

## Simulation-Augmented Methods for Safe and Efficient Manoeuvres in Harbour Areas

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**ABSTRACT:** Safety of navigation is especially challenging and critical when a ship approaches and manoeuvres in harbour areas. Improving the safety especially in the first and last phase of a voyage is crucial and requires measures addressing both the human and technical-technological elements including support systems that shall provide human operators with information relevant for decision making. The present situation is characterized by the introduction of numerous sophisticated technical and support systems often integrated with several components becoming increasingly complex. On the users end, changes are not that obvious and not that rapid as for technology. However, new approaches are under development or already in use. They are characterized by applying and adapting solutions from other transport modes. In this way, tasks and procedures on ships, that are highly safety-relevant and containing high portions of manoeuvring activities 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 shipping, new structures replacing the traditional rank-based with a flexible system based on job functions. This system creates a kind of a safety net around the person conning the vessel. Each operation is cross checked before execution by one or two other persons. The first obvious consequence is higher costs due to doubling personnel. On the other hand there is also a need for a technology appropriately supporting the checking officer by enabling her or him to monitor what the conning officer is doing. "Fast-Time Manoeuvring Simulation Technology" (FTS) developed at the Institute for Innovative Ship Simulation and Maritime Systems (ISSIMS) has huge potential to fulfil this task. FTS calculates within one second of computing time up to 1000 seconds of real manoeuvring time by a very complex ship-dynamic simulation model for rudder, engine and thruster manoeuvres. It enables prompt prediction of all manoeuvres carried out by the conning officer for the observing officer, too. Predictions of path and motion status allow all officers to see whether the manoeuvring actions have at least the correct tendency or indicating the need for corrections. 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. This technology has been used within two research projects: COSINUS (Co-operative Ship Operation in Integrated Maritime Traffic Systems) set out for implementing FTS into integrated ship bridges and to also communicate the manoeuvre plans and display it to VTS centres. Within the European project MUNIN (Maritime Unmanned Navigation through Intelligence in Networks) this technology has been used to investigate if it is possible to steer autonomous ships, in case it would be necessary.

## 1 INTRODUCTION

In (Benedict et al., 2013) 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 Electronic Chart Display and Information System (ECDIS). The SAMMON (“Simulation-Augmented Manoeuvring Design and Monitoring”) - tool box allows for a new type of design of a manoeuvring plan as enhancement exceeding the common conventional pure way-point planning. The toolbox has big potential to play an important role in future enhanced planning processes as well as in education and training in simulators for ship handling.

As an attempt to improve safety of navigation, Hederstrom presented new concepts for innovative organisational structures specifically for bridge management (Hederstrom, 2102).

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, in the long-term, 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 remain the human operator himself and the technical equipment to support their 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)

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

SAMMON is made for both:

- 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,
- The toolbox 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 (Benedict et. al: 2003, 2006) for tuning of simulator-ship model parameters. The modules for Multiple Dynamic Prediction & Control to be used on board as steering assistance tool and later the manoeuvring design and planning technology were described later (Benedict et. al: 2012, 2014).

In this paper, the focus will be laid on the potential of the SAMMON software supporting ship operations in a collaborative way on-board and ashore and to improve safety of navigation and manoeuvring in connection with innovative approaches of bridge organisation.

## 2 FUNCTION-BASED BRIDGE ORGANISATION

### 2.1 *Functional Positions*

The innovative concept of Function-Based Bridge Organisation was introduced by Hans Hederstrom at the INSLC Conference in 2012. 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 is argued that it potentially can help to overcome

organizational shortcomings and even may remove hierarchical barriers. In this way, function-based bridge organization may enhance teamwork and communication, if a traditional rank-based system has been replaced by such an enhanced regime. 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 advantages 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 and the following assigned tasks are included in these procedures (only extracted items specifically for manoeuvring aspects) in Figure 1:

**Operations Director:** Overview of the entire bridge operation, ensuring that it is, at all times, carried out in accordance with these procedures; 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; 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; 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.

**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 Figure 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. Even though rather speculative, the authors are of the opinion, that such an organizational watch regime may potentially have avoided accidents like the capsizing of the "Herald of Free Enterprise" (Department of Transport, 1987) or, maybe even the grounding of "Costa Concordia" (Di Lieto, 2015).

And it is obvious that for the new manning concepts the information sharing is most important, both for the planning phase to prepare and discuss a manoeuvring concept and for the manoeuvring operation to make the results of the momentary

control settings visible to all ship officers who are involved into the conning process.

In the following chapters some elements are presented and discussed on how the communication within the bridge team can be supported by integrating Fast Time Simulation Modules of the SAMMON System into the overall navigation process.

### 3 SIMULATION-AUGMENTED SUPPORT FOR SHIP MANOEUVRING PROCEDURES

#### 3.1 Pre-planning with “Manoeuvre Planning & Design Module”

The basic idea behind simulation augmented manoeuvring support is to materialize and to visualize the mental manoeuvring planning of an experienced navigator. Compared to route planning using waypoints where a change of course and speed is foreseen (macro planning), manoeuvring planning uses manoeuvring points where an order of the steering handles needs to be performed in order to follow a certain path (micro planning).

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 Figure 2. The objective is to berth the ship with port side alongside Grasbrook Berth at Hamburg Port.

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	

Figure 1. Required Functions and Manning Concept for Functional Approach for Bridge Operation

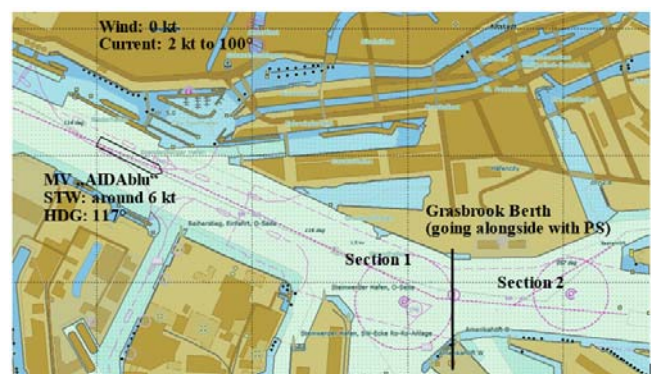


Figure 2. Exercise area and environmental conditions in Port of Hamburg for berthing scenario, divided into two sections for planning the manoeuvres



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

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 Figure 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.

In Figure 4 (top), 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 bottom figure the ship is already brought to the berth. The crabbing by means of bow and stern thrusters needs a further MP5 in order to reduce the transversal speed shortly before berthing at MP6.

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 Figure 4 at the right bottom corner 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.

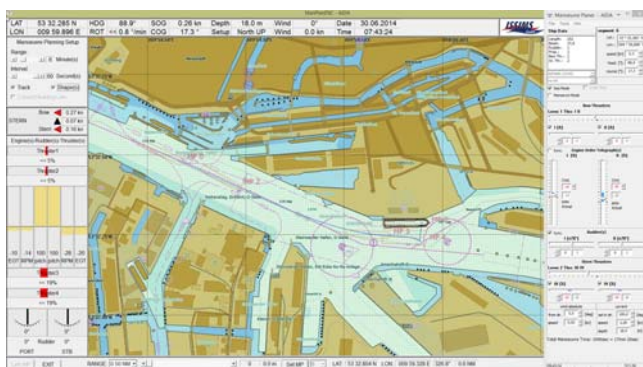
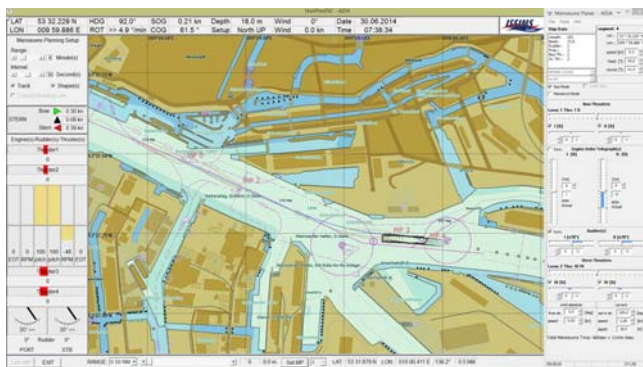


Figure 4 Final part of the manoeuvring plan: At MP4 the vessel is stopped and the heading is chosen in that way, that all handles can be set in zero position (Top); at MP5 / MP6 the ship is already brought to the berth (Bottom)

### 3.2 Berthing making use of Simulation-augmented support in SHS and with SAMMON Monitoring Module and Training Tool

During the exercise it is possible to take advantage from the multiple predictions for the manoeuvres.

In Figure 5 an example is shown for the On-line manoeuvre prediction (dotted ship contours) starting from current position (black ship contours) at the end of black past track. On the ship bridge the prediction is controlled by the handles on the manoeuvring controls. For training and test purposes the manoeuvre can also be tested in the SAMMON Trail & Training Tool – in this software the controls are used to be seen in the Monitoring & Control Interface of the Training Tool presented on the right side in this figure.

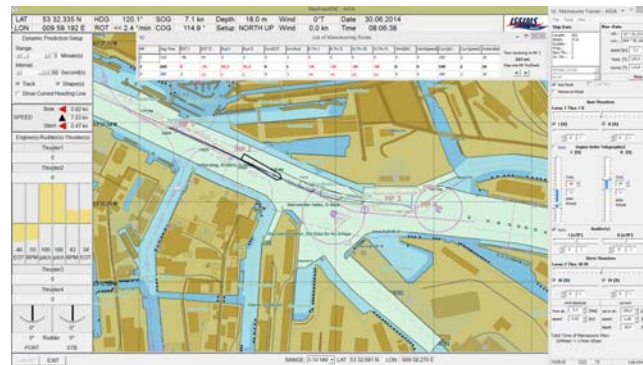


Figure 5. Example for overlay of a pre-planned manoeuvre plan (MP) as manoeuvring basis (blue) and manoeuvre prediction (dotted ship contours) starting from current position (black ship contours) at the end of black past track with her engines ordered in opposite direction presented in Monitoring & Control Interface of the Training Tool (right)

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 parts or even the full support of the SAMMON.

During the exercise it is possible to take advantage from the multiple predictions for the manoeuvres. The students can bring their own laptop onto the simulator bridge (where he has already developed the manoeuvring plan), the prediction is controlled via the bridge handles, and another laptop with the monitoring tool can also be placed at the instructor station.

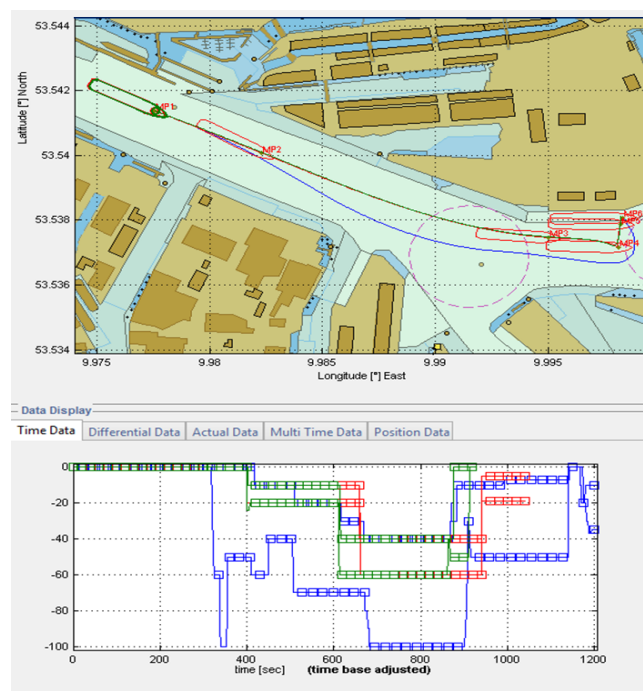


Figure 6. Results from two manoeuvring exercises in SIMDAT interface with ships track and time history of thruster activities. (Blue: run of the trainee without support by Fast-Time Simulation; Green: run of the trainee with full support by pre-planning with Design and Planning Module; Red: prepared manoeuvring plan with manoeuvring points)

In Figure 6 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 predictions 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.

#### 4 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 – Bolles et al., 2014) 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 are the following:

- 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 manoeuvre 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 centre has to be established.

The concept for sharing the information between ship and shore is to be seen in Figure 7- both on the bridge and in the VTS the same display elements for planned routes and manoeuvres can be observed on all screens in the same way. In Figure 8 a first result is to be seen for a ship station to display the manoeuvring plan together with a route plan of another vessel.



Figure 7. Project COSINUS – shared information on manoeuvring plans and multiple prediction in ECDIS between bridge and VTS



Figure 8. Project COSINUS results: Display of manoeuvring plan (green) of own ship together with route plan of another vessel (blue) presented in Integrated Navigation System of project partner Raytheon-Anschütz transmitted from VTS station of partner SIGNALIS

## 5 RESEARCH PROJECT MUNIN - MANOEUVRING SUPPORT FOR AUTONOMOUS SHIPS

### 5.1 Introduction & Objectives

Maritime Unmanned Navigation through Intelligence in Networks (MUNIN) was a collaborative research project of eight partners from five European countries co-founded by the European Commission. MUNIN's aim was the development of an autonomous-ship concept and its simulation-augmented feasibility study. (Burmester et al., 2014). MUNIN Project coordinator was the Fraunhofer Center for Maritime Logistics and Services (CML) in Hamburg, Germany.

The Department of Maritime Studies at Hochschule Wismar (HSW), University of Technology, Business and Design in Rostock-Warnemünde, Germany, was involved in both parts of ship operation the navigational and technical systems.

- 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.
- 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.
- 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.

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.

### 5.2 Remote Manoeuvring Support System –On-line Prediction and presentation 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.

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.

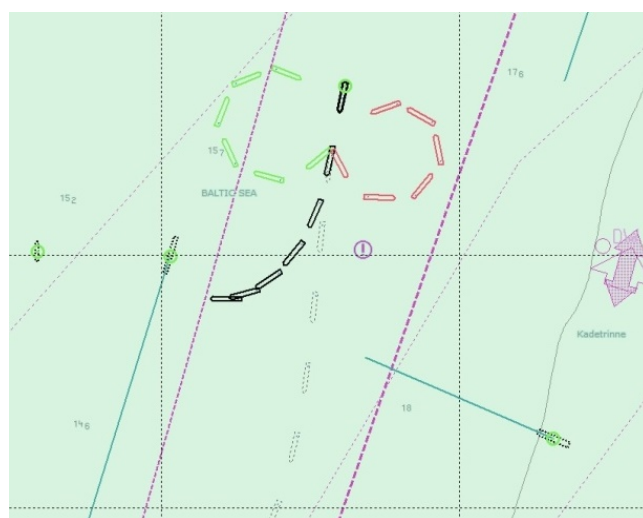


Figure 9. Sample for presentation of dynamic-manoevring prediction of actual manoeuvring track (black-dotted contours) and three parallel predicted manoeuvring tracks for Hard-to-STB (green) and PT (red) as well as for Crash Stop (black) from actual motion parameters - the ship has applied rudder amidships the predicted contours of actual controls are ahead of the ships position.

Figure 9 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 is 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.

The most important 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 (e.g. 10 seconds) in ship-shore communication and the advantage of prediction technology for filtering and remote manoeuvring action by the shore-based controller:

- The messages for the measured position on the ship were all received with the delay of 10s, e.g. at the actual time 10:00:30 the message was sent from ship at 10:00:20 and received in SCC at 10:00:30.
- The position data were filtered (yellow stars), as for the previous measured positions before).
- From this filtered positions the current Assumed position (green star) was calculated by prediction on the Predicted track (black broken line) with control settings from 10:00:20. The assumed Position at current time 10:00:30 is the initial point for the new prediction calculations.
- From the assumed / predicted position at 10:00:30 new control settings 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. In the future, it is planned to do some investigations into the maximum delay allowed to secure a safe control of the vessel from shore.

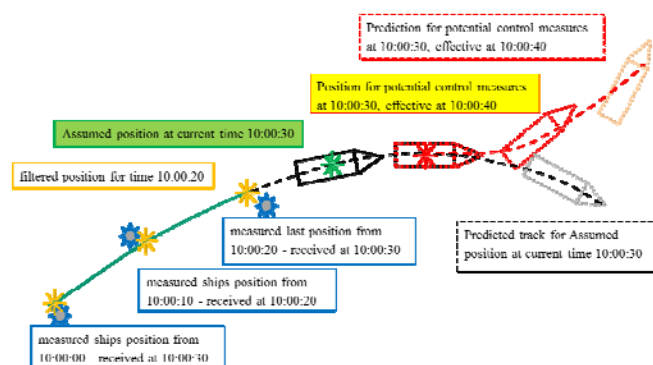


Figure 10. Sample for explanation of the effect of time delay 10s in ship-shore-communication and the advantage of prediction for filtering and remote manoeuvring at time point 10:00:30

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