Analysis of navigational safety by means of simulation studies in the Marine Traffic Engineering Centre in Szczecin

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Abstract: The paper presents possibilities of analysis of the navigation safety criteria acquired by means of simulation studies on several harbour areas in the Marine Traffic Engineering Centre in MU Szczecin. The features of the latest full-mission manoeuvring simulator have been described and assessment of its capabilities done.

1 Marine Traffic Engineering Centre – modern complex of ship's bridge simulators

On 26th April, 2007 the Marine Traffic Engineering Centre (MTEC) Project was officially finished and the new simulator centre in Maritime University of Szczecin, Poland has been activated. The Centre, financed in 75% from the European Regional Development Fund, comprises:

– one full mission navigation bridge simulator with 270° visual projection and live marine ship equipment,

– two part task navigation bridges with 120° visual projection and mix of real and screen-simulated ship-like equipment including Voith-Schneider tug console,

– two desktop PC simulators with one monitor visual projection and one monitor screen-simulated ship-like equipment,

– and a dedicated staff of more than 20 teachers and scientists supervised by Prof. Stanisław Gucma, Ph.D., Master Mariner.

All hardware and software is forming the “Polaris System” from Kongsberg Maritime AS which was granted DNV certificate for compliance or exceeding training capabilities set forward in the regulations of STCW’95 (section A-I/12, section B-I/12, table A-II/1, table A-II/2 and table A-II/3) [5]. The software includes mathematical-hydrodynamic ship-modelling tool with very advanced possibilities of tuning [3] (fig. 1).

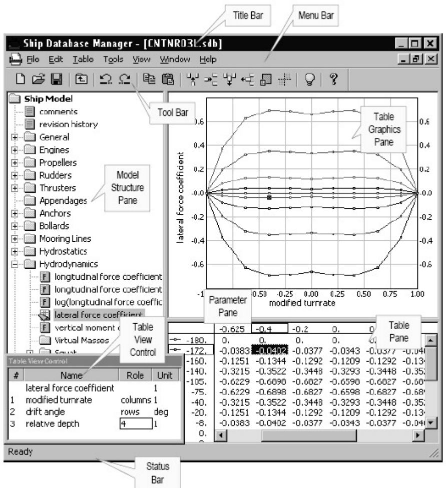


Fig. 1. Parts of ship database manager window.

This tool enables creating almost any ship type (controls for at least two engines with propellers’ controls for fixed propeller, adjustable pitch propeller and azimuth; rudder controls adequate for various types of conventional rudders, active rudders, Z-drive/azimuth and thrusters – DP ready) with very high fidelity hydrodynamics in 6 DOF (surge, sway, yaw, roll, pitch & heave). Visualisations of own ships, target ships and research areas are made in Multi-Gen 3D type environment [6] (fig. 2).

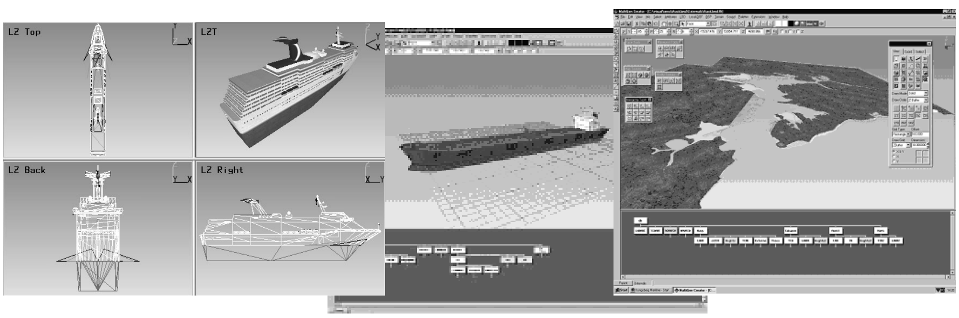


Fig. 2. Screenshots of ship’s and area building process.

In this environment all bathymetric, topographic and navigational marks databases are based on WGS-84 datum coordinates which can be directly loaded from C-Map™ or S-57 unencrypted electronic charts or easily imported from CAD-type and delimited text files.

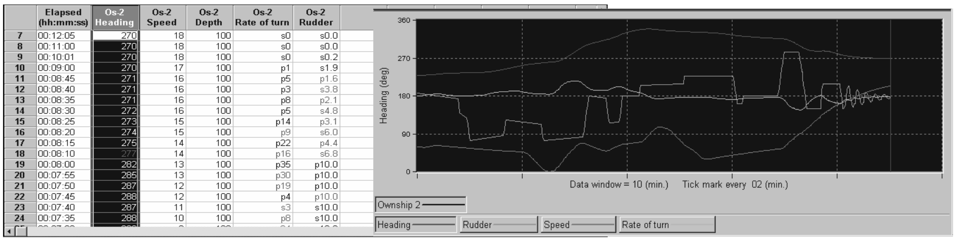
Exercise or research areas consist of the following types of databases interconnected to simulator live-marine equipment, screen-based equipment and hydrodynamic ship models: radar databases, depth databases, buoy databases, chart databases, visual databases, wave databases, current databases, wind databases, tidal height databases, fender databases, bank databases, navtex databases, DGPS databases, VTS databases, lock gates databases. MTE Centre presently has ready to use 7 databases of European sea areas including Europort, Hamburg, Danish Straits (Great Belt, Little Belt, The Sound), Świnoujście and 11 ship models including LNG carriers. Integration of five ship's bridge systems enables actually a great number of research configurations with different or repeating areas and ship models (5^5 with 5 different areas and 5 different models). Area databases and ship models can be used either in one scenario on five MTEC's ship's bridges (five own ships in one area) or can be divided into selected number of ship's bridges, still with possibility to group scenarios on some bridges (for instance two ships in the first area, three ships in the second area).

2 MTEC logging capabilities

The heart of the MTEC system is server station (fig. 3) directly managed by the instructor station (fig. 4).

Fig. 3,4. Instructor and server station.

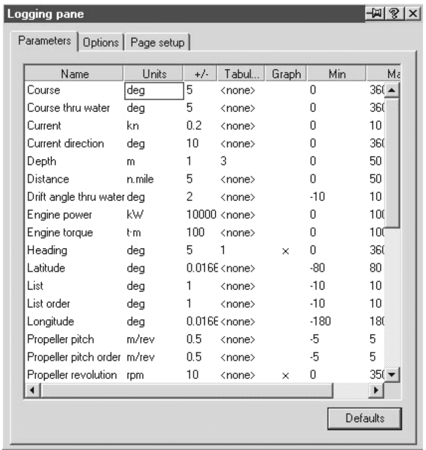
Data logging at the instructor station allows recording very wide range of parameters (more than 50 physical variables for each of the ship's models running independently). They can be presented on-line in tabular or graphic form, but what is most important they can be stored in Excel™ type format for export to other applications and future evaluation (fig. 5).



	Elapsed (hh:mm:ss)	Os-2 Heading	Os-2 Speed	Os-2 Depth	Os-2 Rate of turn	Os-2 Rudder
7	00:12:05	270	18	100	s0	s0.0
8	00:11:00	270	18	100	s0	s0.0
9	00:10:01	270	18	100	s0	s0.2
10	00:09:00	270	17	100	p1	s1.9
11	00:08:45	271	16	100	p5	p1.6
12	00:08:40	271	16	100	p3	s3.8
13	00:08:35	271	16	100	p8	p2.1
14	00:08:30	272	16	100	p5	s4.8
15	00:08:25	273	15	100	p14	p3.1
16	00:08:20	274	15	100	p9	s6.0
17	00:08:15	275	14	100	p22	p4.4
18	00:08:10	277	14	100	p16	s6.8
19	00:08:00	282	13	100	p35	p10.0
20	00:07:55	285	13	100	p30	p10.0
21	00:07:50	287	12	100	p19	p10.0
22	00:07:45	288	12	100	p4	p10.0
23	00:07:40	287	11	100	s3	s10.0
24	00:07:35	288	10	100	p8	s10.0

Fig. 5. Tabular and graphic form the logged data can be presented.

After or even during the exercise or simulation study, a preliminary analysis of navigational safety can be done at a glance by dedicated assessment system SEA™. This system enables selection of parameters to be assessed (for instance: distance from other ships, distance from fixed point, depth, contact energy …) and setting of criterion values (usually max and min values) for dangerous situations (fig. 6).



Logging pane

Parameters | Options | Page setup

Name	Units	+/-	Tabul...	Graph	Min	Ma
Course	deg	5	<none>		0	36
Course thru water	deg	5	<none>		0	36
Current	kn	0.2	<none>		0	10
Current direction	deg	10	<none>		0	36
Depth	m	1	3		0	50
Distance	n.mile	5	<none>		0	50
Drift angle thru water	deg	2	<none>		-10	10
Engine power	kW	10000	<none>		0	10
Engine torque	t·m	100	<none>		0	10
Heading	deg	5	1	×	0	36
Latitude	deg	0.016	<none>		-80	80
List	deg	1	<none>		-10	10
List order	deg	1	<none>		-10	10
Longitude	deg	0.016	<none>		-180	18
Propeller pitch	m/rev	0.5	<none>		-5	5
Propeller pitch order	m/rev	0.5	<none>		-5	5
Propeller revolution	rpm	10	<none>	×	0	35

Defaults

Fig. 6. Logging pane for set up of ship's parameters.

Logged data from several independently running scenarios in the same harbour area can be later statistically evaluated and assessment of the probability of accident (for instance grounding or collision with fixed structures) can be done.

3 Example of navigational safety analysis during harbours' manoeuvres by trainees on STCW courses

Main criterion of navigational safety analysis is meeting the goal of inclusion of manoeuvring area within the safe area what is based on the idea of ships' movement path analysis as presented in the figure 7.

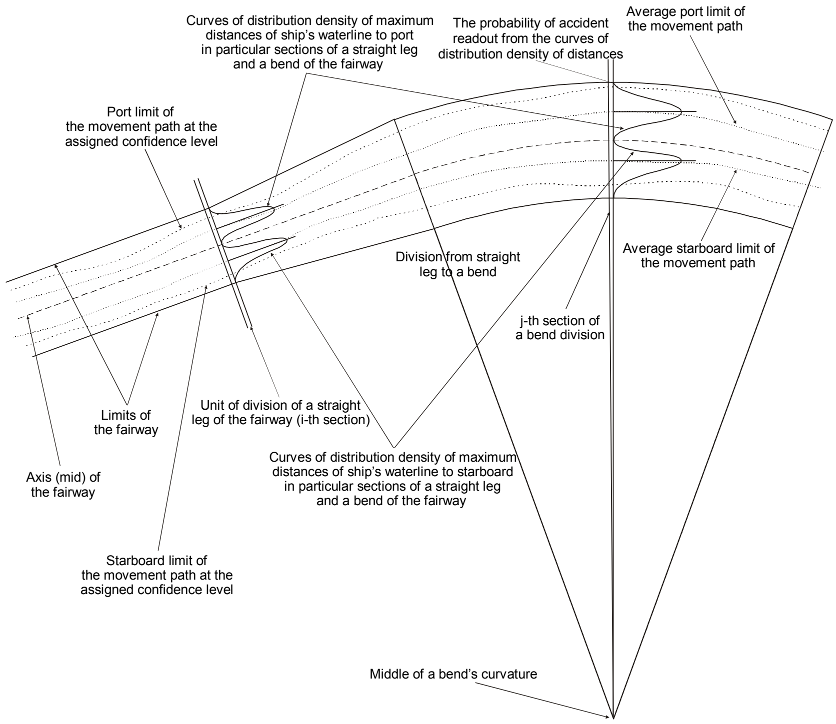


Fig. 7. Random variables of maximum port and starboard distances from the fairway axis and designation of the components of ship's motion path.

Measuring of the ship's manoeuvring area consists of the determination of its horizontal parameters in each point (*x, y*), at the very moment (*t*) of the manoeuvring in progress [1]. The manoeuvring area will be safe if additionally the condition of safe depth is met:

$$h(x, y, t) \geq T(x, y, t) + \Delta_T(x, y, t) \qquad (1)$$

where:

$h(x,y,t)$ - set of charted depths assuming no tides,

$T(x,y,t)$ - set of ship's draughts,

$\Delta T(x,y,t)$ - set of under-keel clearances.

The manoeuvring area determination process usually consists of simulation studies during which the researched ships' movement paths are logged. The reckoning of random variables of maximum distances between extreme points of the assumed ships' hull waterline outline and the reference line, for example: a fairway axis, leads to determination of the manoeuvring water area width. The manoeuvring water area width at a specified confidence level can finally lead to comparison with the existing safe area width and to conclusions of navigational safety within this area. The navigational safety can also be expressed in terms of the probability of accident because manoeuvring area dimensions always meet the safe area dimensions at some confidence level equal to one minus value of the probability of accident:

a) without considering accident consequences, the confidence level usually must be equal or higher than 0.95;
b) including accident consequences the confidence level must be equal or higher then confidence level calculated from variable value of the probability of accident at fixed acceptable accident risk level.

To analyse data logged in MTEC simulator an original Delphi™ application has been created. General algorithm is based on the methods of the ship's movement path and manoeuvring area determination described in [2,4]. To obtain the probability of an accident the probability function of assumed normal distribution (formula 2) has been converted to a standard normal distribution by changing variables to: $Z \equiv (X-\mu)/\sigma$, so $dz = dx/\sigma$ (formula 3).

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/[2\sigma^2]} \quad (2)$$

$$P(x)\,dx = \frac{1}{\sqrt{2\pi}} e^{-z^2/2}\,dz. \quad (3)$$

where:

x – variable distance of logged extreme points of ship's hull outline to fairway axis,

μ – mean of distances of logged extreme points of ship's hull outline to fairway axis,

σ^2 – variance of distances of logged extreme points of ship's hull outline to fairway axis.

The normal distribution function $\Phi(z)$ gives the probability that a standard normal variable assumes a value in the interval $[0, z]$ (formula 4).

$$\Phi(z) \equiv \frac{1}{\sqrt{2\pi}} \int_0^z e^{-x^2/2}\,dx = \frac{1}{2}\,\mathrm{erf}\left(\frac{z}{\sqrt{2}}\right), \quad (4)$$

where erf is so called error function which has been numerically computed by Maclaurin series approximation:

$$\mathrm{erf}(z) = \frac{2}{\sqrt{\pi}} \sum_{n=0}^{\infty} \frac{(-1)^n z^{2n+1}}{n!\,(2n+1)} \qquad (5)$$

Because normal distribution function actually gives us confidence level for whole range of x then for value μ (half of the x range) it gives 0.5. We are interested in confidence levels of values to one side of our μ, and for μ that should be 100% (or 1.0 probability) accident. Finally probability of accident equals:

$$P(x = d_a) = 2(1 - \Phi(z)) \qquad (6)$$

where:

d_a – distance from the fairway axis to the safety limit (isobath or obstacle).

3.1 The results of simulation experiment

The logging possibility of ship's movement parameters during ship's simulation trails gave an opportunity to collect the set of data required for statistical analysis. The pictures below (fig. 8, 9) present the results of 15 Jan Śniadecki ferry passages exiting the harbour. The research area has been established near the east head of breakwater as to cover the straight and turning ship's motion during exiting the harbour. The manoeuvring area (fig.9) and collision probability were calculated (fig. 8).

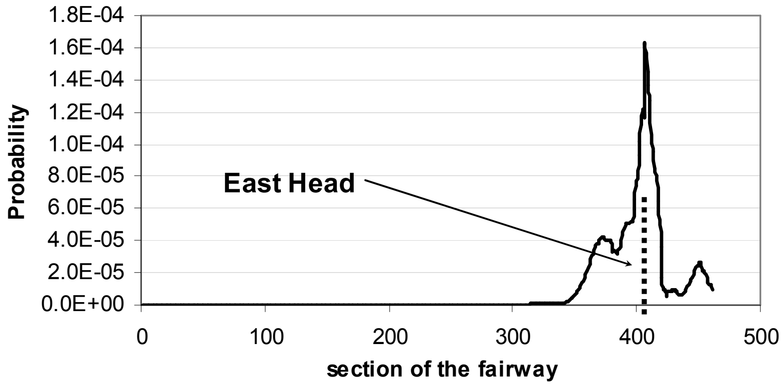


Fig. 8. Probability of collision with east head of breakwater in Świnoujście harbour calculated for Jan Śniadecki ferry.

The highest value of probability was achieved abeam of east head of breakwater (dashed line on the picture). It comes from the quite short distance the ferry passed the breakwater in the majority of researched cases. It can be clearly seen on fig. 9 where the east limit of area achieves the closest approach to the head of breakwater. The manoeuvring area dimensions presented at fig.9 can be interpreted as equivalent to real experiment obtained area in assessment of ship's navigation safety.

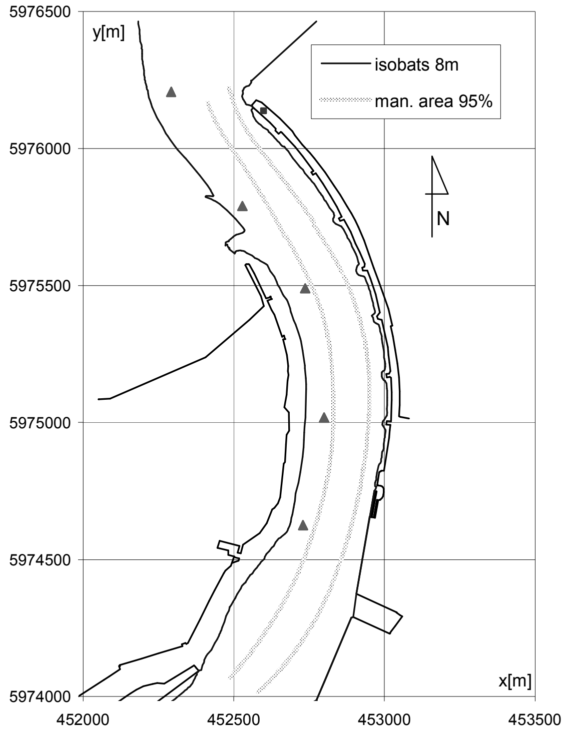


Fig. 9. Manoeuvring area determined for Jan Śniadecki ferry in Świnoujście harbour.

Conclusions

The main advantage of MTEC ship's bridge simulators is their integrity, so capability to run simultaneously scenario with several own ships, and realism of visuals and navigational equipment giving best possibilities to implement full bridge team as in real manoeuvres, with human perception very ship-like. The freedom of hydrodynamic ship's model building and creating the navigation areas in 3D visualisation makes the simulator very flexible and autonomic. This opens quite new frontiers of research of safety at sea without real ship, her cargo and crew involved in any danger.

References

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