New Approach for Shiphandling Training in Simulators Using Small Scaled Simulator Ships as in "manned Model Training"

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Abstract

Full mission simulators have proven benefits for ship handling training in real time on fully equipped bridges throughout the last decades. In parallel the training in manned (or better "crewed") ship models has emerged where the trainee sits onboard the small scaled boats. The benefits of the scaled model training is that the time is also scaled and therefore the exercises with a model ration 1:25 need only one fifth of the time of exercises on a real training vessel or in a full mission simulator.

In order to take advantage of this time saving approach an investigation were made to model an existing simulator ship (container vessel of 2500 TEU) as a small scaled duplicate 1:25 in a Shiphandling simulator. The main parameters of the large model were changed according to the scale ratio as a basic setup for the small model. Series of simulations were made to adjust the manoeuvring characteristics for suitable similarity. For these procedures professional tools SIMOPT and SIMDAT were used for fast time simulation and for automatic assessment of the simulation results.

As test bed for this new approach a specific training area setup was used representing several parallel course manoeuvres passages and return manoeuvres similar to person over board manoeuvres at the Maritime Simulation Centre Warnemuende (MSCW) of Wismar University. This setup was successfully used during the investigations in an IAMU project on Shiphandling training with manned models on a lake and on board the big training vessel of Gdynia Maritime Academy in Poland.

As a result it turned out that some parts of the basic Shiphandling training exercises can be done more efficiently in less time than before. The results clearly indicate that the students' experiences made with the small scaled model could be transferred to the original scaled ship successfully.

I. INTRODUCTION AND AIM OF THIS PAPER

I.I. ORIGIN OF THE IDEA -THE IAMU TRAINING WORKSHOP IN ILAWA AND EXPERIENCES

Full mission simulators have proven benefits for ship handling training in real time on fully equipped bridges throughout the last decades. In parallel the training in manned (or better "crewed") ship models has emerged where the trainee sits onboard the small scaled boats. The benefits of the scaled model training is that the time is also scaled and therefore the exercises with a model ration 1:25 need only one fifth of the time of exercises on a real training vessel or in a full mission simulator. An IAMU research project "Analysis of effectiveness and efficiency of MET in Shiphandling" started in 2006 to compare and to analyse several training methods in small manned ship models, in Shiphandling simulator and on training ships in order to find out the benefits of the approaches.

Within this project a workshop for shiphandling training in 2006 was excellently organized by the Maritime University of Gdynia, Poland. Students from the 4 project partners Maritime Universities (apart from Gdynia they came from Wismar University, from Odesa National Maritime Academy and from Maine Maritime Academy). The Ship Handling Research and Training Centre at Ilawa, Poland was hosting the first part of the workshop with the manned models: This centre has been coaching masters and pilots for more than 20 years in manned models of different ship types. For the students' exercise in the workshop a LNG-Tanker ship model Figure 1 was used, which had to be steered through a buoyed waterway, specifically in a series of "Parallel Course Manoeuvre" and Williamson Turns at both ends to be seen in Figure 2 .
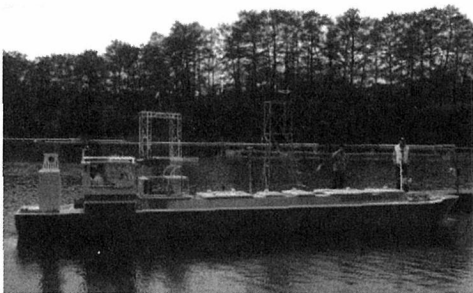

Figure 1: Student Karina Wieseler from Wismar University on the bridge of the LNG tanker model during berthing manoeuvre at Ilawa Training Centre

Figure 2: Track of the ship model (dotted green line) during "Parallel Course Manoeuvre" (Result of Student Nicole Schnell from Wismar University)

During this test it turned out that the training in the small manned models is faster than the training in full mission simulator and much faster than on the training vessel. Therefore the idea was born to transfer the advantage of smaller time consumption of the exercises with the small scaled ship models to simulator training facilities. The German team of the project came to the conclusion to model a small scaled simulator ship in the Shiphandling simulator of the MSCW and to make some tests on the suitability and efficiency which will be described in the following part of the paper.

1.2. SHORT OVERVIEW OF MSCW / SHS As TEST BED FOR THE NEW TRAINING APPROACH

The Maritime Simulation Centre Warnemuende at Wismar University, Department of Maritime Studies in Rostock-Warnemuende accommodates six simulators embracing a common network and comprised of four ship-handling bridge systems with differing levels of equipment, a ship's engine system and a VTS simulation facility. The interaction of many of the simulators can be interfaced either mutually or to form a big scenario comprising all simulators (Benedict 2000).

The Ship handling Simulator (SHS) comprises four bridges: Bridge 1 consists of a fully integrated replica bridge assembly projector-based 360° visual display, Bridge 2 has a similar 257° visual display system which can be specifically used for manoeuvring a ship from bridge wing, the remaining two bridges 3 and 4 are used mainly as radar cabins, each being additionally equipped with 120° visual display screens. A lab with four stations for computer-based Instructorless Training (ILT) completes the setup for effective ship handling training.
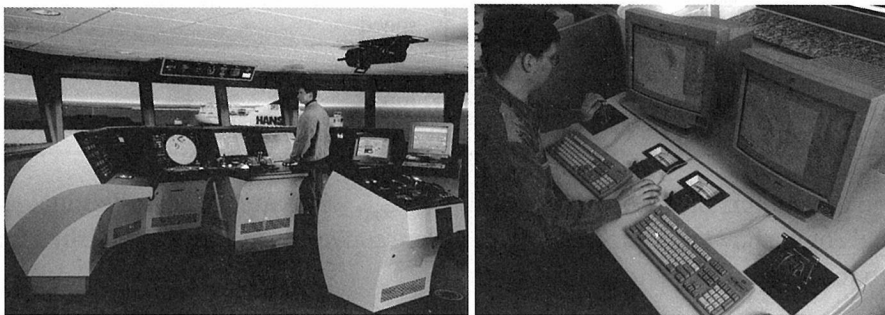

Figure 3: Full Mission Bridge Simulator with CV BALTIC (left) ad Instructorless Training Station for Shiphandling (right) at the MSCW of Wismar University

Specifically the Instructorless Training Stations should be used for the experiments with the small scale models because they are generally used to prepare for the training in the full mission simulators and excellently suitable.

2. TUNING OF A SMALL SCALED SHIP MODEL IN THE SHIP HANDLING SIMULATOR

2.1. SELECTION OF SHIP TYPE, VESSEL DATA AND CALCULATION OF THE MODEL SHIP PARAMETERS AND COEFFICIENTS

As sample ship a 2500 TEU container vessel Type BALTIC was selected from the ship handling simulator database. It is excellently modelled to the original full sized ship and often used in the training sessions as well as highly accepted by the master and pilot trainees. Her length is $L_{OA} = 220$ m and the service speed about 20 kn.

The basis of the calculations is the geometrical similarity of the ship and the model-the aim is the similarity in manoeuvring behaviour. Froude's similarity laws (which is also the basis of regular ship model tests in reality) were used, examples:

a) Geometrical similarity:	
$L_s = l * L_m$ This results in e.g.	Index s: ship; Index m: scaled model l : scale factor (e.g. 24); L: length
$A_s = l^2 * A_m$ and	A: area
$V_s = l^3 * V_m$	V: volume
b) Kinematical similarity:	
$t_s = \sqrt{l} * t_m$ which results in e.g.	t: time
$v_s = \sqrt{l} * v_m$	v: speed
c) Dynamical similarity:	
$F_s = l^3 * F_m$	F: forces
$P_s = l^{3.5} * P_m$	P: power

The parameters of the original vessel (e.g. L_{OA}, wind attack areas, nominal speed, nominal engine power, displacement, etc.) were converted by these established formulas into the small scaled ship model data:

Parameter / Ship data	Original and Full Mission Simulator Ship	Small Scaled Simulator Ship
length over all [m]	217.5	9.06
beam [m]	32.2	1.34
draught [m]	11.0	0.46
rudder area [m²]	45.0	0.08

displacement [t]	49 308	3.57
nominal power [kw]	16 440	0.24 (10)
nominal speed [kn]	18.9	3.9

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

$$X = m\left(\dot{u} - rv - x_G r^2\right)$$
$$Y = m\left(\dot{v} + ru + x_G \dot{r}\right)$$
$$N = I_z \dot{r} + m x_G \left(\dot{v} + ru\right)$$

The ships hull forces 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 nonlinear terms. Normally these dimensionless parameters could be used also for smaller ships and it was expected in the beginning to directly take them into account for the small scaled model. However, the ship database of the SHS was not prepared for such small power driven ships and accepted 10 kw as minimum power input of a simulator ship unfortunately. Therefore some extra work has to be done to adjust the ship model data to this power with the help of the SIMOPT software described below.

By means of a Clarke (e.g. 1983) estimation the hydrodynamic added masses and the coefficients of the equations of motion were estimated. To acquire the desired similarity in manoeuvring behaviour and the required track similarity these values (e.g. *Xup*- dimensionless hydrodynamic added mass in x-direction, N*uv*- hydrodynamic lift coefficient, etc.) were tuned to an acceptable coincidence. To compare the similarity of the tracks it is helpful to present the results divided by L_{pp} (length between perpendiculars).

2.2. TUNING OF MODEL USING FAST TIME SIMULATION AND ASSESSMENT MODULES

2.2.1. FAST TIME SIMULATION MODULE SIMOPT

PC-based fast time simulation software was used for the tuning of the small scaled ship model which was developed at MSCW originally for the tuning of the regular simulator ship models (detailed description in Benedict et.al 2006). This software represents the same ships dynamic capabilities as the Ship Handling Simulator (SHS) system, except for some environmental impact as for instance shallow water, current or banking effects which are not considered for saving computation time. The programming was done in MATLAB and C++. The Advantage and Capabilities of this software is:

- The Math Model reveals same simulation results as SHS,

- It is remarkably faster than "SHS real time simulation " the ratio is up to 1/100,
- The steering of simulator vessels is done by specific manoeuvre-control settings / commands for standard procedures and individual manoeuvres.

The following figures show some examples of the SIMOPT interface:

If a ship file is loaded the ships main data are displayed (or can be entered for a new ship).. The hull coefficients are displayed in the centre. Manoeuvres can be selected from the right top menu. Several options can be chosen from the top menu (Figure 4) in order to calculate the hull data and other parameters based on methods published by Clarke1983, 1997 or Oltmann 2003.
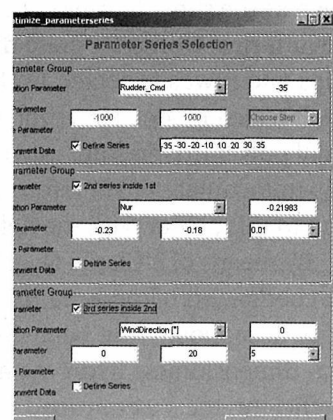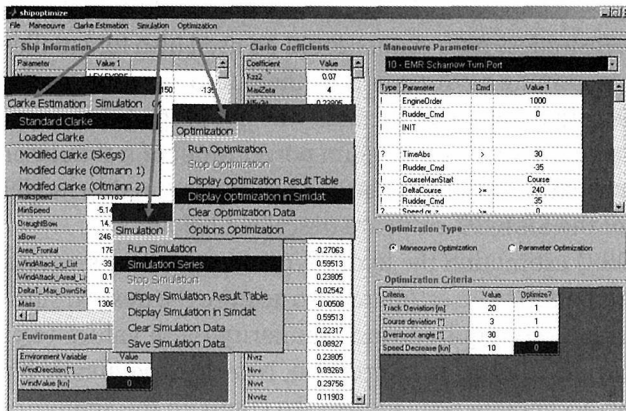

Figure 4: SIMOPT Interface Elements – Top Menus: Detailed Selection of Simulation and Analysis Elements from several menus; Manoeuvre Commands (top right) as well as Manoeuvre Optimisation criteria

Figure 5: SIMOPT - Optimising Ship Model Parameters and Manoeuvres by Parameter-Series

Manoeuvres can be selected from the right top menu. Simulations can be done either as single run or as simulation series following the principle to be seen in interface Figure 5 for selection of up to 3 Parameter series to be simulated in parallel or sequential for:

- Simulation parameters, e.g. Manoeuvre series (here 8 rudder angles)
- Ship Parameters (L, B, T, or others)
- Hull / force parameters Clarke coefficient, e.g. N_{ur}
- Environmental data, e.g. wind force

The example in that figure represents a series of 8 rudder angle variations, 6 parameter changes of Hull yaw moment coefficient N_{ur} and 5 different wind force conditions – that means in total 8x6x5=240 simulation runs, given in the bottom line!

During the simulation run the monitoring of simulation process is clearly indicated e.g. by "coloured bars" in the respective windows at current manoeuvre element.

2.2.2. SIMULATION ANALYSIS MODULE SIMDAT

The specific new "Offline assessment tool" SIMDAT was originally designed at the MSCW to supply the instructor with semiautomatic assessment of the recorded exercise data (BENEDICT et al. 2003). The tool allows for a detailed evaluation of the trainees results, e.g.:

- by analysing the plotted parameters or more complex data (e.g. the risk levels for collision avoidance situation) during the exercise or
- by comparing the ships track steered by the students with reference tracks.

The concept of data evaluation and assessment tool was to evaluate a variety of different manoeuvres and exercise elements with one common interface. During the evaluation all measurement data are analysed automatically according to selected criteria. Time- and limit- dependent violations are shown in the central window as well as penalty points according to an exercise specific algorithm are given. Apart from the evaluation of students training result the tools were used even in waterway investigation (Benedict et al. 2004).

For the purpose of simulator ships 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

In the upper graphic of Figure 6 the complete track history of a simulation run is shown. A slider on the right hand side of the graphic allows for the timely and detailed analysis of periods during the simulation. The track can be presented in x/y co-ordinates or in geographical co-ordinates.

The lower graphic displays a number of ships data measured during the simulation. This includes Rudder angle, speed or course information of all ships. All graphics can be zoomed so that details of the exercise become visible and the graphical data shown on the surface can be saved and exported for further use.

Depending on the simulated manoeuvre types several special evaluation algorithms are used to produce the results for the manoeuvre as shown in resulting graphs and tables of the particular evaluation.

Additionally to the different graphical presentations specific overviews on the results are provided when series of manoeuvres have been simulated. This figure shows a comparison of simulation series results for turning circle with respect to Transfer, Advance, Diameter, Final Speed and Final ROT. It can be given in tables or in diagrams. Moreover the complete set of ships manoeuvring characteristics can be retrieved as a basis for the simulator ships manoeuvring documents. For the tuning of the scaled ship models the track data can be even related to the respective ships length to compare the scaled models results with the respective data of the same ships original data or data of the original sized simulator model.
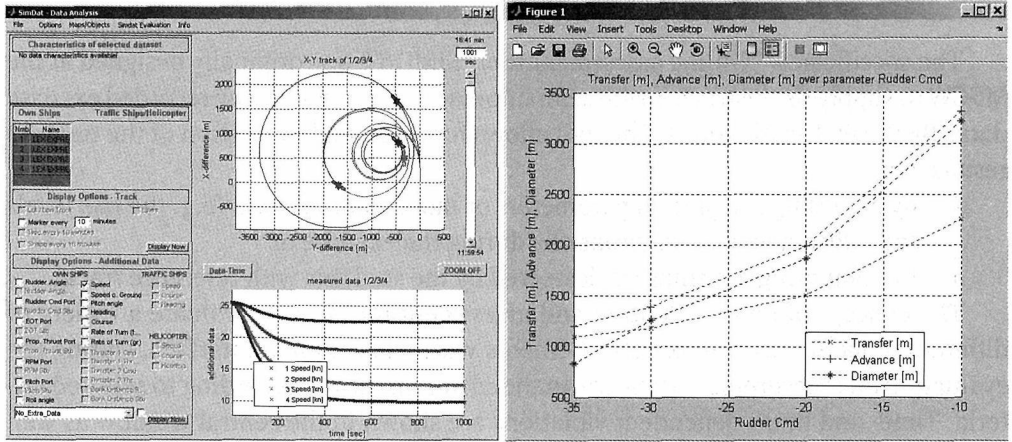
Figure 6: SIMDAT - Simulation result analysis in plots: Main interface and results for turning circle series varying rudder angles – Tracks and plots of time histories

2.2.3. PARAMETER – OPTIMISATION FOR SHIP MODEL FILES

The objective of the parameter optimisation process is to find suitable simulator ship model files which can be used in the simulator to represent the reference ships' dynamic. Starting from the ships main data, Basic Ship data files will be generated using simple methods (e.g. according to CLARKE 1983), to have a first estimation of the dynamic behaviour. By means of the SIMOPT program the fast time simulation produces various results of manoeuvring characteristics which are retrieved by SIMDAT and compared with the manoeuvring characteristics of the reference vessel. By changing the Model-Parameters the manoeuvring performance of Simulator Ship Model is adjusted. The final goal is to achieve a ship file with optimised model-parameters to be applicable for training & research in SHS. The biggest problem is that there are up to 200 parameters and the effects and tendencies of the changes are not very clear; some changes may even have effects which counteract the results of the others. Therefore it is very important to know about the parameters which have a clear impact on the manoeuvring characteristics. As an example for varying one of the Hull parameters here the variation of ships moment of inertia I_z is given; this parameter is expressed as kzz² in the database with

$$I_z = k_{zz}^2 \cdot m \cdot L^2$$

For the demonstration a Parameter-Series of turning circles with Hard Rudder to Starboard was simulated varying the value of k_{zz}^2 (which is initially 0.2) between 0.1 and 0.2 in steps of 0.01. The result in Figure 7 shows a clear effect on the advance of the turning circle whereas the diameter and the speed loss did not change.

The knowledge of those effects can be used to effectively tune simulator ships to have manoeuvring characteristics as the reference ships
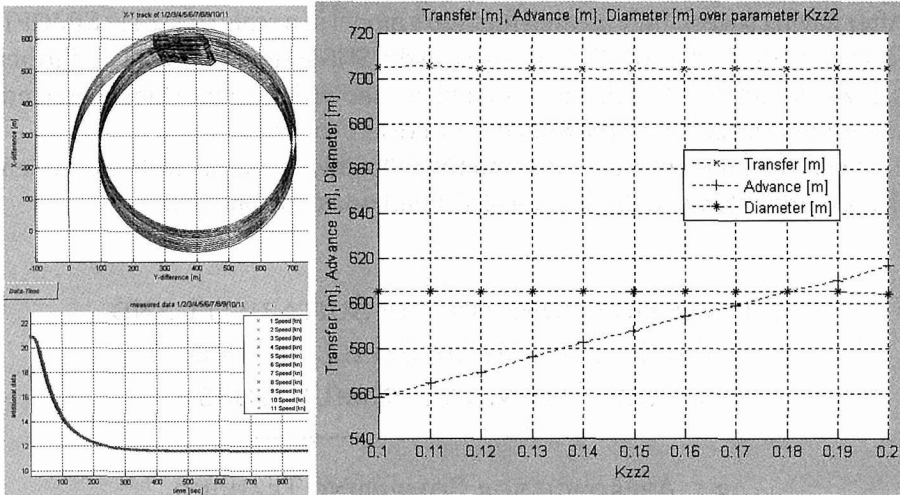
Figure 7: Model tuning - Parameter series for changing Moment of Inertia - Turning circle tracks and speed and extract of characteristic manoeuvring data

2.2.4. COMPARISON OF THE SHIP MODELS - RESULTS OF THE TUNING PROCESS

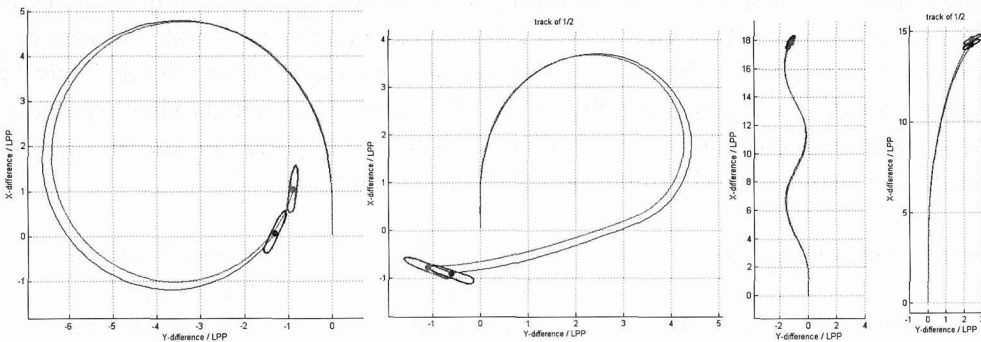The result of the tuning process for the small scaled ship model is to be seen in Figure 8.

Figure 8: SIMDAT - Comparison of manoeuvring track results related to ship length Lpp for full sized ship (red) and the small scaled ship model (blue):
- Turning circle full rudder – left; Single Turn starboard - 2nd left;
- Zig-Zag test Port 10°(3rd left), coasting stop (centre); Crash-Stop Tests from full ahead to full astern (right)

The example tracks were taken from the SIMDAT software, which is used as a tool for manoeuvring data analysis and evaluation. The blue track describes the track of the small scaled model, the red track the motion of the original sized simulator ship model.

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After having successfully created the ship's model in a scale of 1:24 in SIMOPT, the model was transferred to MMOCE database in the SHS system at MSCW for further test trials. It was found that the full mission simulator showed the same ships characteristics as the results as achieved by the SIMOPT / SIMDAT software.

This was the prerequisite to undergo the following test trails with the students to check for the suitability of the small scaled simulator ship approach.

3. Investigations on the Suitability and effectiveness of Small Scaled model Training in Simulators

3.1. Approach for Comparing Training Results and Trail Setup

3.1.1. Different Sea Areas and Experience levels in Groups of Trainees

In order to investigate whether the small scaled ship model is applicable for the shiphandling training three groups of test persons were built. Each group had to complete several voyages through a buoyed waterway identical to the Parallel Course Manoeuvre established for the workshop in the Ship Handling Research and Training Centre – Ilawa (see Figure 2 and Figure 12). This training area had to be prepared in the same scale as the ships, i.e. we had one area for the original ship size and one for the small scaled model. The dimension of the sea areas are:

- original ship model sea area:	north - south	7300m = 3.94 nm
	west - east	2230m = 1.20 nm
- small scaled ship model sea area:	north – south	300 m = 0.164 nm
	west - east	90 m = 0.0485 nm

Most of the trainees did the trips with the small scaled simulator ship model first and afterwards they used this experience gained to check their training skills on the large ship, others started with the full sized simulator ship.

The concept is to compare all these groups in order to find out whether they are able to transfer the skills they had gathered with the small scaled ship to manoeuvre the original sized vessel. Additionally the impact of the level of information to the trainees should be investigated: the test situations for the groups differ in the level of guidance and information they either got provided or had to be prepared by themselves.

- Group 1 - so-called beginners- they did not get any information or manoeuvring parameters of the ship model, they had to steer through this buoyed waterway without any preparation.
- Group 2 - so-called experienced users - they performed a Course-Change-Test for measuring the overswing angle y_0 and determined graphically the course change distance X_c by means of the track figures of turning circles. On the basis of these values they prepared themselves and planned the manoeuvre before-hand.
- Group 3 – so-called informed users – they got provided all necessary parameters on paper documents, they used existing Course-Change-Diagrams to plan their passage.

The following scheme shows the differences between the groups:

Data provided as guidance for the tests	GROUP 1 Beginners	GROUP 2 Experienced users	GROUP 3 Informed users
overswing angle y_0	-	performed Course-Change-Test to measure parameters individually	Provision of Course-Change-Diagram
course change distance X_c 7300m = 3.94 nm	-	determined graphically with tracks of turning circles for diff. course changes	Provision of Course-Change-Diagram

Each group has to pass the track four times at a preset speed of 2 kn, equivalent of Half Ahead of the original simulator ship model.

3.1.2. RESULTS FROM COURSE–CHANGE–TEST AS INFORMATION FOR THE TRAINEES

Results of a course change test are suitable information for voyage planning: This test was developed by Nomoto (see also Benedict 1987) to support ships in course changes e.g. in a given lane width. The following parameters are useful:
- course change distance X_c for wheel-over-point
- overswing-angle y_0 to apply for counter rudder action before having reached the final course

The following test procedures can be applied for the trails to acquire the necessary data:

The ship approaches to the test with constant speed and steady course. Then following actions will be taken:

- apply initial rudder angle d_I , e.g. $d_I = 10°$

- keep until a certain change of heading, e.g. $\Psi_C = 45°$; then apply counter rudder $d_C = 10°$ PT until rate of turn $= 0$
- rudder midships and steady course; - final course-change-angle is to measure e.g. $= 31°$
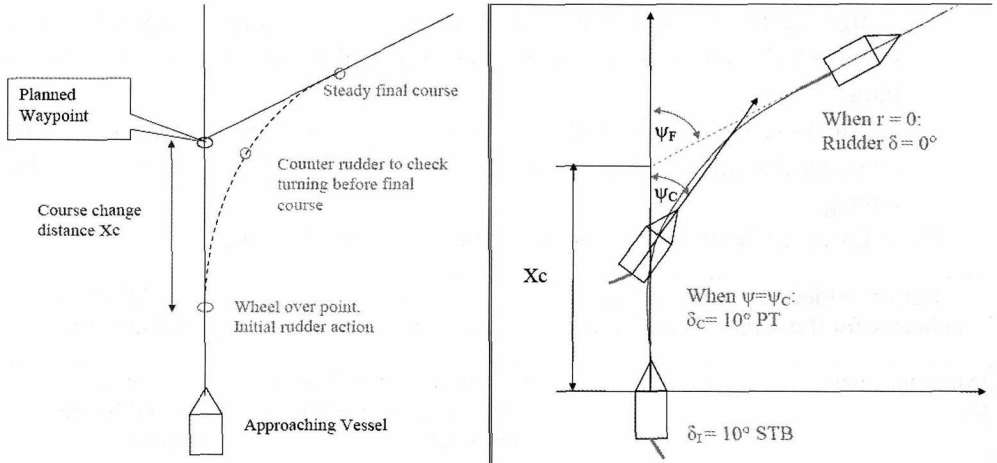- calculate over-swing-angle: $\Psi_0 = \Psi_F - \Psi_C = 56° - 45° = 11°$

Figure 9: Standard course change manoeuvre and data for manoeuvre planning (left); Procedure of a Course Change Test, relevant parameters and actions (right)

This can be repeated for different course changes and/or rudder angles.

The course change distance X_c can be determined graphically by using the track figure of a certain turning circle (Figure 10). The planned course has to be applied as a tangent to the turning circle.
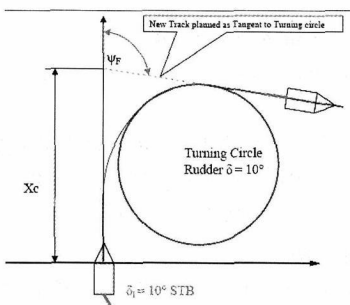

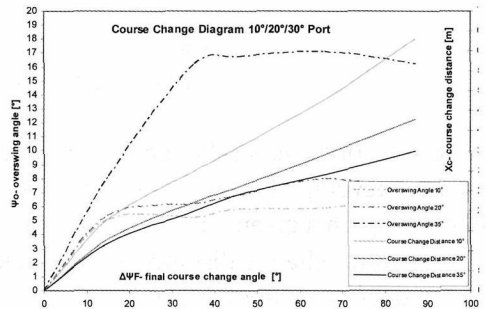*Figure 10: Simplified Estimation of XC from tangent to the related turning circle*

Figure 11: Course change diagram –Student Results of the trails with the small scaled ship model

The results of overswing-angle y_0 and course change distance X_c will be plotted in a diagram versus final course change angle (Figure 11). This diagram can be used for voyage planning according to the planned final course change at a waypoint.

3.2. RESULTS AND ANALYSIS OF THE TEST TRIALS

While performing their voyage through the buoyed waterway the students' results of the different groups were being logged. Data recorded includes track, rate of turn, rudder angle, engine orders. By means of the SIMDAT software these logged sessions can be evaluated and analysed for research purpose. Figure 12 presents an overview of SIMDAT software interface and the track in the small sea area layout.
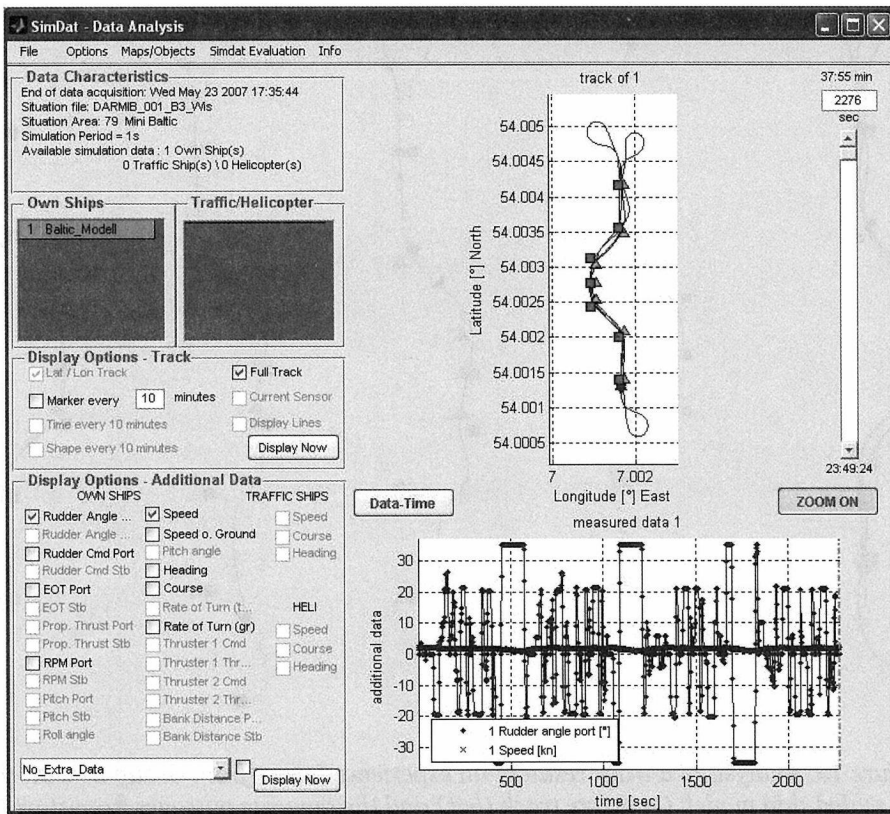

Figure 12: SIMDAT interface with data of a complete test run of a parallel course manoeuvre with the small scaled ship model – track with buoy system layout

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The voyage with the ship model through the buoyed waterway takes 40 minutes on average. In contrast the same passage with the original sized ship takes nearly three hours.

According to the training effect an improvement of the trainees' performance can be seen during the course of the track (Figure 13): Particularly from the second to the fourth passage the test person seems to become acquainted with the manoeuvrability of the ship model. While performing the exercise the students had some problems in considering the overswing angle in case they had to change starboard and port theoretically on the way down from north to south.
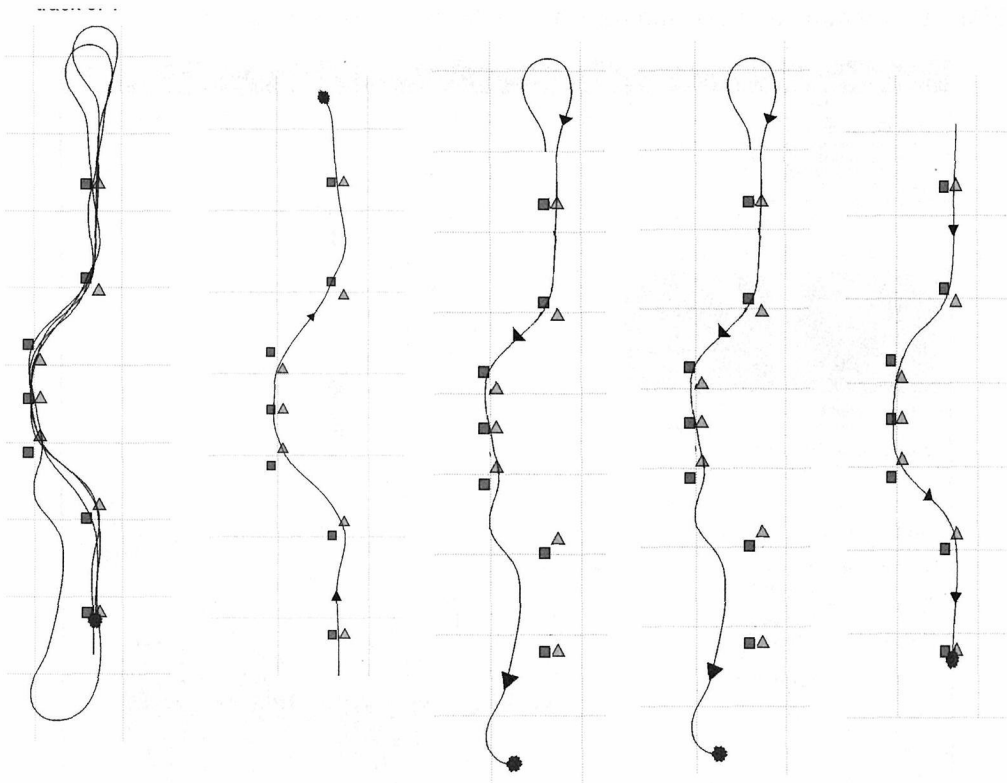

Figure 13: Analysis of a track result of an experienced user (from Group 2) with the small scaled ship model: Complete track (left) and the separate passages from start (2nd left) to the last passage (right)

Additional to the track figures the improvement can be seen also in the data figure of the rudder angle versus time (Figure 14). During the last passage the rudder commands and angles respectively reduced to a maximum value of 20°-25°, the first passage were steered only with hard rudder angles.
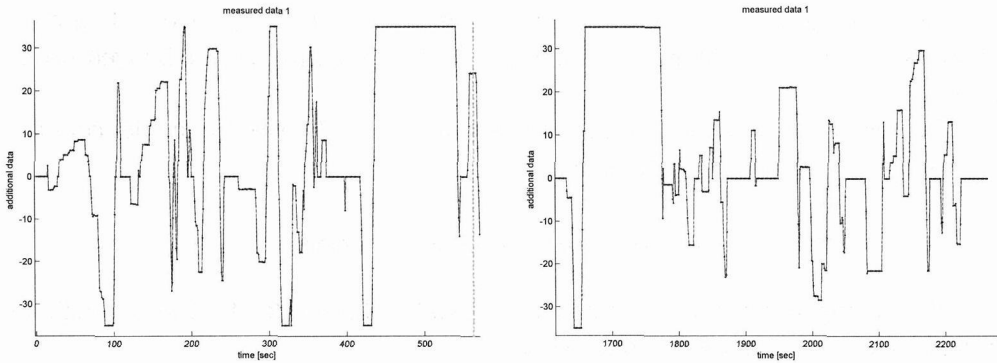
Figure 14: Analysis of a rudder angle plot of an Experienced user (from Group 2) with the small scaled ship model: 1st passage (left) and 4th passage (right)

After the training sessions with the small scaled ship model the same test persons manoeuvred the original sized ship. The person of the group of experienced users whose results are shown above performed now the track below in Figure 15:
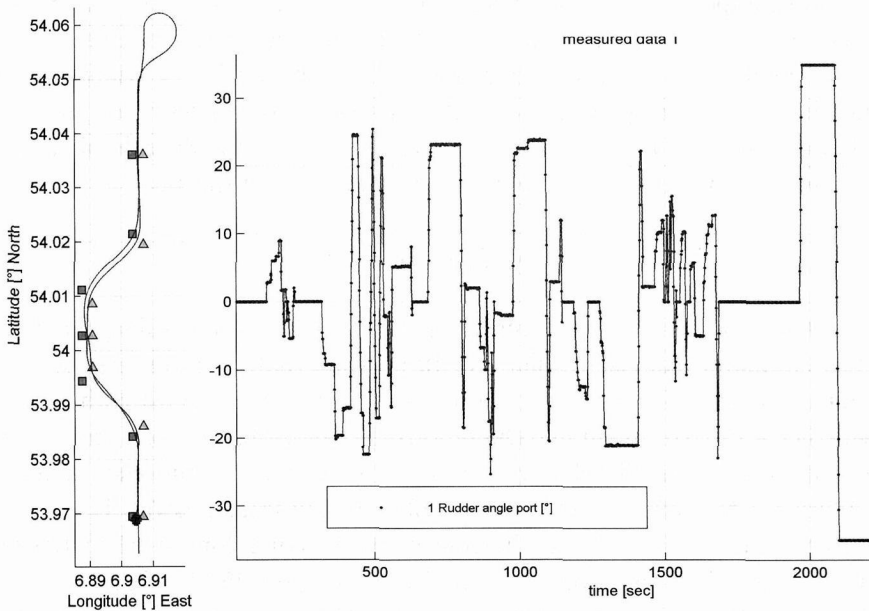

Figure 15: Analysis of test run of an Experienced user (from Group 2) with the original sized ship model: Complete track (left) and rudder angle plot of the first passage (right)

The voyage with the original sized model had to be reduced to half of the passages they had to do with the small scaled model, but even though this took 82 minutes.

There were approximately no deviation from the ideal course, The data figure displays also no higher rudder angles than 25° for steering through the buoyed waterway.

This result clearly indicates that the experiences made with the model could be transferred to the original scaled ship.

4. FINDINGS AND CONCLUSIONS

The investigation of the suitability of small scaled ship models for training in Simulators has led to the following conclusions:

It was possible to model a simulator ship with the same manoeuvring characteristic as a 2500 TEU container vessel in a smaller scale 1:24 successfully. Some extra efforts were necessary because the training area and the buoys had to be scaled, too.

Small scaled model ships could be used on very small bridges only because otherwise the ship might be smaller than the simulator bridge dimensions which imposes some problems with the visual perception; specifically suitable these small ships are on the ILT stations for basic training of manoeuvring aspects.

The most important advantage is the reduction of training time which was about five times less. Whereas for the small model four passages could be done in 40 min the duration for half of the program with 2 passages took 90 min for the original sized vessel model. The results clearly indicate that the students' experiences made with the small scaled model could be transferred to the original scaled ship. More detailed investigation will follow this short overview during students master thesis.

5. REFERENCES

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