.

The benefit of using the FTS is to be seen for several purposes:

- The multiple dynamic predictions are always a great help for the Navigator steering the ship: They have a better overview on the current situation and the chances for the potential success of an action can immediately be seen; also for the Co-Navigator there is the chance to see both the manoeuvres and the success – this is a great situation because they can both share a better situation overview.
- Multiple dynamic prediction may be used to see both the current state of motion by the static path prediction and the future development of the ship motion caused by the current handle settings – it is expected that the static prediction changes into the dynamically predicted track, in this case the prediction is correct. If not then the handle settings can be slightly adjusted to

correct for the tendency of the potential impact of environmental effect which might not have been considered by the dynamic prediction, e.g. a non-detected current.



**Fig. 7: Results from two manoeuvring exercises in SIMDAT interface with “Track Display” and “Data Display” for time history of thruster activities.**

**Blue: run of the trainee without support by Fast-Time Simulation**

**Green: run of the trainee with full support by pre-planning with Design and Planning Module**

**Red: comparison to the prepared manoeuvring plan with manoeuvring points**

## **5. RESEARCH PROJECT COSINUS - SIMULATION AUGMENTED MANOEUVRING FOR BRIDGE OPERATION AND FOR VTS**

The goal of the project COSINUS (“cooperative operation of ships for nautical safety through integration of traffic safety systems”) is to achieve the integration of maritime traffic safety systems on board and on shore. Therefore, novel concepts are investigated regarding the presentation of enhanced data to the operator and operation of new tools and services as well as decentralized data capturing, processing and storage. Processed data of land-based information systems will be visualized in such a way that a complete overview over the traffic and environmental situation is given in order to support the navigational operation of the vessel. This includes e.g. the representation of a shared route and manoeuvring plan, the operational interface to the VTS operator, and the depiction of weather-data along the voyage or at the destination port. The goal is to establish a cooperative picture which offers a dynamically enhanced view for the bridge crew going beyond traditional ship-based sensor information like own ship RADAR or AIS. This will improve the safety particularly in heavy traffic situations. A great deal of work will be carried out concerning the definition and establishment of new standards for the ship based navigation in cooperation with higher level traffic management systems. The main areas of work follow:

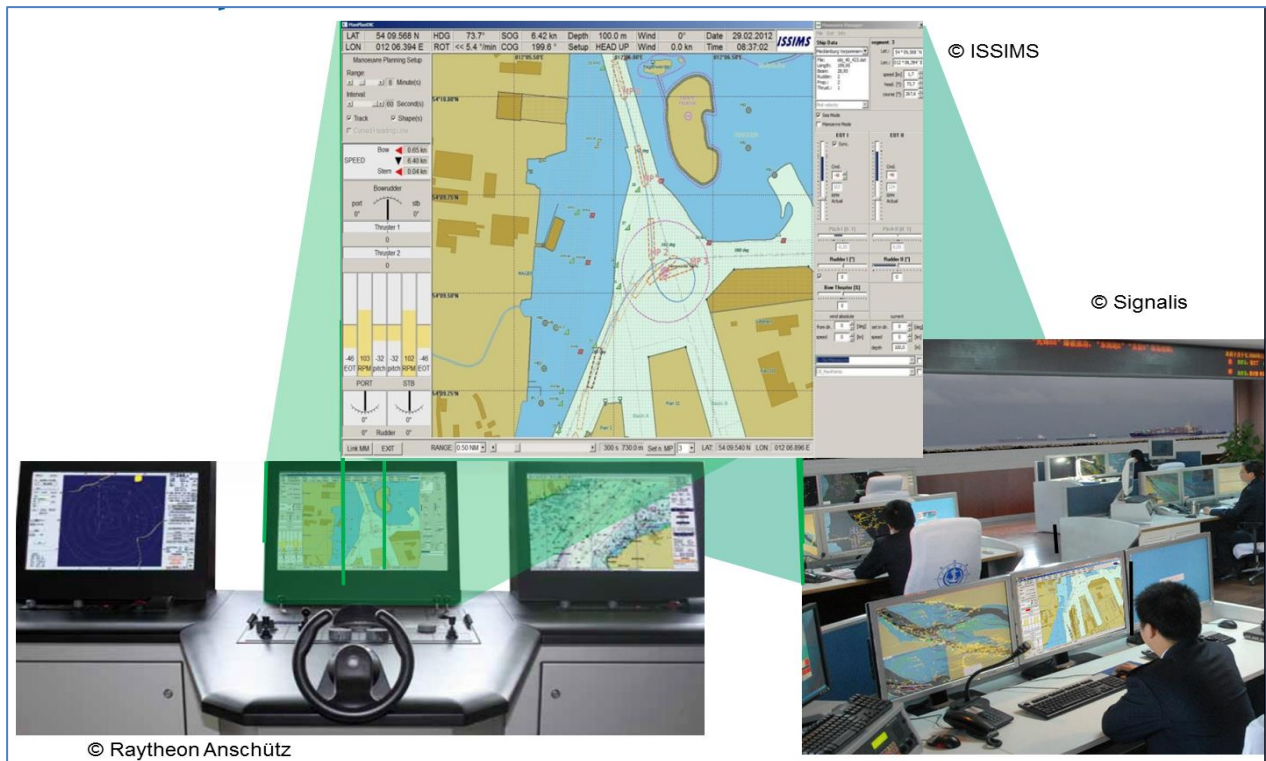
- Visualization concept for representation of land-based information on ship bridges
- The proposal and the validation of modules and interfaces for autonomous communication between VTS and INS
- Combination of ECDIS representation of navigational data and VTS data to an integrated navigational and traffic picture
- Concept for cooperative route- and maneuver planning
- Investigation of communication channels and interfaces for exchange between VTS and INS

Specifically for the integration of the Simulation-Augmented Manoeuvring Support by SAMMON the new functions have to be interfaced:

- The results of the manoeuvre planning have to be made available into the Integrated Bridge System and
- also the data transfer from ship data into the Monitoring and Control Module have to be adjusted
- the data transfer from ship to shore into the VTS center has to be established.

The concept for sharing the information between ship and shore is to be seen in Fig. 8.





**Fig. 8: Project COSINUS – shared information on manoeuvring plans and multiple prediction in ECDIS between bridge and VTS**

## 6. THE MUNIN PROJECT - SIMULATION-AUGMENTED MANOEUVRING SUPPORT FOR AUTONOMOUS SHIPS

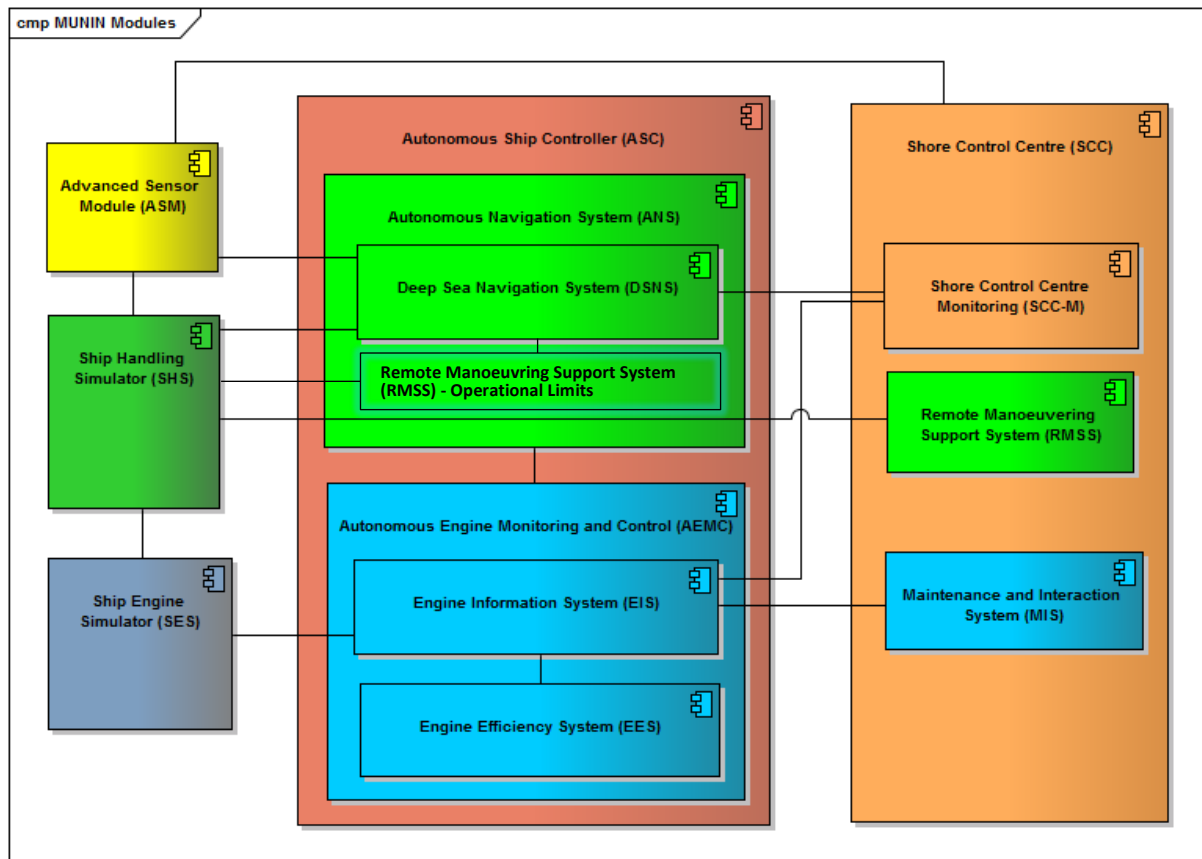
### 6.1 INTRODUCTION & OBJECTIVES

Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) is a collaborative research project of eight partners from five European countries co-founded by the European Commission. MUNIN's aim is the development of an autonomous-ship concept and its simulation-augmented feasibility study.

The main idea behind the MUNIN concept is the autonomous sea passage of an unmanned vessel. Nevertheless, before the ship can be set to autonomous operation it has to put out at sea in the traditional way with a crew on board. For the unmanned voyage part the vessel is monitored by a Shore-Control Centre. When in autonomous mode, the vessel solves appearing problems with regard to weather and traffic situation by autonomous algorithms and follows its pre-defined voyage plan. If necessary, the operator takes over automatic control by commanding the vessels true heading and speed-over-ground. Furthermore, when exact manoeuvring is required, the operator enables a mock-up bridge to manually control the vessels manoeuvring systems like rudder and engine from a situation room within the Shore-Control Centre. Assuming that the connection fails, the vessel has to drift or, if possible, drop the anchor to maintain its position.

The module development within this project is either related to the Shore-Control Centre or to the Autonomous Ship Controller, containing both autonomous bridge and engine-room prototypes.





**Fig. 9: Overview of MUNIN modules for the proof-of-concept simulation tests (Rødseth, 2014)**

## 6.2 PROJECT PARTNERS

- MUNIN Project coordinator is the Fraunhofer Center for Maritime Logistics and Services (CML) in Hamburg, Germany. CML's scope of work is to identify the nautical tasks that need to be changed to enable unmanned navigation and to define the autonomous functionalities needed while subsequently developing these functionalities. In practise, that addresses the development of the Deep-Sea Navigation System prototype within the Autonomous Bridge System which has to carry out the autonomous weather routing, collision avoidance and stability checks.
- The Marine Technology Research Institute MARINTEK in Trondheim, Norway, develops the Maintenance and Interaction System with new maintenance strategies useful for unmanned vessels and furthermore, develops MUNIN-specific interfaces and contributes this to international standards.
- The Maritime Human Factors group at Chalmers University of Technology in Gothenburg, Sweden, is responsible for the Shore-Control Centre prototype. Its focus is the monitoring of the vessels operational status but also providing direct remote control. Thus, the main challenge is to keep situational awareness of the operator appropriately high despite the physical distance between the vessel and the human.
- Aptomar AS, Trondheim, Norway, focuses on the investigation of sensor capabilities for unmanned vessels and develops an Advanced Sensor Module to allow an unmanned vessel to evaluate current and future vessel-traffic patterns and weather conditions. This Advanced Sensor Module enables the unmanned vessel's navigation system to plan and act accordingly to ensure safe and efficient voyage.

- MarineSoft Entwicklungs- und Logistik-gesellschaft mbH in Rostock-Warnemünde, Germany, develops the process-management module called Engine Information System which provides the Autonomous Engine Monitoring and Control System with relevant data. The Autonomous Engine Monitoring and Control System prototype detects errors before the alarm rises and makes counter measurements to avoid or reduce malfunctions in the unmanned engine room.
- Marorka ehf from Reykjavik, Iceland, investigates current and upcoming regulations regarding emissions and ballast water treatment to ensure that the unmanned engine room is designed to meet future challenges of environmental performance. These results and Marorka's product "Marorka Power" will be incorporated and adapted to the MUNIN project in order to optimize how electricity is produced on board.
- The Faculty of Law at University College Cork, Ireland, analyses legal and liability challenges due to autonomous systems on board and remote-controlled operation from ashore.
- The Department of Maritime Studies at Hochschule Wismar (HSW), University of Technology, Business and Design in Rostock-Warnemünde, Germany, is involved in both parts of ship operation the navigational and technical systems.
  - o The ship-engineering department at HSW is responsible for the analysis and conceptual redesign of current engine-related tasks as well as for repair and maintenance optimisation for unmanned operation during the sea passage.
  - o The Institute for Innovative Ship Simulation and Maritime Systems (ISSIMS) at HSW develops a simulation augmented manoeuvring support systems for remote-controlled navigation in near coastal waters.
  - o The Maritime Training Centre Warnemünde at HSW serves with its simulation environment and partner's prototype integration for the feasibility study within the proof of concept.

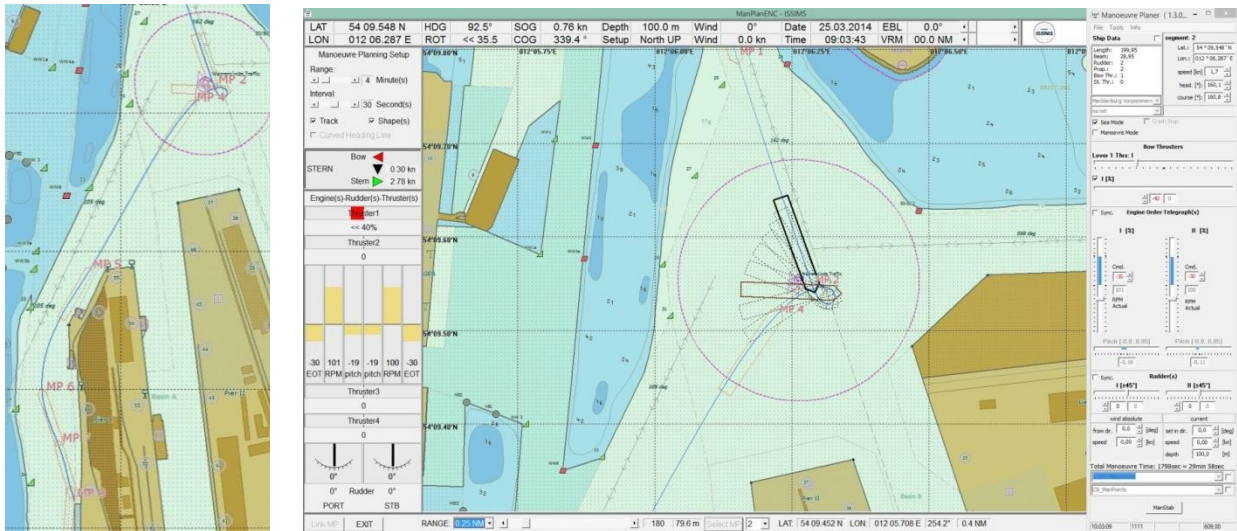
### **6.3 REMOTE MANOEUVRING SUPPORT SYSTEM – SIMULATION AUGMENTED SUPPORT AND PREDICTION OF OPERATIONAL LIMITS**

The Remote Manoeuvring Support System envisages the improvement of the mental model of experienced ship officers on board sea-going vessels to a Shore-Control Centre. Since for the shore-based operators the feeling of the ship's motion is missing, a way must be found to transmit the impression and feeling of the ship's actual and future motion to the operators. The problem is: there is no scope for the conventional "trial and error corrections" or "touch and feel experiences" for vessels fully controlled by shore-side operators.

The remote manoeuvring support system's aim is to allow safe and efficient remote-controlled navigation in near-coastal waters. The innovative value of the Fast-Time Simulation technology is the look-ahead function of ship's motion by dynamic-prediction methods, so that a ship's officer or shore-side operator can foresee the vessels future path.

The Remote Manoeuvring Support System prototype contains three different modules - all based on Fast-Time Simulation und dynamic-prediction methods:

- Monitoring tool with visualisation of future ship track by means of dynamic-prediction methods
- Pre-planning tool to design safe and efficient manoeuvre plans for the upcoming manoeuvring
- Prediction of the operational limits visualising the required room to manoeuvre.



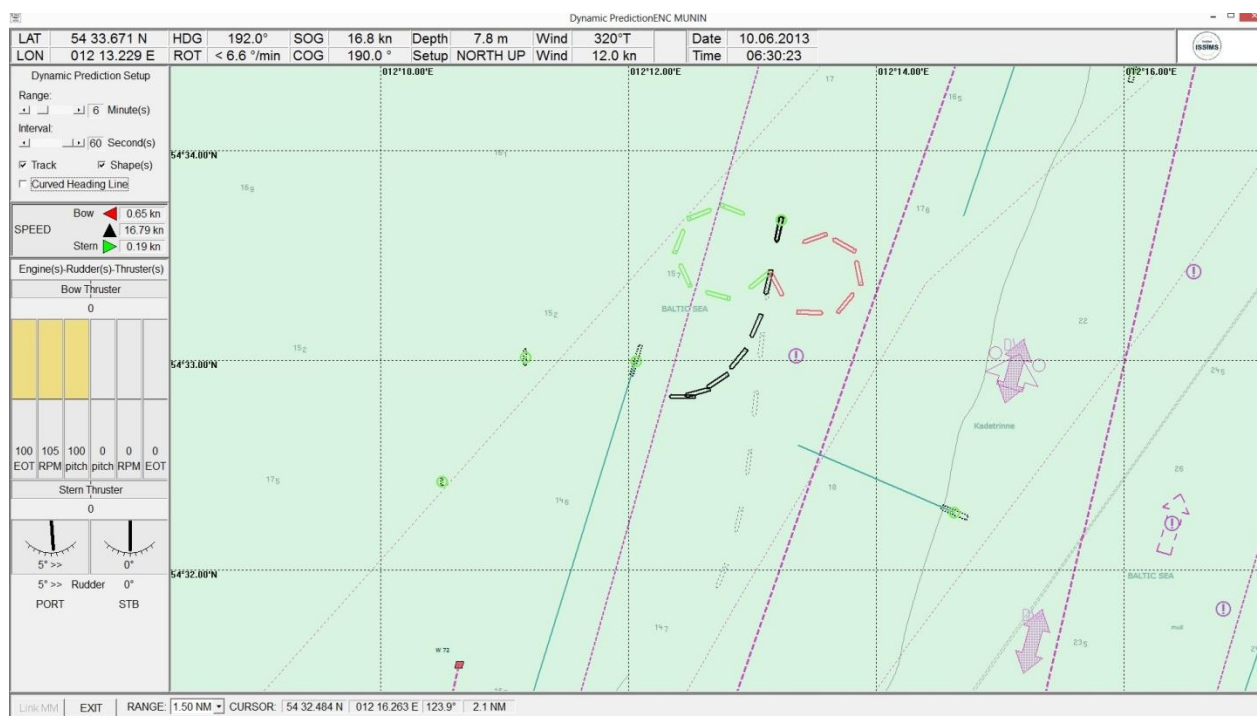
**Fig. 10: Example for a pre-planned manoeuvre plan (MP) as manoeuvring basis (left) and Combined stopping/turning manoeuvre with her bow thruster ordered to port side and both engines reversing in Monitoring & Control Interface (right)**

Not only for collision avoidance but also for navigation in narrow waters it is from high importance for a shore-side operator to know the operational limits of the vessels under his surveillance. The problem is that the manoeuvrability depends on many hard-to-estimate factors. High speed in shallow water e.g. causes squat effects, and the speed-through-the-water to speed-over-ground ratio increases/decreases rudder effectiveness as well as waves and gales affect the turning and stopping behaviour. The mariner aboard senses this and directly interprets the effect by the above named factors. He can feel and observe a squat effect way easier as an operator sitting in a control centre ashore in front his screens. He has trained his mental model of ship's motion by years of experience at sea.

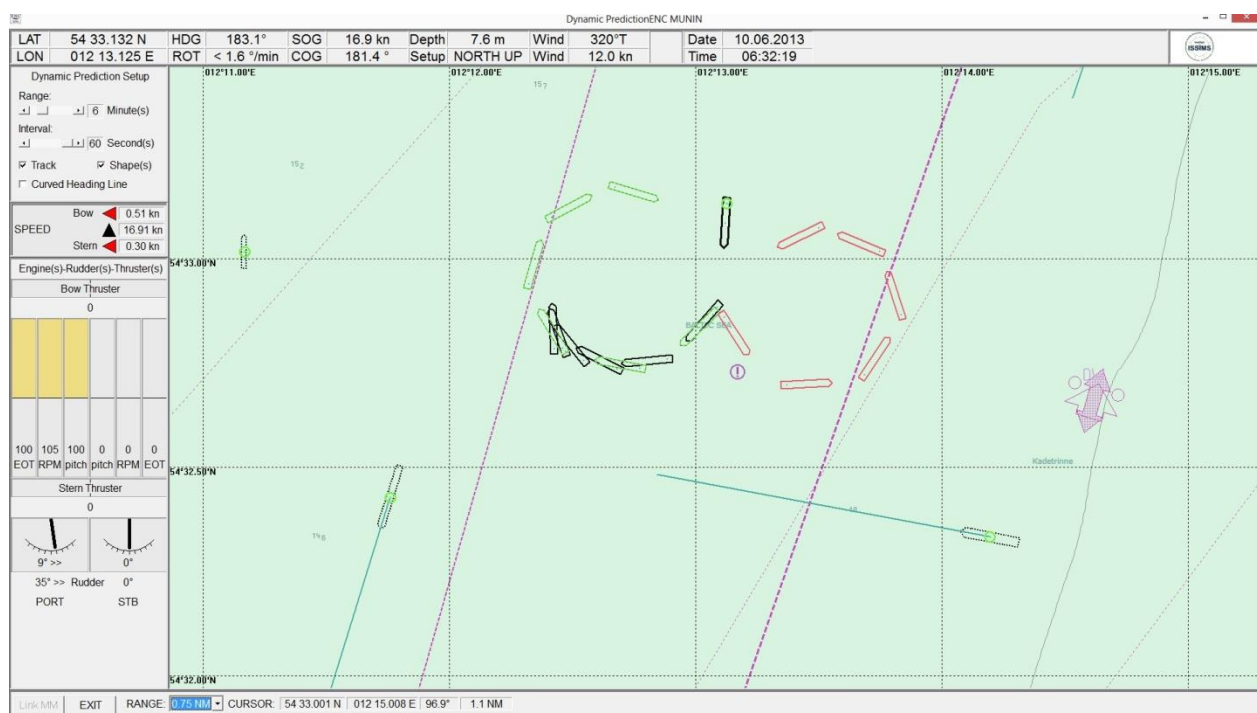
To support the shore based operator by information on ship's motion dynamics, the Remote Manoeuvring Support System supplies the operator (and the collision avoidance system on board) with vessel data regarding its operational manoeuvring limits. These are in detail:

- Normal prediction of the future track with current handle control settings (grey)
- Hard Rudder Turning circle port side (red)
- Hard Rudder Turning circle starboard side (green)
- Crash Stopping manoeuvre (black)

Fig. 11 shows the monitoring concept with the prediction of the manoeuvring limits. All four manoeuvre predictions will be supplied in a 1 Hz update rate. This figure shows a situation for a collision threat: the own ship is the stand-on vessel and the ship on its port side is expected to do a course change to avoid a collision according to COLREG rule 15. In case the ship as not acting in proper time, the own ship is obliged to do an evasive manoeuvre according to COLREG rule 17. From the figure it is to be seen that a stopping manoeuvre would not help anymore but a turning circle to starboard would help. In Fig. 12 the ship has already ordered full rudder angle to starboard side. In addition to the emergency turning circle, the black shapes indicate a combined turning/stopping manoeuvre with the engine ordered full astern.



**Fig. 11: Sample for presentation of dynamic-manoeuving prediction of actual manoeuvring track (black-dotted contours) and additional manoeuvring tracks for hard-to-STB (green) and PT (red) as well as for crash stop (black) from actual motion parameters - the ship has applied rudder amidships the contours of actual control are ahead of the ships position.**



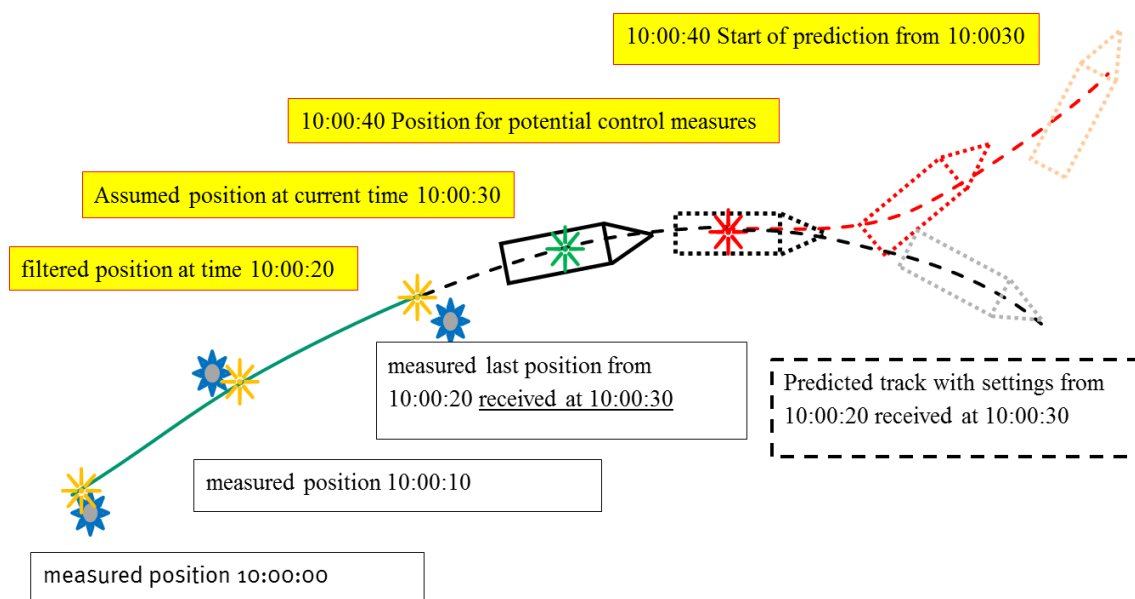
**Fig. 12: Sample for presentation of dynamic manoeuvring prediction of actual controls manoeuvring track (black-dotted contours) and additional manoeuvring tracks for hard-to-STB (green) and PT (red) as well as for crash stop (black) from actual motion**

**parameters – the ship has applied full rudder the contours of actual controls full to STB are identical with the green contours.**

The most import support is necessary if there is a time delay in the communication between the autonomous ship and the shore control centre during the remote manoeuvring status: in Fig. 13 a sample is given for explanation of the effect of time delay in ship-shore communication and the advantage of prediction for filtering and remote manoeuvring action by the shore-based controller.

- The message for the measured position was received at 10:00:30 with time delay of 10 sec, i.e. the message was sent 10:00:20.
- This position was filtered (yellow star, as for the previous measured positions before).
- From this filtered position the current position was calculated by prediction on the Predicted track (blue broken line) with control settings from 10:00:20. In the same way the position at 10:00:30 was found which the initial point for the new prediction is.
- From the assumed / predicted position at 10:00:30 the new prediction for new settings from 10:00:30 will take effect after another delay of 10 sec at the position at 10:00:40 – from there the red dotted contours and track are shown for the new predicted track.

It is obvious that it is very difficult to steer the ship if the time delay is increasing. Within the project it is planned to do some investigations into the maximum delay allowed to secure a safe control of the vessel from shore.



**Fig. 13: Sample for explanation of the effect of time delay in ship-shore-communication and the advantage of prediction for filtering and remote manoeuvring at time point 10:00:30**



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