Potential of Fast Time Simulation
for Training in Ship Handling Simulators and
for Decision Making On-Board Ships

Knud Benedict

Professor, Hochschule Wismar, University of Applied Sciences - Technology, Business and Design, Dept. of Maritime Studies Warnemuende, Maritime Simulation Centre Warnemuende / Germany,
Knud.Benedict @hs-wismar.de

Michael Gluch, Matthias Kirchhoff, Sebastian Klaes, Sandro Fischer

Senior Scientists, Hochschule Wismar, University of Applied Sciences - Technology, Business and Design, Dept. of Maritime Studies Warnemuende, Maritime Simulation Centre Warnemuende / Germany,
michael.gluch @hs-wismar.de

Michael Baldauf
Assistant Professor, World Maritime University WMU, Malmoe / Sweden, mbf@wmu.se

Abstract Simulation tools for Prediction of future situations of the ship manoeuvring process are very helpful and already in use on ships for a long time, beginning with trial modes in ARPA radars up to curved headline overlay in ECDIS. New concepts for on board displays were developed at Maritime Simulation Centre Warnemuende (MSCW) and presented at the last IAMU conference. In recent research projects fast time simulation tools for ships motion with complex dynamic models were used for a wider use of that technology for manoeuvring applications. These simulations allow on one hand for new type of manoeuvring design and on the other hand of unmatched monitoring of ship handling processes to follow the underlying manoeuvring concept. During the manoeuvring process the planned manoeuvres can be displayed together with the actual ship motion and the predicted future track by prediction tools. This future track is based on input from the ships actual steering and propulsion control handles.

Within this paper investigations into the feasibility of the new concept and selected results of simulation studies will be discussed. These methods are intended to be used both as an effective tool for training in ship handling simulators but also on board of real ships because the trainee or the ship officer in charge respectively can immediately see the result of the actual rudder, engine or thruster commands. Examples will be given for results from test trials in the full mission ship handling simulator at MSCW.

Keyword: *Fast time simulation, manoeuvring, ship handling, decision support*

1. Introduction – description of the Concept

Normally ship officers have to steer the ships based on their mental model of the ships motion characteristics only. This mental model has been developed during the education, training in ship handling simulator in real time simulation and most important during their sea time practice. Up to now there is nearly no electronic tool to design a manoeuvring plan effectively, even in briefing procedures for ship handling training the potential manoeuvres will be explained and drafted on paper or described by sketches and short explanations. This paper present a new method based on fast time simulation: effective tools were developed in the past for simulation of standard manoeuvring elements (basic manoeuvres) based on fixed manoeuvring elements in control files. This concept will be extended now to freely change the manoeuvring controls to design manoeuvre and sequences of manoeuvres connected to manoeuvring plans. For the execution of the manoeuvre this plan can be activated later to be

superimposed in ECDIS together with the actual position of the ship and most important with the prediction of manoeuvring capabilities (see [2]) for effective steering under the actual manoeuvring and environmental conditions.

2. Math model and fast time simulation tools for optimal standard ship manoeuvring elements

2.1 Ship dynamic model

The following equation of motion was used as math model for the ships dynamic:

$$
\begin{aligned}
X &= m \cdot \left(\dot{u} - r \cdot v - x_G \cdot r^2 \right) \\
Y &= m \cdot \left(\dot{v} + r \cdot u + x_G \dot{r} \right) \\
N &= I_z \cdot \dot{r} + m \cdot x_G \cdot \left(\dot{v} + r \cdot u \right)
\end{aligned}
\tag{1}
$$

On the right side are the effects of inertia where u and v represent the speed components in longitudinal and transverse direction x and y, r is the rate of turn of the ship. The ships mass is m and x_G is the distance of centre of gravity from the origin of the co-ordinate system, I_z is the moment of inertia around the z-axis.

The ships hull forces X and Y as well as the yawing moment N around the z-axis are on the left side. Their dimensionless coefficients are normally represented by polynomials based on dimensionless parameters, for instance in the equation for transverse force Y and yaw moment N given as the sum of terms with linear components N_r, N_v, Y_r and Y_v and additional non-linear terms depending on speed components u, v, rate of turn r, revolution n and rudder angle δ. Other forces as for instance rudder forces and wind forces are expressed as look up tables. There are additional equations for the engine model, additionally with look-up tables to represent automation systems characteristics.

The solution of this set of differential equations is calculated every second; some internal calculations are even done with higher frequency to avoid numerical instabilities and guarantee required accuracy.

This equation of motion (1) can be written in the form:

$$
x'(t) = f(x, u_c, t)
\tag{2}
$$

Where:
- State spaces with track co-ordinates ζ-η, heading ψ:

$$
x = [u, v, r, \xi, \eta, \psi, \delta, n_{ME}, n_{TH}, ...]
$$

- Controls with commanded values Cmd for main engine ME and thrusters TH:

$$
u_c = [\delta_{Cmd}, n_{ME\_Cmd}, n_{TH\_Cmd}, ...]
$$

- with initial conditions at: $t = t_0$: $x(t_0) = x_0$, $u(t_0) = u_{c0}$:

$$
x_0 = [u_0, v_0, r_0, \xi_0, \eta_0, \psi_0, \delta_0, n_{ME0}, n_{TH0} ...]
$$
$$
u_{c0} = [\delta_{Cmd0}, n_{ME\_Cmd0}, n_{TH\_Cmd0}, ...]
$$

This equation of motion (2) can be solved by numerical integration for the simulation time period t_0 to t_1 in the form of the general solution:

$$x(t) = x(t_0) + \int_{t_0}^{t_1} x'(t)\,dt$$

i.e. for the full set of states and controls:

$$x(t) = x_0 + \int_{t_0}^{t_1} f(x, u_c, t)\,dt \tag{3}$$

A simplified solution for a simplified simulation is used by integration of track and heading assuming only constant speed u_0, v_0 and rate of turn r_0, which results always in a circular motion with constant speed and will be used for simplified prediction with reduced accuracy or to indicate the current motion status valid only for a small time span:

$$x(t) = x_0 + \int_{t_0}^{t_1} f(u_0, v_0, r_0)\,dt \tag{4}$$

2.2 Technological setup for simulation - SIMOPT & SIMDAT as tools for fast time ship simulation and assessment

The quality of the math model for the simulation and the parameters in the equations are of high importance for the effectiveness of the dynamic prediction. There is a great need for fast and effective modelling / tuning processes not only for the predictor but also in Ship handling simulators where clients from shipping companies need to be trained on their ship types. This is the same procedure as we need for tuning the ship model parameters in the predictor.

A PC-based software package was developed at MSCW (Benedict [1]) to be used for the fast time simulation (SIMOPT) and assessment of the results (SIMDAT). The Advantage and Capabilities of this software is: The Math Model reveals same quality for simulation results as the Ship handling simulators SHS, but it is remarkably faster than real time simulation, the ratio is up to 1/1000, the steering of simulator vessels is done by specific manoeuvre-control settings / commands for standard procedures and individual manoeuvres dedicated for calculation standard ship manoeuvring elements (basic manoeuvres) but moreover for the estimation of optimal manoeuvring sequences of some characteristic manoeuvres as for instance person over board manoeuvres.

Fig. 1 show some details of the SIMOPT interface: The ships main data are displayed in the left part. The hull coefficients are displayed in the centre. Manoeuvres can be selected from the right top menu.

Manoeuvres can be selected from the right top menu. Simulations can be done either as single run or as simulation series for selection of up to 3 Parameter series to be simulated in parallel or sequential for:

- Simulation parameters, e.g. Manoeuvre series;
- Ship Parameters (L, B, T, or others);
- Hull / force parameters coefficient and
- Environmental data, e.g. wind force.

A specific new "Offline assessment tool" SIMDAT was originally designed at the MSCW to supply the instructor with semiautomatic assessment of the recorded exercise data in ship

handling simulator ([1]). For the purpose of ships model parameter tuning and optimisation of manoeuvres this SIMDAT tool was extended: The Data for the manoeuvring characteristics can now be automatically retrieved for all manoeuvres used for simulator ships tuning; enhanced Graphic tools are available for displaying various types of results. The results of a particular evaluation are shown in Fig. 2 and Fig. 4. Additionally to the different graphical presentations specific overviews on the results are provided when series of manoeuvres have been simulated. This figure shows e.g. a comparison of simulation series results for turning circle with respect to Transfer, Advance, and Diameter. It can be presented in tables or in diagrams or used for optimization algorithms.
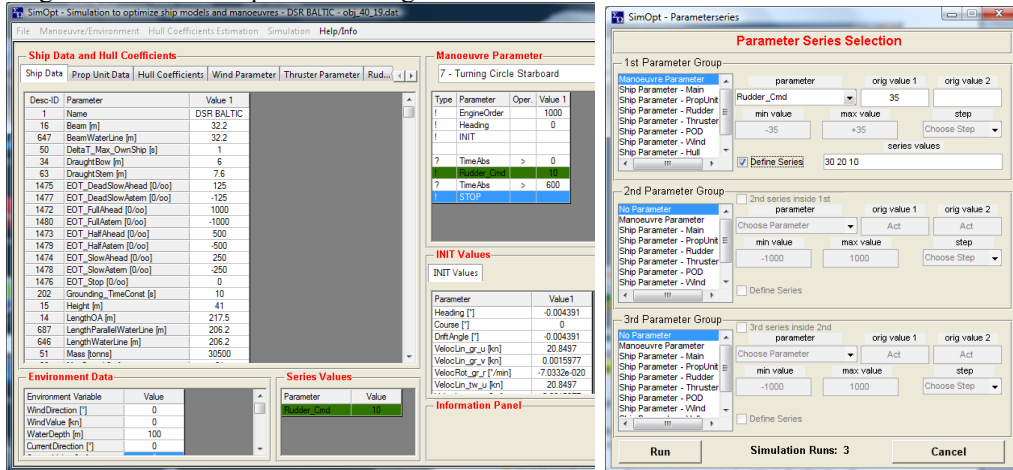

Fig. 1 SIMOPT Interface Elements – Overview (left): Ship Data / Hull Coefficients, Manoeuvre Commands as well as Manoeuvre Optimisation criteria and Parameter series values (right)
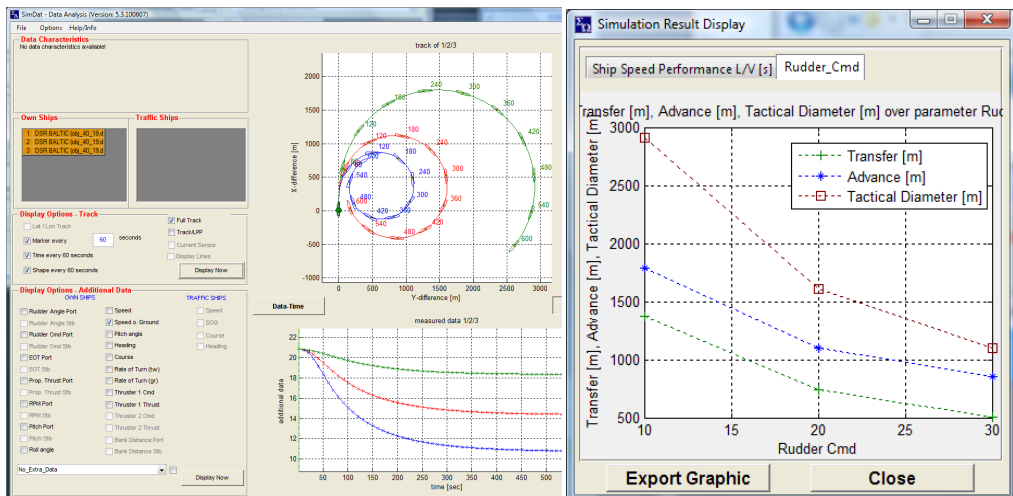

Fig. 2 SIMDAT Interface Elements – Overview with tracks and time histories (left) and extracted results in tables or here in graphs respectively (right)

2.3 Sample of a Manoeuvre Optimisation

The objective of the manoeuvre optimisation process is to find suitable procedures which can be used in the simulator or in reality with the real ships.

In the beginning there are standard files for manoeuvre control settings for the specific manoeuvres. By means of the SIMOPT program the fast time simulation produces various results of manoeuvres which are retrieved by SIMDAT and compared with Manoeuvre-Quality Criteria. By changing the Manoeuvring-Parameters the manoeuvring performance can be improved. The final goal is to achieve an Optimised Manoeuvre control setting for training & research in SHS. The biggest problem is that there are many options possible and the effect of the changes of the parameters is not very clear; some changes may even have effects which counteracts the results of the others. Therefore it is very important to know about the parameters which have a clear impact on the manoeuvring characteristic. Results have to be applicable as reference manoeuvre for training & assessment e.g. in SHS. An example is given below to indicate the need and the effect of manoeuvring optimisation by means of an Emergency Return Manoeuvre.

The STCW Code emphasises a thorough knowledge of and ability to apply the procedures of search and rescue operations. The following extract is an example Fig. 3 of an emergency return manoeuvre in Fig. 3, well known as the "Scharnow-Turn" (see [3][4]).
The main aim of this person over board manoeuvre is to return the vessel to the original track by the shortest route and with minimum loss of time. In practice the vessel initially follows the turning circle, and after shifting the rudder by a course change of about 240°, finally turns to counter rudder and amidships, the vessel then swings back to the opposite course at a certain measurable distance from the original track, respectively at a certain distance from the reference manoeuvre.
The problem is how to get the "Optimal reference manoeuvre" because the heading change of 240° is an average only and can differ among ships between 225 up to 260° in the same way as for the Williamson Turn which can vary from 25° to 80° instead of the standard average value of 60°.
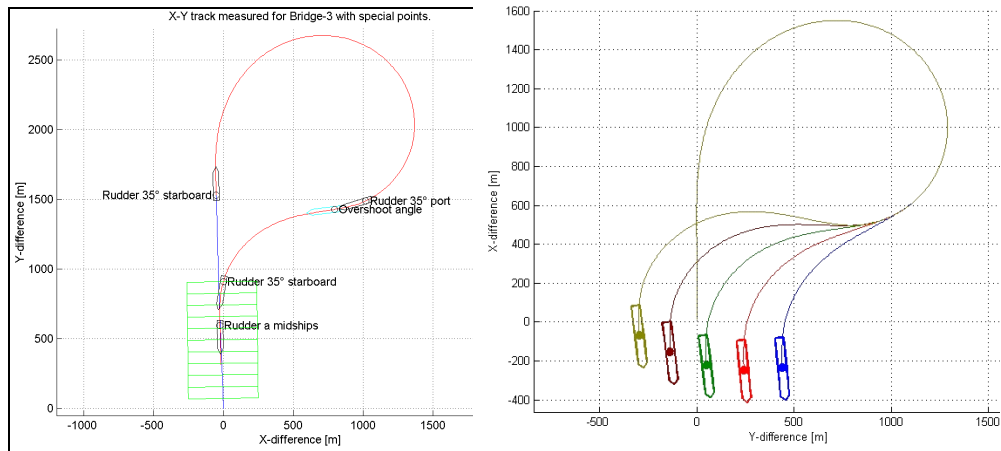

Fig. 3 Reference outline for the Scharnow–Turn (left) and Optimisation Series for different heading changes 220°, 230°, 240°,250° and 260° for counter rudder (right)

Using the SIMOPT and the SIMDAT programs there are two ways to come to the optimal result:
- The 1st Option is to simulate series of manoeuvres using standard „Scharnow-Turn" manoeuvring commands in automated simulation series: This method can be seen in Fig. 3 (right) where several heading changes were used as parameter to vary final result of distance between the initial track and return track.

- The 2nd Option is to start with a Standard „Scharnow-Turn" manoeuvring command series for automated simulation (centre right) together with optimisation procedure: An optimising algorithm is used to find suitable heading change for counter rudder as parameter to achieve smallest distance (limit=10m) between initial track and return track on opposite heading (limit=2°). The Optimal track is indicated by yellow colour in Fig. 4. The main parameters of the optimised manoeuvre procedure are given in the table format.


```
X-Y track of 1/2/3/4/5/6/7
```

```
*********** Manoeuvre information***********************
main parameter for emergency return manoeuvre
    with starting speed of 25.5 kn
***************************************************

TYPE:          port    Scharnow turn
initial approaching heading            : -0.0 °
initial approaching course/track       : 0.0 °
time of hard rudder port               : 0 min 1 sec
hard counter rudder to starboard after : 233.1 °
time of hard rudder starboard          : 5 min 20 sec
overshoot angle                        : 24.7 °
opposite course/track (+180°)          : 180.0 °
hard counter rudder to port    after : 204.5° at 155.5°
time of hard rudder port               : 8 min 3 sec
time of rudder a midships               : 8 min 40 sec
cross distance to original track       : 3.9 m
final heading                          : 179.4 °
final course/track                     : 179.0 °
```
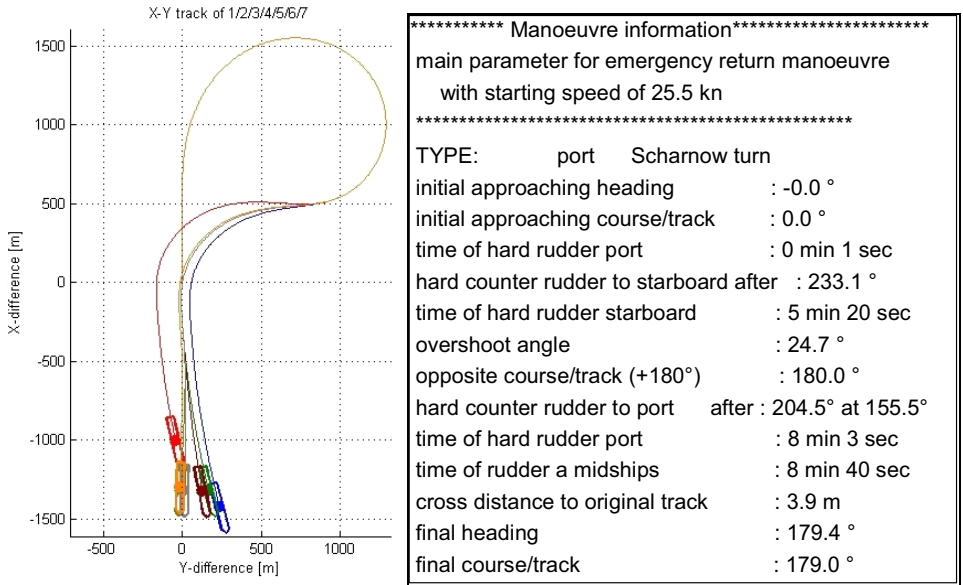
Fig. 4 Tracks of SIMOPT Emergency Return Manoeuvre Optimisation procedure (left) and Display of manoeuvring details for Optimised manoeuvre by SIMDAT (right)

3. Fast time simulation for manoeuvring design in sea chart

3.1 Presentation of fast time simulation of manoeuvres in ECDIS environment
The same fast time simulation tools were used to find out efficient manoeuvres for the design of manoeuvring plans. Some basic functions are shown in the next figures.
Fig. 5 explains the method in a sea chart environment present by an interface which combines the electronic navigational chart ENC window (centre), the status of the current actual ship manoeuvring controls (left) and the interface window for the steering panel of the ship (right). The ship was positioned in a certain place to demonstrate the ships motion for a very simple manoeuvre kick turn from zero speed. The ships motion can be controlled by the settings in the control panel window where any manoeuvre can be generated and will be immediately displayed in the ENC in less than one second with full length. The length of the track corresponds to the settings in the prediction window (left top corner): the range value represents the duration of the manoeuvre; the interval value controls the number of displayed ship contours on that manoeuvre track. The sample represents a kick turn from zero speed to full ahead with one rudder (PT).
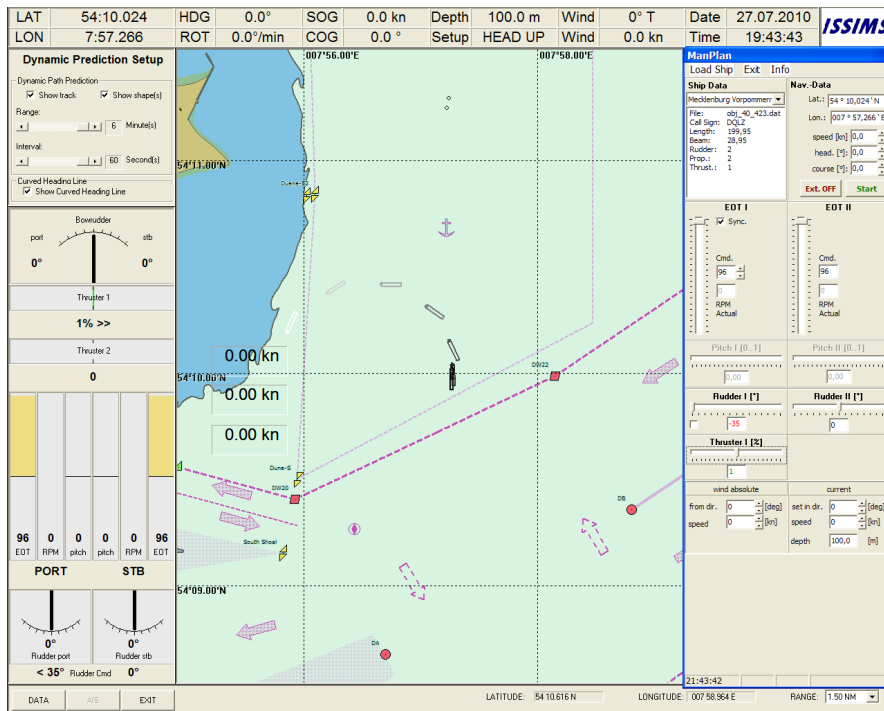
Fig. 5 Kick turn from zero speed to port as sample for potential ships manoeuvring capabilities

Fig. 6 show a specific manoeuvring situation: a ship is positioned in a fairway and is going to enter the harbour basin. This shall be done using a Kick turn from zero speed to port: the suitable rudder is found 10° and also the thruster is used adequately.

Fig. 7 presents the situation after execution of the manoeuvre previously planned – the ship is entering the moles and it is time to plan the following manoeuvre. This is to be seen in Fig. 8: starting with the initial conditions from the previous manoeuvre the control settings have to be found for bringing the ship alongside the berth. This can be done very easily by trial an error varying manually the rudder, thruster and engine order values until the result is acceptable. The different settings of the controls and the track of the planned manoeuvre sequences are stored in a manoeuvre planning file to be displayed in the ENC.

For the execution of the manoeuvre this plan can be activated later to be superimposed in ECDIS together with the actual position of the ship and most important with the prediction of manoeuvring capabilities (see [2]) for effective steering under the actual manoeuvring and environmental conditions. This concept will be explained more detailed in samples in the presentation at the IAMU 2010 Conference.
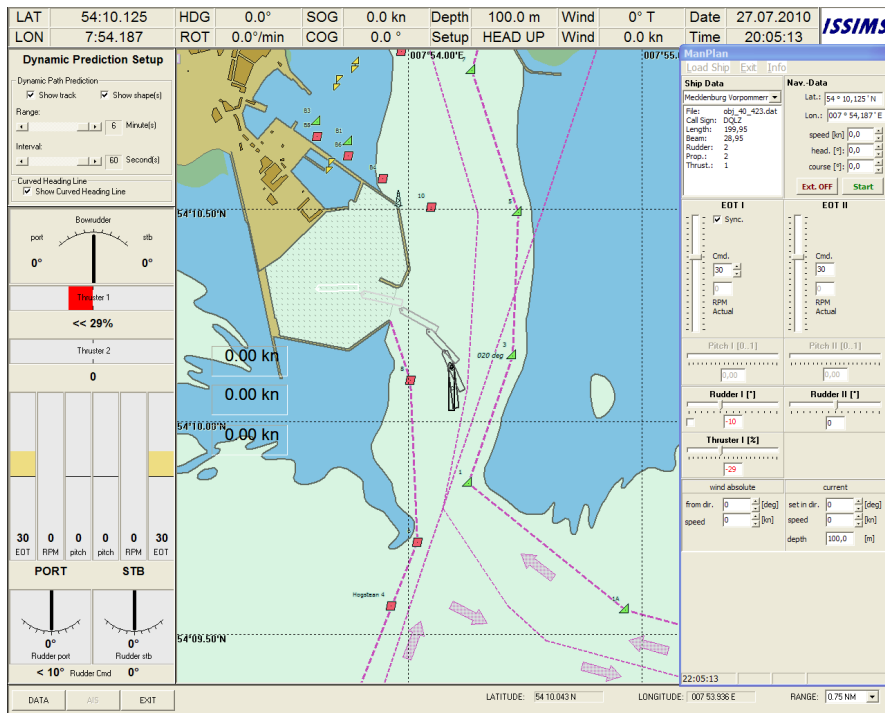
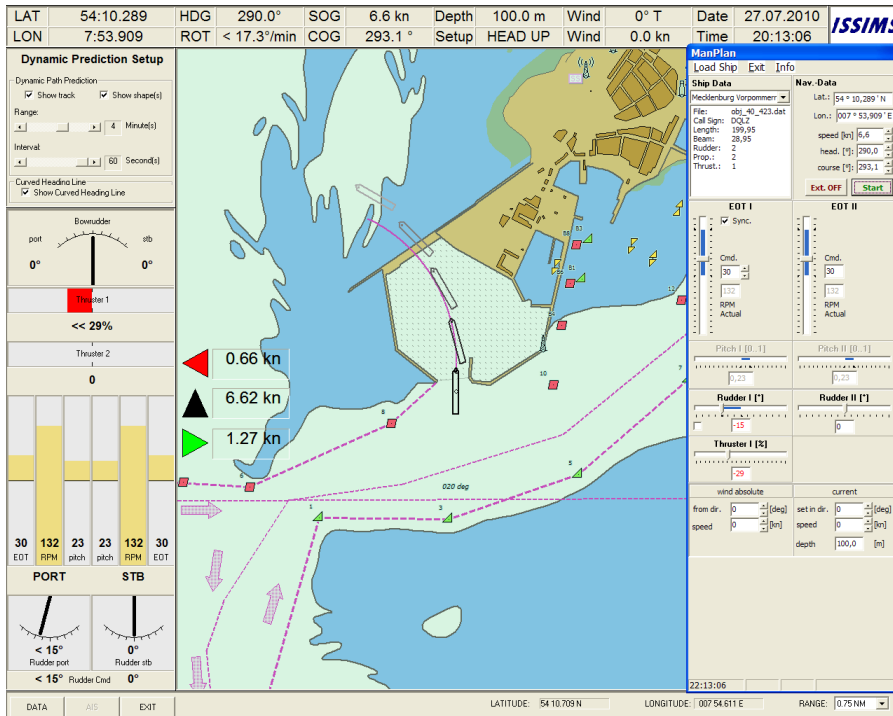**Fig. 6 Kick turn from zero speed to port adjusted for entering a specific port from initial conditions in a fairway**

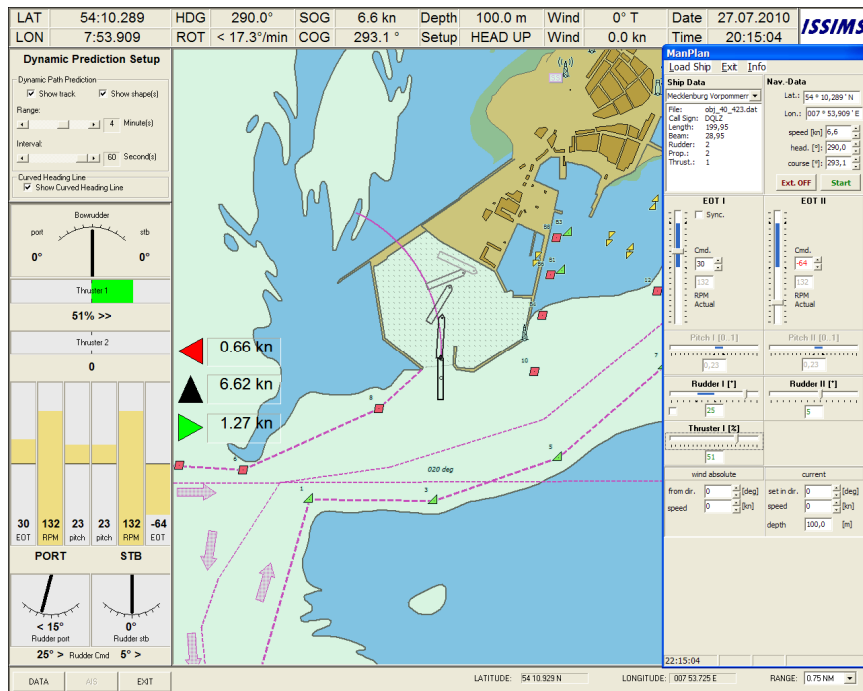**Fig. 7 Execution of the manoeuvre previously planned - Position of ship entering when the moles**

Fig. 8 Planning of the next manoeuvre starting with the initial conditions from the previous – adjustment of manoeuvre details for bringing the ship alongside the berth

References

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[2] Benedict, K., Baldauf, M., Fischer, S., Gluch, M., Kirchhoff, M.: Manoeuvring Prediction Display for Effective Ship Operation On-Board Ships and for Training in Ship Handling Simulators. IAMU 10th Assembly & Conference 2009 St. Petersburg / Russia at AMSMA, 19-21 September, 2009

[3] Benedict, K.; Hilgert, H. "Rueckfuehrung des Schiffes bei Mann-über-Bord-Unfällen", Part 1 HANSA, Hamburg, 1986

[4] Benedict, K.; Hilgert, H. "Optimising man-overboard manoeuvres", 15th Conference of Bulgarian Ship Hydrodynamic, Centre Varna, Proceedings Vol. 1, 1986