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IAMU 2011 Research Project
(No. 2011-2)

Simulation-based training module to promote green energy-efficient ship operation
Part I: Basics
(ProGreenShipOperation-I)

By

World Maritime University (WMU)

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Part I: Basics

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Contents

Simulation-based training module to promote green energy -efficient ship operation –Part I: Basics

(ProGreenShipOperation-I)

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Abstract Within the project "ProGreenShipOperation I" basic investigations into potential contributions of ships to reduce greenhouse gas emissions have been performed. Focus was laid on operation of ferries and the introduction enhanced maneuvering assistance in the view of enhancements of MET by taking into account the challenges connected to IMO's aims. The main objective of the first part of the project was to perform investigations into the development of the basics for a simulation based training module that supports optimized ship operation by means of enhanced integrated maneuvering planning to assist captains, pilots and navigating officers when entering port entrances and maneuvering in harbor areas in a way that time saving will allow for reducing greenhouse gas emissions by reducing fuel consumption while simultaneously keeping the economic constraints of the voyage's time schedule. For this purpose a prototyped maneuvering assistance system has been integrated into a full-mission simulation environment and tested with respect to potentials for time and energy savings.

It is very well recognized, that best results regarding maritime safety and efficiency is basing on well-trained crews. Same is valid with respect to green ship operation. Only mariners who have background knowledge and who know how they can contribute in the best way to energy efficient and environmentally-friendly ship operation will be able to contribute to the ambitious aims. Therefore a concept for maneuver training using enhanced technology has been drafted.

Keywords: *Maneuvering Assistance, Reduction of GHG-Emissions, Simulation-based training*

1 Introduction

1.1 *Overall subject, aims and objectives of the project*

The research project "Simulation-based training module to promote green energy-efficient ship operation" brings together four recognized IAMU institutions by merging and combining research competencies on their specific subject areas related to environmentally friendly shipping. Under the leadership of WMU the partners commonly developed their ideas for a project dedicated to investigate potentials for the enhancement of MET by taking especially into account the challenges connected to IMO's aims in reducing greenhouse gas emissions when operating a ship. The project is divided into two phases. This report belongs to the project's first phase, which deals with basic investigations to identify potentials for energy-efficient ship operation focusing on maneuvering in harbor areas and into the fundamentals for the development of a simulation based training module. The second phase is to apply the concept for simulation-based exercises and to integrate and to demonstrate it in a simulation environment of a ship-handling simulator.

It is recently stated and very well recognized, that best results regarding maritime safety and efficiency is basing on well-trained crews. Same is valid with respect to green ship operation. Only mariners who have background knowledge and who know how they can contribute in the best way to energy efficient and environmentally-friendly ship operation will be able to contribute to the ambitious aims.
From several investigations it is known, that shipping is a main contributor to air pollution especially in coastal zones and harbor areas where many people are concerned. Measurements in south Sweden region have shown that almost 70% of SO_2 and approximately the half of NO_x and also 20% of particles in the air are caused by shipping activities. The maneuvering activities in coastal zones, port approaches and harbor areas are usually higher as when sailing in open seas (see graphs in the figure below).

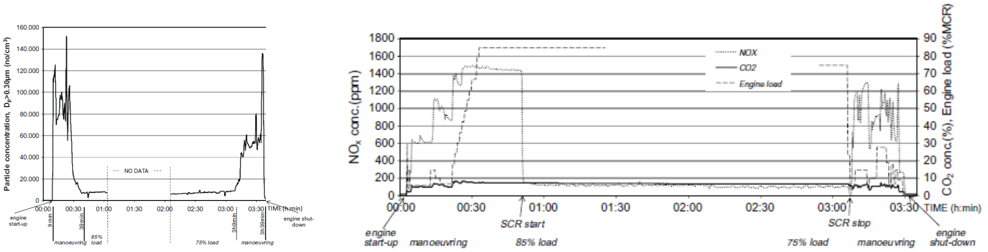


Fig. 1: Particle concentration (left), NO_x and CO_x emissions during different maneuvering phases of a ferry (source: H. Winnes & E. Fridell (2010))

That is why it is assumed that optimized maneuvering regimes contribute to decrease Greenhouse gas emissions and reduce fuel consumption. However, this aspect has not been addressed sufficiently yet, by navigators when operating ships in harbor areas. Therefore this project will study the fundamentals that are needed for the development of related modules to be integrated into maritime education and training schemes in general but especially into professional development courses for captains, pilots and navigating officers. Consequently, the focus of the project is laid on investigations into enhanced methods for planning of environmentally-friendly maneuvering strategies and their practicing.

1.2 *Methodology of work*

The main objective of this research project is to perform investigations into the fundamentals for the development of a simulation based training module that supports optimized ship operation by means of enhanced integrated maneuvering planning to assist captains, pilots and navigating officers when entering (or leaving) port entrances and maneuvering in harbor areas in a way that time saving will allow for reducing greenhouse gas emissions by reducing fuel consumption while keeping the economic constraints of the voyage time schedule.

For this purpose an onboard prototyped maneuvering assistance system will be integrated into a full-mission simulation environment in order to provide situation dependent recommendation for optimal maneuvering strategies to save time.

Generic modeling work will be performed on the basis of recorded real data about the quantity and the dependencies of potential savings and reductions. A concept for a training module will consider potential demonstration of the intended effects. Comparable sets of data should be created in order to perform analysis with respect to characteristic data of energy efficiency (as e.g. fuel consumption, time and cost saving).

1.3 Research activities

The principle project work of the first project phase consists of the following work packages:

- WP 1: an experimental field and simulation study into the potential of maneuvering assistance for "green ship operation",
- WP2: investigations into appropriate design of the Human-Machine-Interface of the Maneuvering Assistance module and
- WP 3: Investigation into effects of time savings on reduction of GHG emissions
- WP 4: the development of a concept for an integrated simulation based training module.

After a virtual (skype conference) kick-off meeting the project was started by all partners with the collection and comprehensive review of state of the art studies on relevant related issues including reviews of experiences from classification societies and shipping companies. Data have been collected and analyzed together with associated partners as e.g. a German ferry company operating in the Baltic Sea in order to provide data for a case study. Analysis has been performed to identify characteristic data and define a maneuvering scenario including also the prevailing environmental conditions for demonstration in a simulation environment. One characteristic scenario will be designed for implementation and use in a simulation study. Simulation runs will be performed to demonstrate the impact of a maneuvering assistance system on the defined evaluation parameters.

In accordance with the contractual requirements an interim report on the state of progress of the project was given at the IAMU's IEB meeting in Kobe (Japan) end of October. Project coordinator participated in the meeting sessions and delivered a report using powperpoint presentation. A summary of the main research activites is given in the following table.

Table 1 Summary of activities of ProGreenShipOperation I for FY 2011

Activity	Date/period	Venue	Members being involved
Kick-off meeting	August	skype	MBF, MP, GdM & KB
Review of	Sept. – Oct.	Rijeka/Malmo	TN, BP, DZ & VF
Research presentation at IEB meeting	20-22 October	Kobe	MBF
Simulation trials	Oct. – Dec.	Malmo/Rostock	MBF & KB
Drafting the final report	December	Malmo	MBF & WMU for Part I MBF, GdM, BB & KB for Part II

Further interim bilateral meetings have been held throughout the whole project period using phone conferencing and intensive email communication as well. The detailed work and the gained results are presented in the following chapters of this report.

1.4 Research results and structure of the report

Chapter 2 contains the work performed with respect to the investigations into effects of time savings by highlighting the development of a model for the calculation of the NO_x and CO_2 emissions from the ships during port operations. Moreover the chapter contains the establishment of some interesting conclusions for the reduction of the mentioned emissions which would help the maritime industry to move towards the GREEN SHIP concept.

The following third chapter reports about the field and simulation studies regarding the potential of implementing maneuvering assistance with high sophisticated prediction functions in order to allow for alternative maneuvering strategies that allows for time savings. Recordings of real harbor entrance maneuvers and berthing actions have been analyzed. The analysis was followed by a comparing simulation study which identifies the potentials of enhanced maneuvering assistance for time savings and energy and fuel efficient ship operation in port areas and harbor basins.

Chapter four summarizes the work performed in the first project period regarding the fundamentals for the appropriate design of the Human-Machine-Interface (HMI) of the maneuvering assistance system. Basic concepts are developed and principle requirements are derived from the human factors point of view. Functional and technical requirements are considered by referring, i.a., to the present developments of e-Navigation and modular structured integrated navigation systems (INS).

The fifth chapter contains the framework for the development of a dedicated simulation exercise to train energy-efficient ship operation in port and harbor areas. The development of the framework especially takes into account the demands and needs of the draft IMO model course on "Energy-efficient Operation of Ships".

The concluding sixth chapter provides an overall summary and conclusions for the further work of the ProGreenShipOperation project.

2 Measures towards green ship operation - Emission Calculation for a RoRo-Passenger ship

2.1 *Preliminary remarks*

Ships, during their normal operation, generate different kind of pollutant emitted to the atmosphere. For example refrigeration plants of the ships can contain ozone depleting substances; these are CFC's and HCFC's. On the other hand, greenhouse gases (CO_2) are emitted during the normal combustion processes with fossil fuels. These are mainly generated in the main and auxiliary engines, the boilers and the incinerators.

It is assumed that during combustion all of the carbon in the fuel is converted into CO2 and that therefore the emission factor is dependent on the carbon content of the fuel. [56]. The European Maritime Safety Agency (EMSA) is working together with the different Member States of the EU in analyzing the ships efficiency from the so called Energy Efficiency Design Index (EEDI) and the Energy Efficiency Operational Indicator (EEOI)1.

The EEDI represents how "efficient" a new ship is according to a math model based on different variables as the propulsion power, the specific F.O. consumption, the cargo capacity of the ship, the ship's speed and so on. High values of EEDI indicate that the ships are not "efficient" and low values represent "efficient ships". So, to optimize a ship's Diesel propulsion installation, the best solution from the point of view of the operation, would be to select an oversized engine and optimizing it to a reduced power corresponding to the design speed of the ship. The EEOI also quantifies the environmental efficiency of a ship, but applied to ships in service (existing ships).
The objectives pursued with this indicator are mainly the energy measurement, the efficiency per voyage, the operational evaluation, the continuous monitoring of the ships or the evaluation of the changes carried out in ships in service. This indicator is of volunteer application.

The EMSA is looking for the way to encourage the owners for the use of these indicators and for the development of plans to optimize the energy and to reduce the emissions; these are the Ship's Efficiency Management Plans (SEMP).

The sulphur oxides (SO_x) are other kind of gases emitted to the atmosphere from the ships during the combustion process. The way to regulate these emissions is by limiting the sulphur content of the fuel oil use don board. In addition, the worldwide average sulphur content of residual fuel oils supplied for use on board the ships is controlled having into account the IMO guidelines established in the Res. MEPC.183(59).

Moreover volatile organic compounds (VOC's) emitted by some kind of ships are also pollutant gases.

These pollutants are emitted from cargo of the tankers (oil tankers o chemical tankers). The VOC's emissions are regulated by the ports or the port facilities, which, if subject to a Party to the Annex VI of the MARPOL Convention, will develop the required regulations according with the Convention.

Every tanker to which the above paragraph applies should be provided with a recovery vapor system to be used during the loading of such cargoes. Regarding the nitrogen oxides (NO_x), and as background information it should be noted that the precursors of the NO_x formation during the combustion process are the nitrogen and the oxygen. These compounds together represent the 99% of the engine inlet air. The oxygen is consumed during the combustion and the exceeding oxygen depends on the air/fuel proportion. During the combustion process, the nitrogen does not react, even so a small nitrogen amount is oxidized forming the NO_x. Among these, NO and NO_2 can be formed and their amount depend on the flame or combustion temperature and on the quantity of organic nitrogen, if any, coming from the fuel.

The NO_x formation is also a function of the nitrogen and oxygen excess time of exposition to high temperatures produced by the combustion in the Diesel engine. The higher the combustion temperature (for instance, high maximum pressure, high compression ratio, high flow of supplied fuel,…), the higher the NO_x amount formed. In general, the low speed Diesel engines produce more NO_x than the high speed engines. NO_x has an adverse effect on the environment causing acidification, formation of tropospheric ozone, nutrient enrichment and contributes to adverse health effects globally.

On 26 September 1997, the Conference of Parties to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78) adopted, by Conference resolution 2, the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines (NO_x Technical Code). Following the entry into force, on 19 May 2005, of MARPOL Annex VI – Regulations for the Prevention of Air Pollution from Ships, each marine diesel engine to which regulation 13 of that Annex applies, must comply with the provisions of this Code. The purpose of this Code is to provide mandatory procedures for the testing, survey and certification of marine diesel engines which will enable engine manufacturers, ship owners and Administrations to ensure that all applicable marine diesel engines comply with the relevant limiting emission values of NO_x as specified within regulation 13 of Annex VI.

The difficulties of establishing with precision, the actual weighted average NO_x emission of marine diesel engines in service on ships have been recognized in formulating a simple, practical set of requirements in which the means to ensure compliance with the allowable NO_x emissions, are defined. Regarding the NO_x emission control application, the Code applies to the marine Diesel engines with a power output of more 130 kW installed on a ship subject to the R.13 of the Annex VI (MARPOL). The limits are established according with different tiers scale from Tier I to Tier III.
The Tier I applies to engines installed on ships constructed on or after 1 January 2000 and prior to 1 January 2011, the Tier II to engines installed on ships constructed on or after 1 January 2011 and the Tier III to engines installed on ships constructed on or after 1 January 2016 and the ship is operating in an Emission Control Area. The limits established for the Tier I match those applied to the engines installed on ships constructed on or after 1 January 1990 and 1 January 2000 with a power output of more than 5000 kW and a per cylinder displacement at or above 90 litres [39].

As indicated above, the emissions control only applies to Diesel engines and does not apply to a marine Diesel engine intended to be used solely for emergencies, or solely to power any device or equipment intended to be used solely for emergencies on the ship on which it is installed, or a marine Diesel engine installed in lifeboats intended to be used solely for emergencies [39].
This chapter firstly develops a calculation of NO_x emissions and CO_2 emissions by means of an analytic methodology, but not the weighted average NO_x, which could be analyzed in other paper with other aims. This calculation is applied to a Ro Ro Passenger ship with representative particulars and configuration during the port operations and maneuvers.

2.2 Methodology applied in a Port - NO_x and CO_2 emissions calculation for a Ro Ro Passenger ship

Firstly, the fuel oil consumption details of the ships during the different port operations have to be defined.
So, the fuel oil consumption in port is generated in the following stages:

- Propulsion for the port navigation.
- Arrival and departure maneuvers.
- Electric supply for the auxiliary systems required to maneuver, loading and unloading operations, hoteling of the ship.

Below the method is developed in detail for a Ro Ro Passenger ship in the Port of Barcelona.
The general ship particulars of the chosen RoRo-Passenger MV Sorolla, with overall length of 172,00 m and tonnage 26.916 GT, built in Spain in 2001 were taken from available public sources. Details of the engine and machinery equipment were taken from authenticated web access at www.sea-web.com.

2.2.1 Approach for the definition of the power, consumption and emissions of the propulsion installation during the navigation in port.

To carry out the calculation, a math model universally accepted is used in this paper. This is the Admiralty formula [27]:

$$P = \frac{\Delta^{2/3} \cdot v^3}{C_A} \qquad (1)$$

$P =$ Indicated power – IHP

$\Delta =$ Ship's displacement – Long Tons (1 Long Ton= 1,016 t)

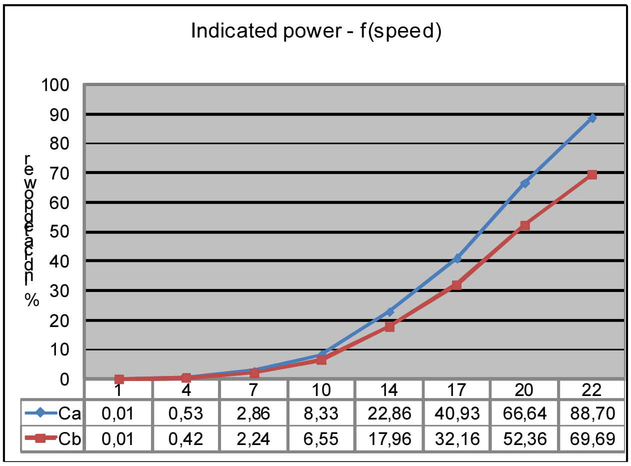
$v =$ Ship speed – kn

$C_A =$ Admiralty Coefficient. Values between 264 – 336

It is not being considered the additional power demand that would require a PTO (Power Take Off) consisting of a shaft generator. That is why the hypothesis supposed during the maneuver is that the electric power is supplied by two auxiliary engines.

The propulsion power approach includes an additional power margin represented by the heavy running (propeller and hull), but also the calm weather has been considered in port.

The ship is equipped with four main engines (4-stroke) with a MCR power of 7240 kW (9,844 HP) each one at 500 rpm. The displacement at summer load line is 16567 t. The mechanical efficiency has been considered 0,98. So, the Admiralty formula results in a graphic of the indicated power versus the ship's speed (see graph 2.1). The graphs C_a and C_b correspond to an Admiralty coefficient of 264 and 336, respectively.
These values are located within the limits established in the reference [27].



	1	4	7	10	14	17	20	22
Ca	0,01	0,53	2,86	8,33	22,86	40,93	66,64	88,70
Cb	0,01	0,42	2,24	6,55	17,96	32,16	52,36	69,69

Fig.: 2 Indicated power versus ship's speed at summer draft.

Bearing in mind that the speed of the ships during the maneuvers in the Port of Barcelona is limited to 10 knots at breakwater head and 6 knots once in the port, this last value should be the speed taken to calculate the necessary power during the navigation at port, even that the minimum steering speed for big ships could be higher than that. So, the paper is going to take as reference the parameters imposed by the Port Authority.

Due to the nature of the trades developed by this kind of ships, it has been considered that both manoeuvres are carried out at summer displacement.

$$P_{calc} = \frac{16567^{2/3} \cdot 6^3}{336} = 418 \; IHP \qquad (2)$$

Having into account that the available power data coming from the information supplied by IHS-2011 [22] are given as power at MCR (maximum continuous rating) corresponding to the brake power, the mechanical efficiency is to be applied to this value with the aim of obtaining the indicated power percentile required during the navigation at port. So, knowing that the total power at MCR of the ship is 28960 kW, applying a mechanical efficiency of 0,98, the indicated power results as follows:

$$P_i = \frac{P_B}{\eta_m} = \frac{28960}{0{,}98} = 29551 \; IHP \qquad (3)$$

The relationship of calculated power by the Admiralty formula and the ship's indicated power is 0,014, therefore 1,4%. To include the ship's temporary state from stopped to 6 knots, the power relationship is increased to 4%.

In addition, the fouled hull and the applicability of the Admiralty formula at these very low speed values have to be considered, and also the selected Admiralty Coefficient, that is why the relationship is finally increased up to 10% which leads to 2955 IHP at both manoeuvres (arrival and departure) during the navigation stage.

Since several approximation hypothesis have been introduced, the final percentile established can be directly applied to the MCR power of the ship with an insignificant error.

So, the final power at the maneuvering navigation stage is 2896 kW for the ship, which leads to an engine power of 724 kW (4 main engines).

Related to the time elapsed during the navigation stage in the Port of Barcelona from the north buoy to the pier and vice versa at 6 knots is 1,5 h in total.

With the data obtained up to now, the engine consumption has to be estimated for the navigation stage at port. To do that, it is necessary the specific fuel oil consumption (SFOC) curve of the main engine. In this case, the studied ship is provided with four 4-stroke engines, with a MCR power of 7240 kW each one at 500 rpm.

This SFOC curve is based in the data provided by the engines maker for the usual working loading ranges [55] the range is completed by extrapolating, having into account that the required values for the calculation at hand are around the 10% f MCR.

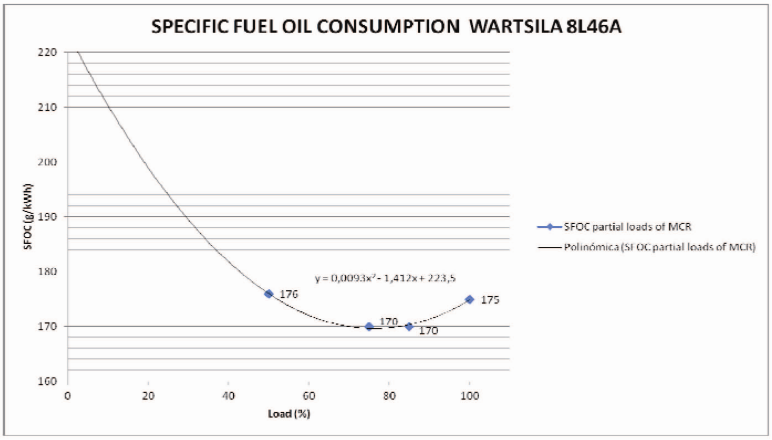


Fig. 3: Specific Fuel Oil Consumption – Main Engine WARTSILA 8L46A
(Source: Own from the limited range data provided by WARTSILA-2010b)

Based on the estimated power during the maneuvers and the SFOC of the main engine (see Figures 2 and 3), the approximated fuel oil consumption during the navigation in port can be calculated. It is emphasized from the Figure 3 that the SFOC at low loads is significantly increased.

Main engine fuel oil consumption during the navigation in port:

$$C_{port\ navig} = (0{,}0093 \cdot L^2 - 1{,}412 \cdot L + 223{,}5) \cdot P_{port\ navig} \cdot t_{port\ navig} \cdot n \qquad (4)$$

$C_{port\,navig}$: Total main engine fuel oil consumption during the navigation in port (kg).

L : Main engine load (% of MCR).

$P_{port\ navig}$: Brake power of the main engine during navigation in port (kW).

$t_{port\,navig}$: Maneuvering time (h).

n : Number of main engines running.

Navigation parameters at maneuvers:

$L = 10\%$

$P_{port\ navig} = 724$ kW

$t_{port\,navig} = 1{,}5$ h

$n = 4$

So:

$$C_{port\ navig} = \frac{(0{,}0093 \cdot L^2 - 1{,}412 \cdot L + 223{,}5) \cdot P_{port\ navig} \cdot t_{port\ navig} \cdot n}{1000} = \frac{210{,}31 \cdot 724 \cdot 1{,}5 \cdot 4}{1000} = 914\,kg \qquad (5)$$

Once the fuel oil consumption is determined for the period of navigation in port, the emission factors corresponding to the engine type with which the ship is provided (see Figure 4 for NO_x) are applied and the NO_x emissions and CO_2 emissions for the main engine at manoeuvres are obtained (one complete maneuver, arrival+departure).

The NO_x emission factors data taken as a base to extrapolate and define the factors for the complete running load range (in the same way that the SFCO curves) have been obtained from the engines maker MAN B&W [8].

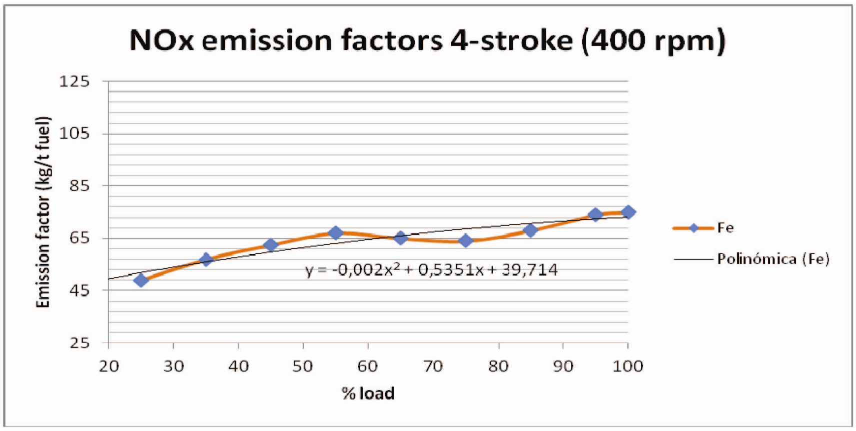


Fig. 4: NO_x emission factors for 4-stroke engines (about 400 rpm)
Source: Own from the data for a limited range of CORBETT [8]

So, applying the next formula, we are calculating the NO_x quantity emitted from the main engine during the port maneuver (arrival+departure)

$$E_{NOX-ME} = F_{E-NOX} \cdot C_{ME} \qquad (6)$$

E_{NOX-ME} : NO_x emissions from the main engine during the navigation in port (arrival+departure) (kg)

F_{E-NOX} : NO_x emission factor (kg/t fuel)

C_{ME} : Main engine total fuel oil consumption during the maneuver in port (t).

$$E_{NOX-ME} = (-0{,}002 \cdot L^2 + 0{,}5351 \cdot L + 39{,}714) \cdot C_{ME} = 44{,}87 \cdot 0{,}914 = 41\,kg \qquad (7)$$

The emissions from the main engine at maneuver in port are therefore **41 kg of NO_x**.

Proceeding as above for the CO_2 emissions, results are obtained as follows.

The CO_2 emission factor for the main engine of the model ship, so medium speed 4-stroke and burning IFO (Intermediate Fuel Oil) is, as per WHALL [56], 745 g/kWh, so applying the power during the navigation in port and the time spent in this stage, the total amount of CO_2 emissions is got.

Main engine fuel oil consumption during the navigation in port:

$$E_{CO2-ME} = F_{E-CO2} \cdot P_{port\ navig} \cdot t_{port\ navig} \cdot n \tag{8}$$

E_{CO2-ME} : CO_2 emissions from the main engine during the navigation in port (arrival+departure) (kg)

F_{E-CO2} : CO_2 emission factor (g/kWh)

$P_{port\ navig}$: Brake power of the main engine during navigation in port (kW).

$t_{port\ navig}$: Maneuvering time (h).
n : Number of main engines running.

Navigation parameters at maneuvers:

$P_{port\ navig} = 724$ kW

$t_{port\ navig} = 1{,}5$ h
$n = 4$
So:

$$E_{CO2-ME} = \frac{F_{E-CO2} \cdot P_{port\ navig} \cdot t_{port\ navig} \cdot n}{1000} = \frac{745 \cdot 724 \cdot 1{,}5 \cdot 4}{1000} = 3236\,kg \tag{9}$$

The emissions from the main engine at manoeuvre in port are therefore **3236 kg of CO_2.**

2.2.2 Approach for the definition of the power, consumption and emissions of the main source of electric power during the navigation in port and berthing/unberthing

In general, it is a common practice to keep running two generators during the maneuvers in port for safety reasons.

This chapter has not considered the installation and running of any PTO (Power Take Off – Shaft Generator) for the studied ship. It is justified because the ships provided with this kind of equipment carry out the maneuvers without it also for safety reasons.

The power developed by the main source of electric power in maneuvers will be that corresponding to the navigation in open sea (see the relationship between main and electric power in figure 5) increased by 20 or 30% due to the starting and running of the necessary services for the maneuvers (auxiliary blowers, bow thruster, mooring equipment,…)

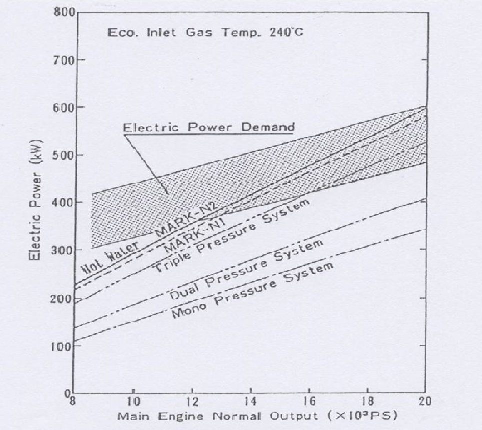


Fig. 5: Supply and demand of electric power versus propulsion power (Source: FUKUGAKI [14])

The main source of electric power of the studied ship is provided with three auxiliary engines and one shaft generator per main engine, the last ones not considered in this chapter.

The features of the auxiliary engines and the electric source are:

- 4-stroke.
- 1620 kW MCR.
- 1000 rpm (medium speed)
- 380 V, 50Hz.

As indicated above, two main generators are connected during the navigation in port. Bearing in mind that the load can vary from 55% to 75% of MCR each one, depending on the ventilation fans running, the reefers connected etc., it is going to be taken for calculation proposes the 65% of load per auxiliary engine, so around 1050 kW.

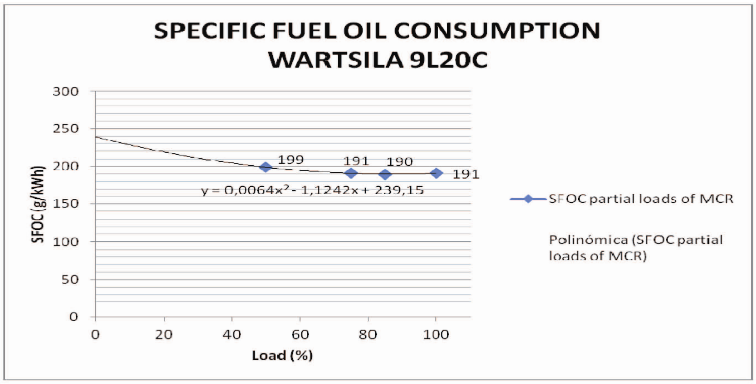


Fig. 6: Specific Fuel Oil Consumption – Auxiliary Engine WARTSILA 9L20C
Source: Own from the limited range data provided by WARTSILA [55]

Related to the duration of the navigation stage of the maneuvers in the Port of Barcelona (north entrance), from the November buoy to the berth and vice versa, as indicated in the previous point, has been considered to be 1,5 h.

So, then the fuel consumption of the electric power main generator plant is going to be calculated for the navigation in port stage. In the same way that made for the propulsion plant, the corresponding consumption curve has been obtained from the data provided by the engines maker for the usual running load ranges, by extrapolating these values for the whole range.

$$C_{AAEE-Ng} = (0,0064 \cdot L^2 - 1,1242 \cdot L + 239,15) \cdot P_{AAEE-Ng} \cdot n \cdot t_{maneuv} \tag{10}$$

$C_{AAEE-Ng}$: Fuel oil consumption for the main generator plant during the navigation in port (kg).

L : Load of each AAEE (% of MCR).

$P_{AAEE-Ng}$: Brake power of each AAEE during the navigation in port (kW).

n : Number of AAEE's running.

t_{maneuv} : Time spent during the navigation in port (arrival and departure) (h).

Main generator plant conditions at maneuver:

$L = 65\%$

$P_{AAEE-Ng} = 1050 kW$

$n = 2$

$t_{maneuv} = 1,5 h$

$$C_{AAEE-Ng} = \frac{193,12 \cdot 1050 \cdot 2 \cdot 1,5}{1000} = 608,32 kg \tag{11}$$

Once the fuel consumption of the main source of electric power is known for this stage, the emission factors corresponding to the AAEE's with which the ship is provided are to be applied (see Fig. 6), thus obtaining the NO_x emissions from the AAEE's in the indicated period.

The emission factors values, as for the main engine, did not cover the whole running load range, so the basic factors have been extrapolated to complete the curves.

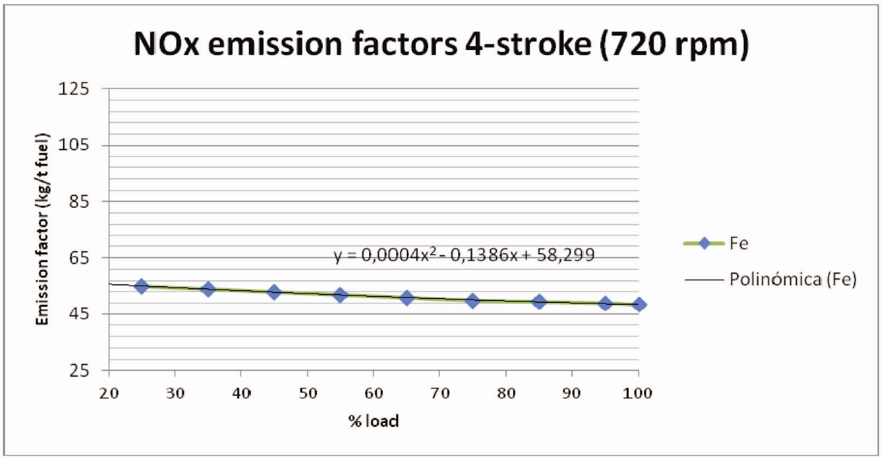


Fig. 7: :NO$_x$ emission factors for 4-stroke engines (about 720 rpm)
Source: Own from the data for a limited range of CORBETT [8]

Thus, the NO$_x$ emissions from the main source of electric power during the navigation in port:

$$E_{NOX-AAEE-Ng} = F_{E-NOX} \cdot C_{AAEE-Ng} \tag{12}$$

$E_{NOX-AAEE-Ng}$: NO$_x$ emissions from the main source of electric power during the navigation in port (kg).

F_{E-NOX} : NO$_x$ emission factor (kg/t fuel).

$C_{AAEE-Ng}$: Main generator plant fuel oil consumption during the navigation in port (t).

L : Load of each AAEE (% of MCR).

$$E_{NOX-AAEE-Ng} = (0{,}0004 \cdot L^2 - 0{,}1386 \cdot L + 58{,}299) \cdot C_{AAEE-Ng} = 50{,}98 \cdot 0{,}608 = 31 kg \tag{13}$$

The main source of electric power emissions are **31 kg of NO$_x$** during the navigation stage in port.

So for the calculation of the CO$_2$ emissions from the main source of electric power during the navigation in port, firstly the emission factors for the auxiliary engines of the model ship has to be defined, therefore for a medium speed 4-stroke and burning IFO is, as per WHALL [56], 722 g/kWh, and applying the power during the navigation in port and the time spent in this stage, the total amount of CO$_2$ emissions during this stage is obtained.

Auxiliary engines CO$_2$ emissions during the navigation in port:

$$E_{CO2-AAEE-Ng} = F_{E-CO2} \cdot P_{AAEE-Ng} \cdot n \cdot t_{maneuv} \tag{14}$$

$E_{CO2-AAEE-Ng}$: CO$_2$ emissions from the main source of electric power during the navigation in port (kg).

F_{E-CO2}: CO_2 emission factor (g/kWh).

$P_{AAEE-Ng}$: Brake power of each AAEE during the navigation in port (kW).

n: Number of AAEE's running.

t_{maneuv}: Time spent during the navigation in port (arrival and departure) (h).

Main generator plant conditions at maneuver:

$L = 65\%$

$P_{AAEE-Ng} = 1050\,kW$

$n = 2$

$t_{maneuv} = 1{,}5\,h$

$$E_{CO2-AAEE-Ng} = \frac{F_{E-CO2} \cdot P_{AAEE-Ng} \cdot n \cdot t_{maneuv}}{1000} = \frac{722 \cdot 1050 \cdot 2 \cdot 1{,}5}{1000} = 2274\,kg \tag{15}$$

The main source of electric power emissions are **2274 kg of CO_2** during the navigation stage in port. In addition to the auxiliary engines that are used to generate electricity for onboard uses, most OGVs (Ocean Going Vessels) have one or more boilers used for fuel heating and for producing hot water. Boilers are typically not used during transit at sea since many vessels are equipped with an exhaust gas recovery system or "economizer" that uses main engine exhaust for heating purposes and therefore the boilers are not needed when the main engines are used. Boilers are assumed to be turned on, or off (when headed out to sea), at approximately 20 miles out from the outer sea buoy. They are used during maneuvering and when the vessel is at port and the main engines are shut down.

So the CO_2 emission factor used for the auxiliary boiler using residual oil (no data for MGO) is 970 g/kWh and the energy default for the ship type of this paper 278 kW both maneuvering and berthing [47]. Therefore:

$$E_{CO2-BOILER-Ng} = F_{E-CO2} \cdot P_{port} \cdot t_{port\ navig} \tag{16}$$

$E_{CO2-BOILER-Ng}$: CO_2 emissions from the boiler during the navigation in port (arrival+departure) (kg)

F_{E-CO2}: CO_2 emission factor (g/kWh)

P_{port}: Energy of the boiler (kW).

$t_{port\ navig}$: Maneuvering time (navigation in port) (h).

Navigation parameters:

$P_{port} = 278$ kW

$t_{port\ navig} = 1{,}5$ h

So:

$$E_{CO2-BOILER-Ng} = \frac{F_{E-CO2} \cdot P_{port} \cdot t_{port\ navig}}{1000} = \frac{970 \cdot 278 \cdot 1{,}5}{1000} = 405\,kg \tag{17}$$

The emissions from the auxiliary boiler maneuvering (navigation in port) are **405 kg of CO_2**.

2.2.3 Approach for the definition of the power, consumption and emissions of the main source of electric power at berth

The auxiliary services to be considered are the main generators and the auxiliary boilers. Since the Annex VI of MARPOL does not apply to boilers with regard to the NO_x emissions, they will not be had into account.

To establish the power supply two situations have to be distinguished:

a) When the cargo requires the auxiliary machinery for the condition maintenance or handling.
b) Hoteling: When the electric supply is only engaged in the galley services, accommodation and safety means of the ship.

In this paper, the ship can be loaded with reefer containers, so the conditions describe in the points a) and b) above can take place.

For the studied ship it is considered that during the call while the ship is moored, two generators are kept running at 50% of the MCR. This value can vary depending on the started fans, connected reefers and further prevailing circumstances.

The calculation is going to be carried out for one call, supposing that the average time per call (ship moored) could be around 3,5 h.

So, the fuel consumption of the main source of electric power with the ship alongside the berth is calculated as follows:

$$C_{AAEE-Port} = (0{,}0064 \cdot L^2 - 1{,}1242 \cdot L + 239{,}15) \cdot P_{AAEE-Port} \cdot n \cdot t_{Port} \tag{18}$$

$C_{AAEE-Port}$: Total fuel consumption of the auxiliary engines while the ship is berthed (kg).

L : Load of each AAEE (% of MCR).

$P_{AAEE-Port}$: Brake power of each AAEE while the ship is berthed (kW).

n : Number of AAEE running.

t_{Port} : Time of call (ship alongside) (h).

The main source of electric power conditions are:

$$L = 50\%$$

$$P_{AAEE-Port} = 810\,kW$$

$$n = 2$$

$$t_{Port} = 3{,}5\,h$$

$$C_{AAEE-Port} = \frac{198{,}94 \cdot 810 \cdot 2 \cdot 3{,}5}{1000} = 1127{,}99\,kg \tag{19}$$

Once the fuel consumption of the AAEE in port (ship berthed) is known, the corresponding emission factors are applied (see Fig. 3). So done, the NO_x emissions produced by the main source of electric power are obtained for the indicated period.

Then, the NO_x emitted in port from the AAEE are:

$$E_{NOX-AAEE-Port} = F_{E-NOX} \cdot C_{AAEE-Port} \tag{20}$$

$E_{NOX-AAEE-Port}$: NO_x emissions from the AAEE during the berthing period (kg).

F_{E-NOX} : NO_x emission factors (kg/t fuel).

$C_{AAEE-Port}$: Total fuel oil consumption of the main source of electric power – berthing period (t).

$$E_{NOX-AAEE-port} = (0{,}0004 \cdot L^2 - 0{,}1386 \cdot L + 58{,}299) \cdot C_{AAEE-Port} = 52{,}37 \cdot 1{,}128 = 59{,}07\,kg \tag{21}$$

The main source of electric power produces **59,07 kg of NO_x** while the ship is berthed in port. Meanwhile the CO_2 from the auxiliary engines and from the auxiliary boiler during the call in port is calculated as follows.

Firstly the emission factors for the auxiliary engines of the model ship has to be defined, therefore for a medium speed 4-stroke and burning MGO (Marine Gas Oil) of 0,1% S and downwards (compulsory at port according with the Royal Decree 1027/2006) is, as per WHALL [56], 690 g/kWh, and applying the power during the navigation in port and the time spent in this stage, the total amount of CO_2 emissions during this stage is obtained.

Auxiliary engines CO_2 emissions while the ship is berthed:

$$E_{CO2-AAEE-Port} = F_{E-CO2} \cdot P_{AAEE-Port} \cdot n \cdot t_{Port} \tag{22}$$

$E_{CO2-AAEE-Ng}$: CO_2 emissions from the main source of electric power during the berthing period (kg).

F_{E-CO2} : CO_2 emission factor (g/kWh).

$P_{AAEE-Port}$: Brake power of each AAEE while the ship is berthed (kW).

n : Number of AAEE's running.

t_{Port} : Time of call (ship alongside) (h).

The main source of electric power conditions are:

$P_{AAEE-Port} = 810 kW$

$n = 2$

$t_{Port} = 3{,}5 h$

$$E_{CO2-AAEE-Port} = \frac{F_{E-CO2} \cdot P_{AAEE-Port} \cdot n \cdot t_{Port}}{1000} = \frac{690 \cdot 810 \cdot 2 \cdot 3{,}5}{1000} = 3912\ kg \tag{23}$$

The main source of electric power produces **3912 kg of CO_2** while the ship is berthed in port.

For the auxiliary boilers, the CO_2 emission factor using residual oil (no data for MGO) is 970 g/kWh and the energy default for the ship type of this paper 278 kW both maneuvering and at berth [47]. Therefore:

$$E_{CO2-BOILER-Port} = F_{E-CO2} \cdot P_{port} \cdot t_{port-berth} \tag{24}$$

$E_{CO2-BOILER-Ng}$: CO_2 emissions from the boiler during the navigation in port (arrival+departure) (kg)

F_{E-CO2} : CO_2 emission factor (g/kWh)

P_{port} : Energy of the boiler (kW).

$t_{port-berth}$: Time at berth (h).

At berth parameters:

$P_{port} = 278$ kW

$t_{port-navig} = 3{,}5$ h

$$E_{CO2-BOILER-Port} = \frac{F_{E-CO2} \cdot P_{port} \cdot t_{port-berth}}{1000} = \frac{970 \cdot 278 \cdot 3{,}5}{1000} = 944\, kg \tag{25}$$

The emissions from the auxiliary boiler at berth are **944 kg of CO_2.**

At this moment, the calculation for all the stages that take place during a complete call of a RoRo passenger ship has been carried out. So, the total emissions in port per call [42] are calculated as follows:

1. NO_x emissions:

$$E_{NOX-Total-call} = E_{NOX-ME} + E_{NOX-AAEE-Ng} + E_{NOX-AAEE-Port} = 41 + 31 + 59{,}07 = 131{,}07\,kg \qquad (26)$$

2. CO_2 emissions:

$$E_{CO2-Total-call} = E_{CO2-ME} + E_{CO2-AAEE-Ng} + E_{CO2-BOILER-Ng} + E_{CO2-AAEE-Port} + E_{CO2-BOILER-Port} = \\ = 3236 + 2274 + 405 + 3912 + 944 = 10771\,kg \qquad (27)$$

2.3 Conclusions regarding methods for the reduction of NO_x/CO_2. emissions

After calculating the emissions produced during a complete maneuver in port (Barcelona taken as model for this paper), by the main and auxiliary machinery of a representative Ro Ro Passenger ship, let's proceed to establish some interesting conclusions for the reduction of the mentioned emissions.

From the big amount of papers and documents referred to this subject, this point has been focused in the information contained in the document MAN B&W-2005 for the NO_x reduction methods.

It has to be born in mind that due to the high dependence that the NO_x formation has on the temperature, the way that results in most immediate reduction is the decrease of that parameter during the combustion process. This has the inconvenience of the efficiency reduction of the thermodynamic cycle, therefore the fuel consumption increases. This has resulted in the so called Diesel Dilemma: either the NO_x formation is reduced increasing the fuel consumption or to reduce the fuel consumption, the NO_x formation greatly rises (CARRERAS-1990).

Therefore, the methods used to decrease the temperature during the combustion process of diesel engines are: delay of the timing of the fuel injection, introduction of water into the combustion space or in the admission air reducing the maximum peak temperatures in the combustion process because of its evaporation, there are different ways to do so (emulsifier of water and fuel, saturation of the admission air, water directly injected into the cylinders), recirculating of part of the exhaust gases in the combustion chamber based on a reduction of the oxygen content in the cylinder charge and a reduction of the maximum combustion temperatures. Some makers suggest reducing the injection timing and simultaneously increasing the nozzle working pressure of the injectors up to around 720 bar improving the atomization and obtaining a best air/fuel mixture.

The possibility of reducing the air quantity during any part of the combustion process cannot be carried out in Diesel engines because the fuel is spread in the cylinder full of air, but it is carried out with the burners of the boilers where the quantity of air is reduced in the higher temperature combustion areas, adding the necessary air to complete the combustion in areas of lower temperature.

The alternative to avoid the NO_x emissions is the treatment after their formation; this can be performed in Diesel engines by means the SCR (Selective Catalytic Reduction) technique. With this method, the exhaust gas is mixed with ammonia NH_3 or urea before passing through a layer of a special catalyst at a temperature between 300 and 400ºC, where the next reactions take place:

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \tag{28}$$

$$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O \tag{29}$$

The efficiency of these reactions is related to the available surface of the catalyst. The greater is the contact area between the catalyst and the exhaust gases, the higher is the NO_x reduction. That is why the ceramic elements of the catalyst are arranged in a honeycomb through where the exhaust gases flow.

The optimum temperature of the reaction is between 350 and 400ºC. In addition, there is another important criterion, the opening of the catalytic reduction system installed in the exhaust gases duct, which if insufficient produces an excessive counter pressure that leads to an increase of the engine consumption.

Now, for the reduction of both of the studied gases emissions (it will be specified in each method explained) the next possibilities or alternatives are proposed to improve the air quality and to lead the maritime industry towards the green ship.

The possibility of using dual auxiliary engines, methane and fuel/diesel oil, would reduce substantially the CO_2 production. Looking at the hydrocarbon chains of each fuel type it can be verified that the methane has a chain with only one C atom while the fuel oil has between 15 and 18 C atoms, so the lower quantity of atoms of carbon reacting with the oxygen of the air leads to an important reduction of the CO_2 emissions.

This option has another advantage; the methane has not to be treated in a purifier, so the sludge production is also reduced.

Taking into consideration the basic components of the fuel oil and given a stoichiometric combustion process, the reaction that defines it is as follows:

$$C_xH_y + n\ Air(O_2 + N_2) \rightarrow xCO_2 + (y/2)H_2O + 0{,}79nN_2 + Heat \tag{30}$$

From the above reaction and bearing in mind the number of C atoms of each combustion type it can be confirmed the high influence of the fuel used on the CO_2 generated.

If the fuel type used in the main engine is changed during the maneuver or once the ship is in berth, it is not necessary to produce steam for heating the fuel oil to be recirculated and therefore, the boiler is not needed for this service.

The only function for the boiler in port would be the sanitary water heating, which could be carried out by a heat exchanger where the exhaust gases of the auxiliary engines transfers its energy to the water.

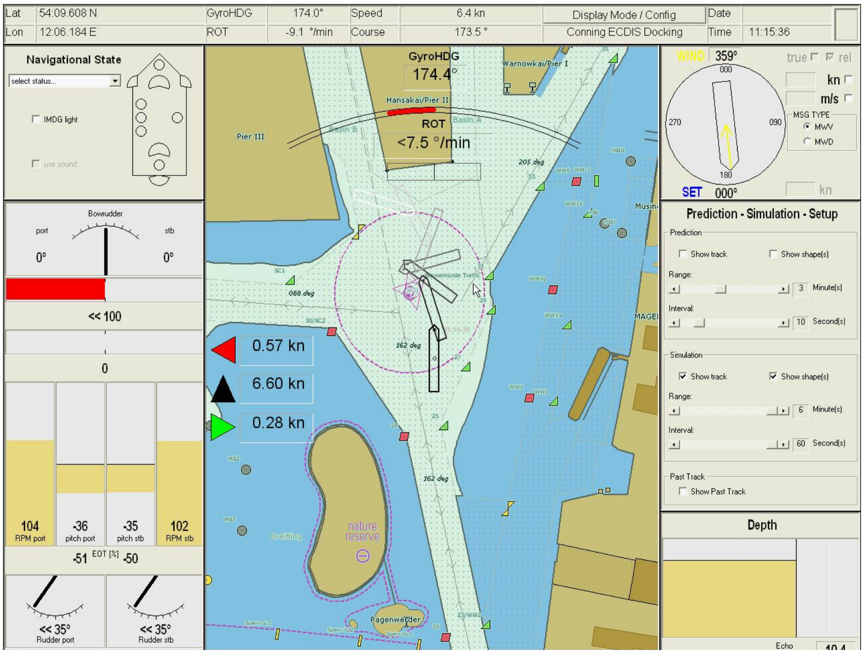
At this moment, the boiler has no function in port, so it can be stopped and a reduction of NO_x and CO_2 is achieved.

It is important to bear in mind that any method for the reduction of the fuel consumption in order to reduce the CO_2 emissions is not compatible with the NO_x reduction, this can be understood by the mentioned Diesel Dilemma, this optimization of the fuel consumption leads to an increase of the efficiency, so a higher temperature of the thermodynamic cycle takes place and then an increase of the NO_x emissions.

3 Ship operation in harbor areas – maneuvers for entering and approaching the berthing place

3.1 Subject and aim of Investigations

Based on a substantial analysis of recorded maneuvers there is room for improvement to point out, this also leads to the opportunity to name alternative concepts.
Using the simulation facilities at the Maritime Simulation Centre Warnemuende (MSCW) of Hochschule Wismar's Department for Maritime Studies and the application of innovative fast-time simulation modules for 'track and position predictions' it is possible to develop and evaluate opportunities for saving time by using alternative maneuvering strategies when entering a port. For this purpose a in the frame of the ProGreenShipOperation project an exemplary case study is performed dealing with investigations of the situation in the Port of Rostock. For the first time developed software tools, which facilitate such simulations are applied for the purpose of enhanced environmentally-friendly maneuvering in harbor areas. These tools are able to analyze, calculate and display enhanced information of future maneuvering status (Dynamic Predictor).



Lat 54:09.608 N
Lon 12:06.184 E
GyroHDG 174.0°
ROT -9.1 °/min
Speed 6.4 kn
Course 173.5 °
Date
Time 11:15:36

Prediction
☐ Show track ☐ Show shape(s)
Range: 3 Minute(s)
Interval: 10 Second(s)

Simulation
☑ Show track ☑ Show shape(s)
Range: 6 Minute(s)
Interval: 60 Second(s)

Past Track
☐ Show Past Track

Fig. 8: Case study scenario –complex combined rudder, thrusters and engine maneuvers to enter a port and approaching the berth

Data sources for the case study were data recorded by the mandatory VDR recorder of the RoRoPax ferry "Mecklenburg-Vorpommern" operating in this sea area. Input data were provided by the ferry company for period of 01.01.2008 20:20 till 03.01.2008 01:50. Additionally also recorded AIS data has been used specifically for validation of the VDR-based recorded data.
The maneuvers to enter the port and berthing can be split into its two essential parts: passing jetties and maneuvering to berth the ferry. The ship operations during this crucial part of the ferry's voyage can be divided into the following four phases, which differ substantially in terms of their potential for improvement and optimization of energy efficient regime:

1. Passing Jetties - passage of canal: The first phase is regarding the speed limit of 6,5 kn and straight ahead, a benefit in time hardly possible. The aim in that phase is to avoid speeding.
2. Heading for and entering the turning basin- stopping the ship – turning the ship- proceeding with going astern and leave the turning basin:
   While the second phase the ship has to execute a sequence of different maneuvers, which aim to stop the vessel within limited space, turn and proceed to go astern. In that phase the optimization potential is very likely.
3. Maneuvering astern to the berthing place: The third phase is characterized by going astern in limited maneuvering space. Due to the use of all existing command handles, it seems that maneuvering assistance is useful and may have significant effect on energy-efficient operation and reduction of emissions accordingly.
4. Berthing at the dedicated berthing place no. 64: There is great optimization potential here too.

The conducted investigations, which are presented below, are focussing specifically on Phase 2. This phase is limited from 54°10' N (abeam Pagenwerder Island) to 54°09' N (abeam Berth no. 66).

3.2 Analysis of data material

Dedicated software tools were developed, applied and used for analysing the data. These tools are able to read VDR-Backup data and AIS data as well. An output function has been implemented to write data in .csv- Files, which can be interpreted by Excel.

Content of the Data in VDR Backup:

- Time
- Lat, Lon
- EOT, Pitch, RPM of Port-Propulsion system
- EOT, Pitch, RPM of StB-Propulsion system
- (actual) Rudder angle Port aft and (actual) Rudder angle StB aft
- (actual) Bow Rudder angle Port and (actual) Bow Rudder angle StB
- Commanded and actual value of Bowthruster 1
- Commanded and actual value of Bowthruster 2
- Heading
- Course over Ground
- Speed over Ground
- Rate of Turn
- Speed ahead, grounded
- Speed abeam, grounded
- Wind direction
- Wind speed

Content of AIS data:

- Time
- Latitude, Longitude
- Course over Ground
- Heading
- Rate of Turn

AIS data contains all the information regarding the usage of maneuvering handles (Rudder, Engine, Bowthruster, Bowrudder). In Comparison, the data sets from VDR and AIS for Course over Ground, Speed and Heading are quite similar (see Fig. 9 to 11). It is assumed, that entering the port of Rostock is maneuver routine, which is adapted to inner and outer circumstances, such as draft, wind and current (see Fig. 12).

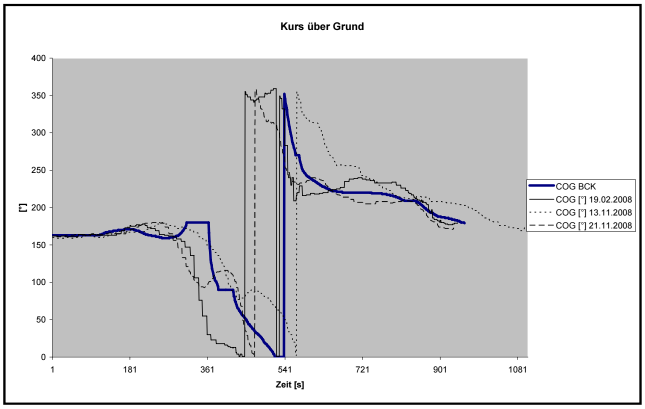


Fig. 9: Course while considered observation period

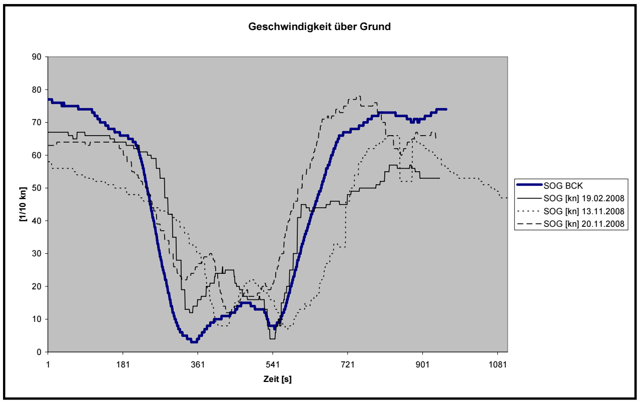


Fig. 10: Speed while considered observation period

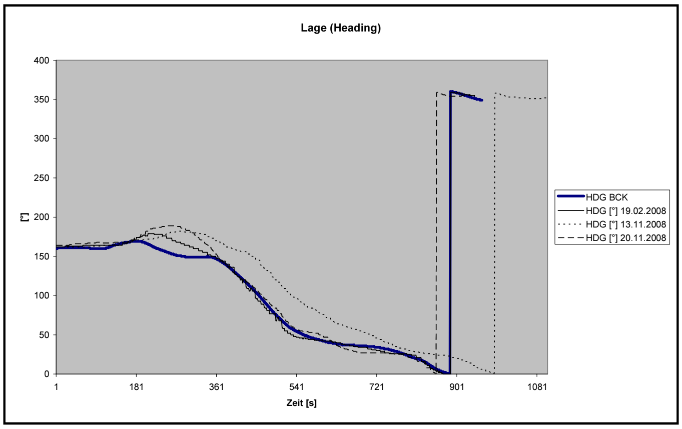


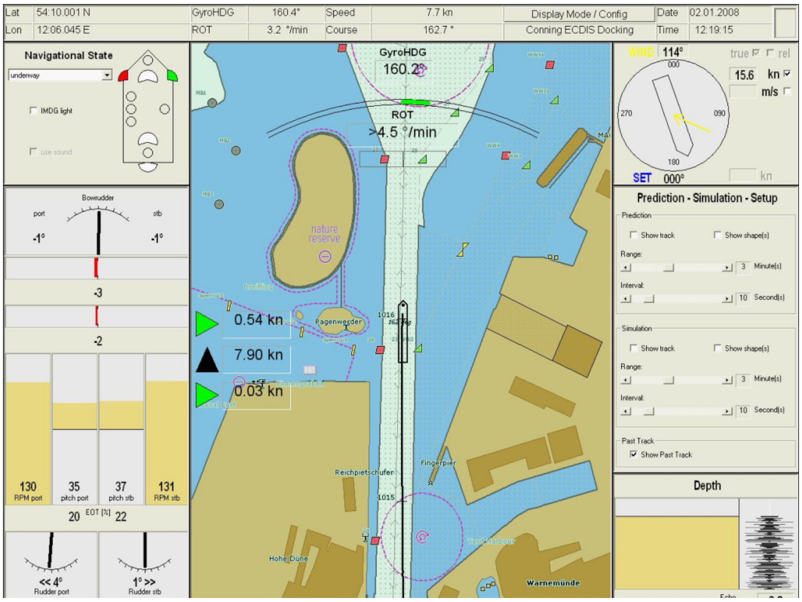
Fig. 11: Heading while considered observation period

Fig. 12: Real track of harbor maneuvering of MV „Mecklenburg-Vorpommern", based on VDR (high spot density), and recorded AIS information

3.2.1 Analysis of conventional maneuvering concept and description of steering sequence

The following steering sequences illustrate the essential navigation and maneuvering actions and their effects on the complete harbor maneuver from passing the breakwaters up to the berthing place.

The MV „Mecklenburg-Vorpommern" is heading into the sea canal along the radar line with a course over ground of 162° and a speed ahead of more than 7 knots. The ordered Engines are 20% (Port engine) and 22% (Stb engine). The Rudders are working in parallel mode and small angles are used to keep the course. The wind speed is 15 knots from a south easterly direction (see Fig. 13).



Lat	54:10.001 N	GyroHDG	160.4°	Speed	7.7 kn	Display Mode / Config	Date	02.01.2008
Lon	12:06.045 E	ROT	3.2 °/min	Course	162.7 °	Conning ECDIS Docking	Time	12:19:15

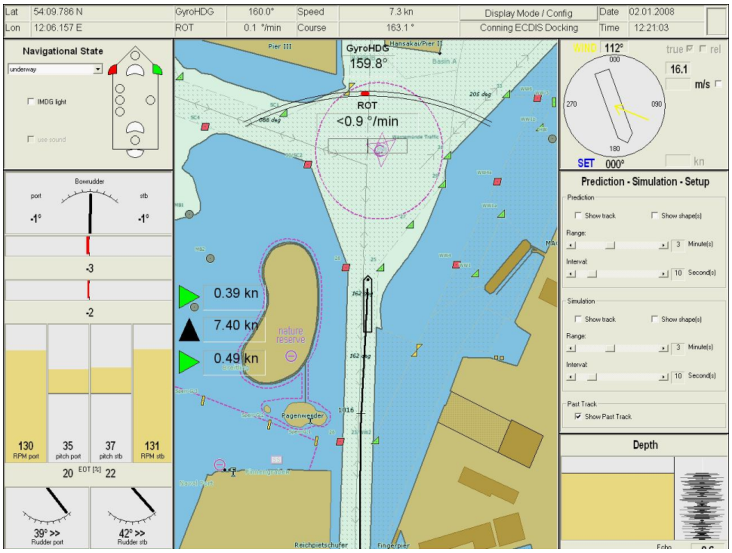
Navigational State: underway

WIND 114° true ☑ ☐ rel 15.6 kn ☑ m/s ☐

SET 000° kn

Fig. 13: MV „Mecklenburg-Vorpommern" in the sea canal

Before passing buoys 25/28 the rudder is put to Stb (Fig. 14) for a short moment, which results in a turn to Starboard. Additionally, the EOT is set to Port 17% and Stb 19%.



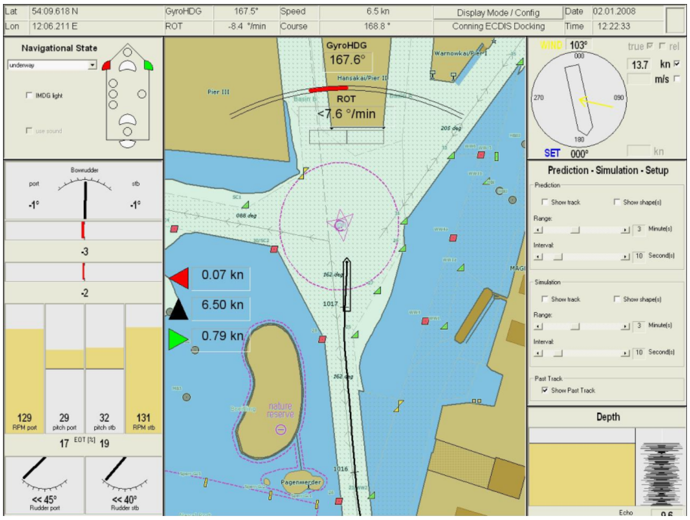
Lat 54:09.786 N | GyroHDG 160.0° | Speed 7.3 kn | Display Mode / Config | Date 02.01.2008

Lon 12:06.157 E | ROT 0.1 °/min | Course 163.1 ° | Conning ECDIS Docking | Time 12:21:03

Navigational State: underway

Fig. 14: Approaching the turning area using StB-Rudder

The Turning is stopped by using rudder to port at a heading of 170° the turning to port side starts. Rudder Hard to Port is used after that (Fig. 15).



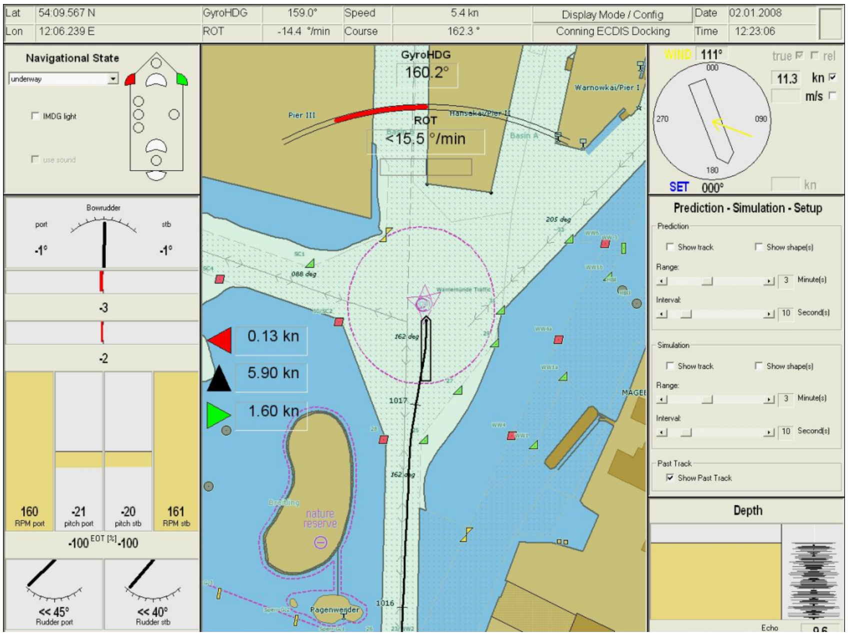
Lat 54:09.618 N | GyroHDG 167.5° | Speed 6.5 kn | Display Mode / Config | Date 02.01.2008

Lon 12:06.211 E | ROT -8.4 °/min | Course 168.8 ° | Conning ECDIS Docking | Time 12:22:33

Navigational State: underway

Fig. 15: Approach to turning basin (2) – Rudder commanded to portside

Finally both engines are set to „full astern“ to stop the vessel (Fig.16).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Lon 12:06.239 E
GyroHDG 159.0°
ROT -14.4 °/min
Speed 5.4 kn
Course 162.3 °
Display Mode / Config: Conning ECDIS Docking
Date 02.01.2008
Time 12:23:06

Fig. 16: Stop maneuver with commanded engine at „full astern“

During the continuing navigation process, the port-turn is stopped by using hard rudder to Stb (Fig. 16).

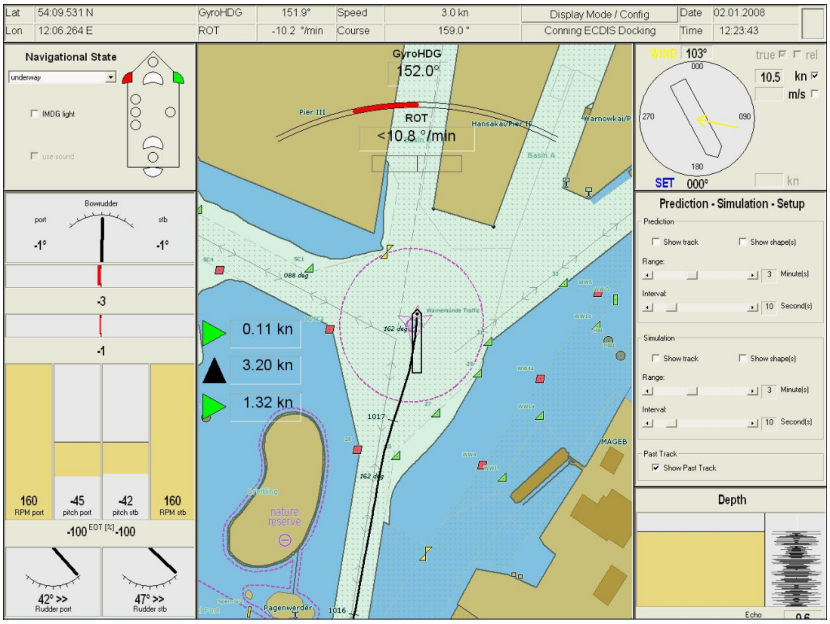
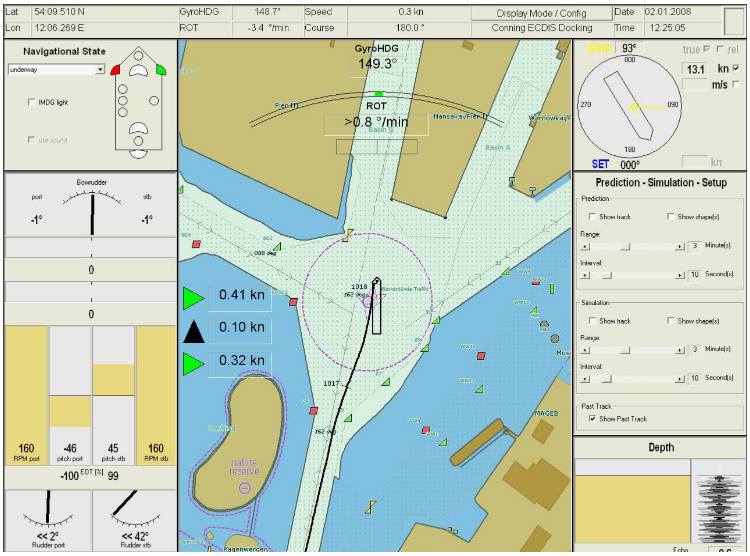

Lat 54:09.531 N
Lon 12:06.264 E
GyroHDG 151.9°
ROT -10.2 °/min
Speed 3.0 kn
Course 159.0 °
Display Mode / Config: Conning ECDIS Docking
Date 02.01.2008
Time 12:23:43

Fig. 17: Stop of the turning maneuver

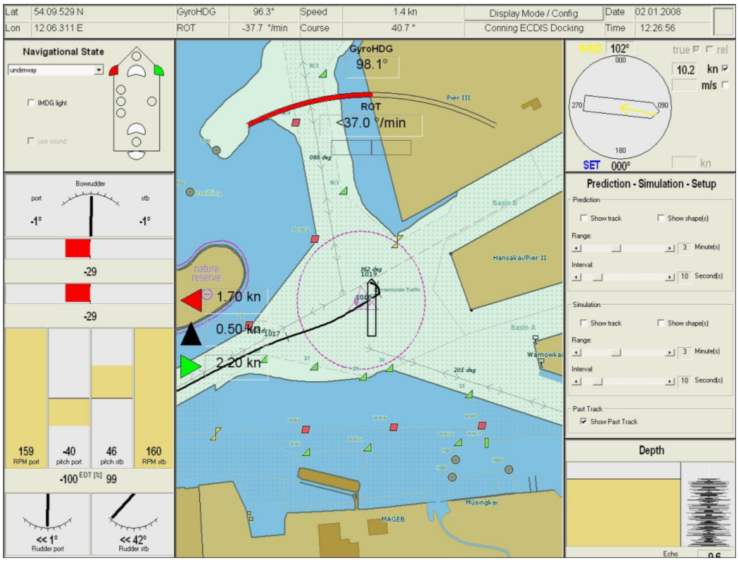
When the ship's turning is almost finished, the starboard engine is set to "full ahead". The starboard rudder is put hard to port, while port engine remains at „full astern" (Fig. 18). This maneuver – the turning of a ship on a constant position by counter rotating propellers - is known as "Backsen" and is also used by this ferry in this harbor.



Lat 54:09.510 N
Lon 12:06.269 E
GyroHDG 148.7°
ROT -3.4 °/min
Speed 0.3 kn
Course 180.0 °
Display Mode / Config: Conning ECDIS Docking
Date 02.01.2008
Time 12:25:05

Fig. 18:Begin of "Backsen" to turn inside the Turning Basin

Turning to port-side begins; thereby the ship achieves a Rate of Turn of about 33°/min. For a further increase in the Rate of turn, bow thrusters are used at circa 30 % (Fig. 19). The Rate of Turn increases because of that, up to a value of approximately 40°/min. The vessel should now be making any headway.



Lat 54:09.529 N
Lon 12:06.311 E
GyroHDG 96.3°
ROT -37.7 °/min
Speed 1.4 kn
Course 40.7 °
Display Mode / Config: Conning ECDIS Docking
Date 02.01.2008
Time 12:26:56

Fig. 19: Onward turning in the turning basin

At a heading of approximately 60° preparations for going astern begin. Both bow thrusters are used to decrease the rate of turn to zero. Also both propulsion systems are ordered to astern, and both rudders are set to amidships. The ship is going to slowly go astern.

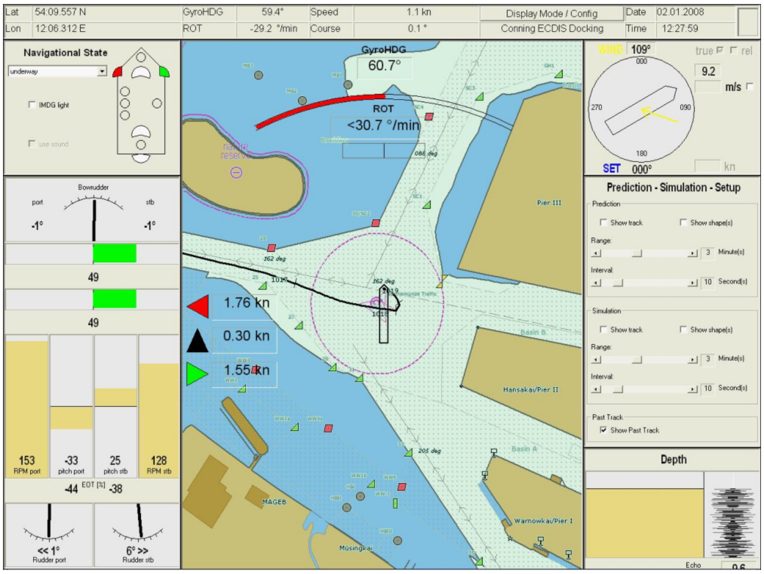
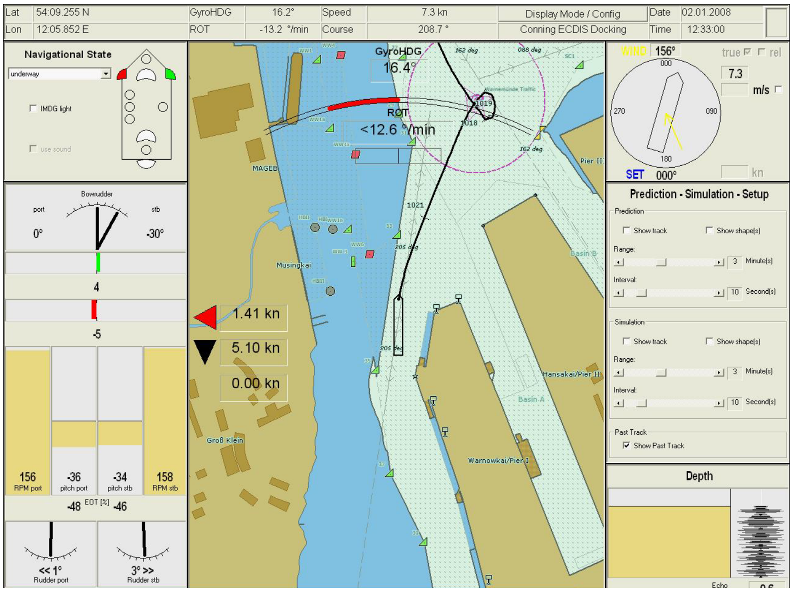


Fig. 20: Absorbing and stopping of the turning to port-side

Only the bow rudder is used for steering, until the approach at the berth. Both engines are ordered equally astern.

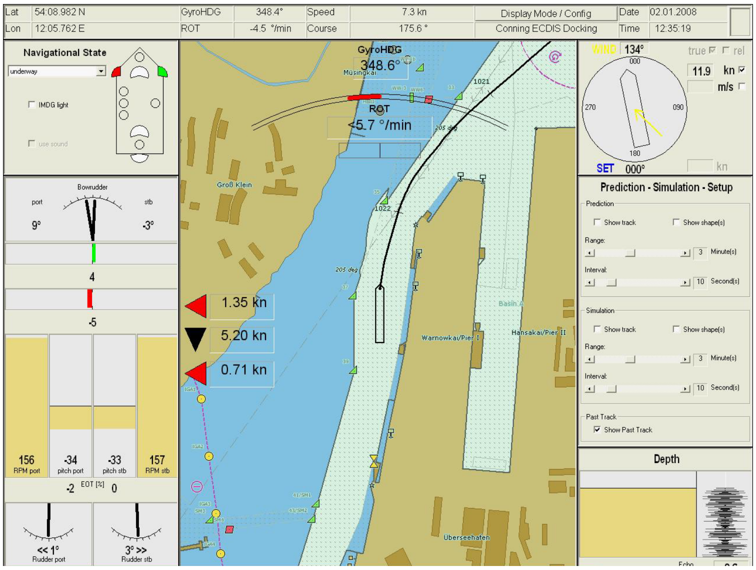
Fig. 21: Going astern, using the bow rudder ordered to port



Lat 54:09.255 N
Lon 12:05.852 E
GyroHDG 16.2°
ROT -13.2 °/min
Speed 7.3 kn
Course 208.7 °
Display Mode / Config
Conning ECDIS Docking
Date 02.01.2008
Time 12:33:00

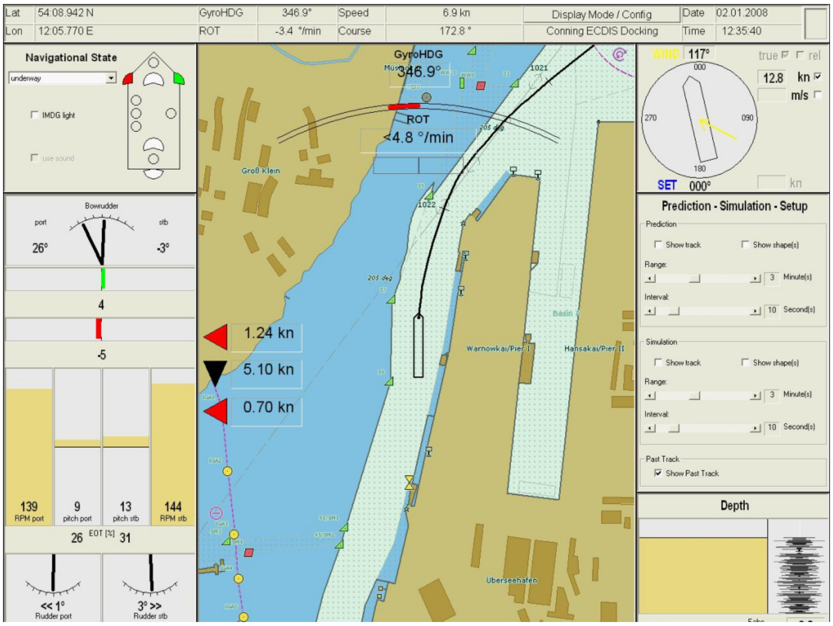
Fig. 22: Going astern, using the bow rudder to Stb

Abeam berth 66 the approach to berth 64 begins. Both Propulsion systems are temporary stopped, to be ordered afterward on ahead (Fig. 23/24).



Lat 54:08.982 N
Lon 12:05.762 E
GyroHDG 348.4°
ROT -4.5 °/min
Speed 7.3 kn
Course 175.6 °
Display Mode / Config
Conning ECDIS Docking
Date 02.01.2008
Time 12:35:19

Fig. 23: Approach to the dedicated berthing place 64 (1)



Lat 54:08.942 N
Lon 12:05.770 E
GyroHDG 346.9°
ROT -3.4 °/min
Speed 6.9 kn
Course 172.8 °
Display Mode / Config: Conning ECDIS Docking
Date 02.01.2008
Time 12:35:40

Navigational State: underway
☐ IMDG light
☐ use sound

Bowrudder: port 26°, stb -3°
4
-5
139 RPM port
9 pitch port
13 pitch stb
144 RPM stb
26 EOT [%] 31
<< 1° Rudder port
3° >> Rudder stb

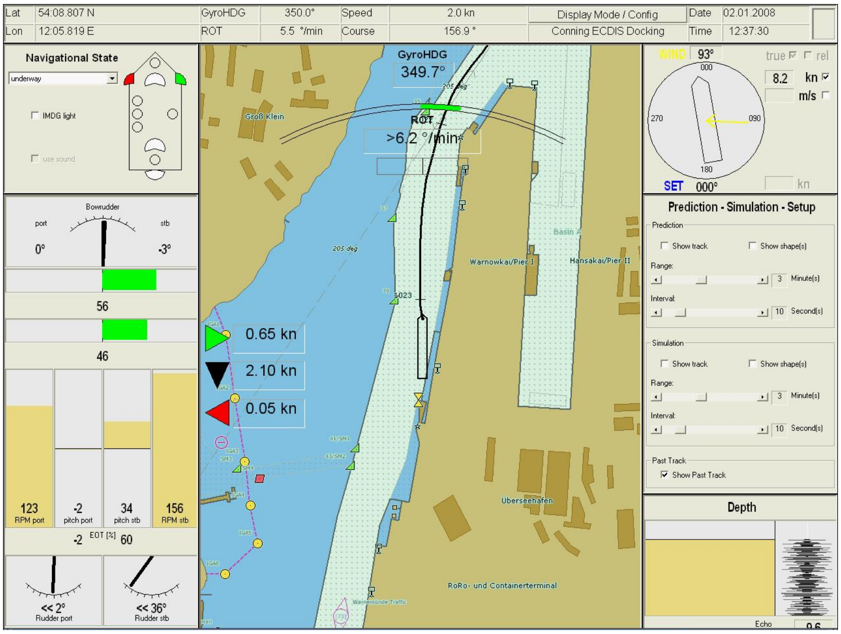
GyroHDG 346.9°
ROT <4.8 °/min
1.24 kn
5.10 kn
0.70 kn

WIND 117° true ☑ rel ☐
12.8 kn ☑
m/s ☐
SET 000°

Prediction - Simulation - Setup
Prediction: ☐ Show track ☐ Show shape(s); Range: 3 Minute(s); Interval: 10 Second(s)
Simulation: ☐ Show track ☐ Show shape(s); Range: 3 Minute(s); Interval: 10 Second(s)
Past Track: ☑ Show Past Track

Fig. 24: Approach to the dedicated berthing place 64 (2)

In the final phase, all possibilities for steering are used, except the bow rudder (Fig. 24).



Lat 54:08.807 N
Lon 12:05.819 E
GyroHDG 350.0°
ROT 5.5 °/min
Speed 2.0 kn
Course 156.9 °
Display Mode / Config: Conning ECDIS Docking
Date 02.01.2008
Time 12:37:30

Navigational State: underway
☐ IMDG light
☐ use sound

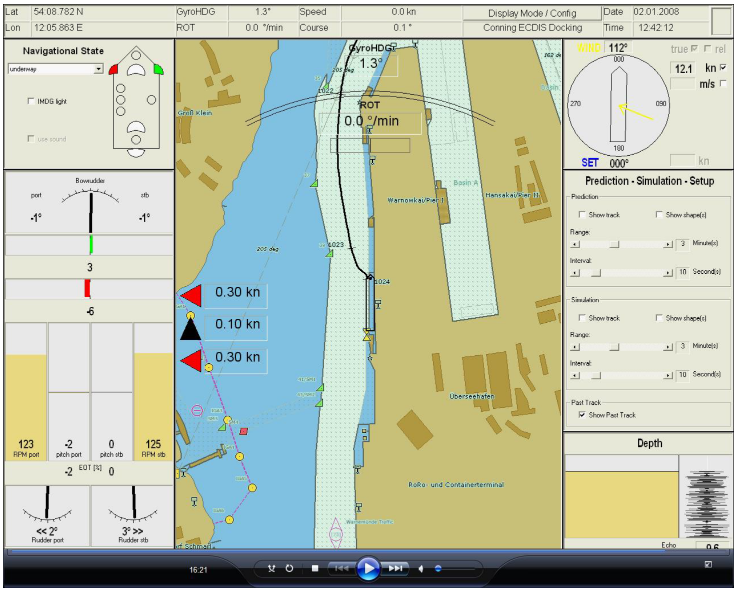
Bowrudder: port 0°, stb -3°
56
46
123 RPM port
-2 pitch port
34 pitch stb
156 RPM stb
-2 EOT [%] 60
<< 2° Rudder port
<< 36° Rudder stb

GyroHDG 349.7°
ROT >6.2 °/min
0.65 kn
2.10 kn
0.05 kn

WIND 93° true ☑ rel ☐
8.2 kn ☑
m/s ☐
SET 000°

Prediction - Simulation - Setup
Prediction: ☐ Show track ☐ Show shape(s); Range: 3 Minute(s); Interval: 10 Second(s)
Simulation: ☐ Show track ☐ Show shape(s); Range: 3 Minute(s); Interval: 10 Second(s)
Past Track: ☑ Show Past Track

Fig. 25: Berthing (1)



Lat 54:08.782 N
Lon 12:05.863 E
GyroHDG 1.3°
ROT 0.0 °/min
Speed 0.0 kn
Course 0.1 °
Display Mode / Config: Conning ECDIS Docking
Date 02.01.2008
Time 12:42:12

Fig. 26: Berthing(2)

3.2.2 Results and basic conclusions from data analysis

The following results be concluded according to the illustrated maneuver and are best broken down into four distinct phases:

- Phase 1: Keeping the course at 162 ° is the highest priority. There is no real potential for optimization. The speed is as high as allowed.
- The maneuvers performed in Phase 2 have potential to be optimised. The turning operation started with a Stb turn up to 170°, after that the ship was turned over her portside up to heading of 150°, whereby the rate of turn was nearly eliminated. Additional to that, the ship was nearly brought to a stop. Immediately afterwards, the turn begins with Stb-engine ahead, Port-engine astern (the so called “backsen”), supported by port side rudder angle of the Stb rudder. It seems that this strategy costs some time, beside this it also seems the energetic/ ecologic aspect is worth for further consideration. Time and fuel could possibly be saved by using an alternative concept for turning the vessel, as illustrated further below.
- Phase 3 is characterized by the repeated use of the bow rudder for conning the vessel going astern. This element is not implemented in the simulation model. Instead the bow rudder was used for that purpose.
- Phase 4 (Berthing at Berth 64) has not been taken into detailed consideration yet. There is especially potential for optimization during adverse environmental conditions. The continuous usage of separate Rudder and engine settings for swaying and berthing shall be indicated.

The total time needed for the considered area (54°10’N to 54°09’N) analyzed here, was:
15:56 Minutes (VDR -Backup),
15:43 Minutes (AIS 19/02/2008),
15:31 Minutes (AIS 13/11/2008),
18:24 Minutes (AIS 20/11/2008).

3.3 Simulation study of alternative maneuvering concept for Phase 2

3.3.1 Description of the concept idea

The outcome from the data analysis indicates that the greatest opportunity for development is in Phase 2. Where the vessel is to be turned in the turning basin, a change of maneuver sequence is possible and gives room for improvement. The choice of basic maneuver orders is orientated around two major aspects:

1. There are advantages to be had in avoiding the stopping of the vessel in the turning basin. (Rate of turn = 0, Speed =0) It seems only necessary to stop the vessel, if the turn is realized with the “Backsen” strategy. Simulation trials showed that the need for space by proceeding at very slow headway is too much. If the full stop should be avoided, the initial turn has to be started when the vessel is still making headway.
   Simulation in unrestricted waters showed a simple way to perform in that manner. Giving rudder 'Hard to Port!', supported by the use of bow thrusters and full astern allow the vessel to turn while simultaneously decreasing speed. Simulation trials in the port of Rostock using the predictor showed the feasibility, where the maneuver orders were even not used up to 100%, to achieve the desired berth. So there are still safety reserves for harsher conditions.
2. It should be possible to increase the rate of turn from the initial rate of 40°/min. While the turn trials mentioned above achieve rates of turn of 46°/min. The fourth trial the rate of turn achieved was 60°/min. One must investigate if that value can be achieved in reality and if it is useful to subject the passengers and ship to such a exposure.

3.3.2 Test trails using alternative maneuver sequences with provision of Dynamic Predictor

Firstly, it must be pointed out, that the simulation model of MV “Mecklenburg-Vorpommern” slightly deviates in some parts of handling design from the real ship. For instance, the maximum rudder angle of the model is limited to 35°, whereas the real vessel achieves 45° rudder angle. Additionally, the model doesn’t have bow rudder. Furthermore the model is to be conned from the front bridge. The model ship was conned by persons who are not familiar with conning of this ferry. Due to the use of the Dynamic Predictor it was possible to navigate the vessel safely. The simulation trials were executed in the manner, which is described above (rudder hard to port, bow thruster to portside, EOT astern). Therefore see also Figure 27.

Fig. 27: Examples of maneuver tracks from simulation trials

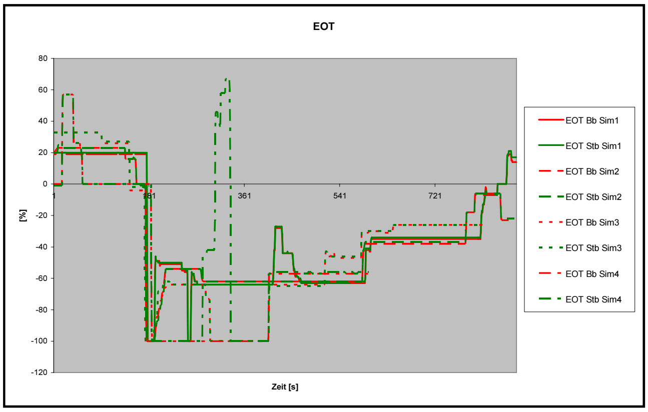


Fig. 28: EOT Orders while Simulation trials

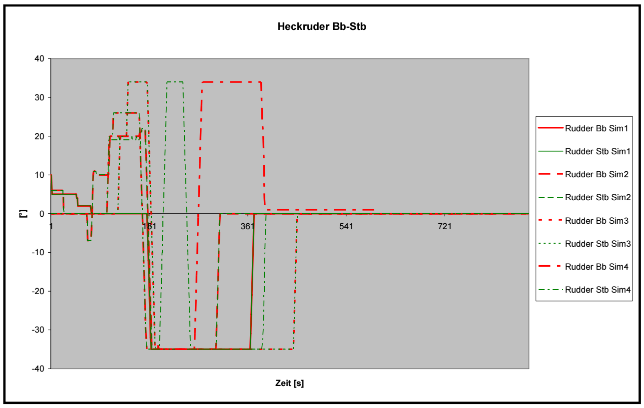


Fig. 29: Ordered rudder angle while Simulation trials

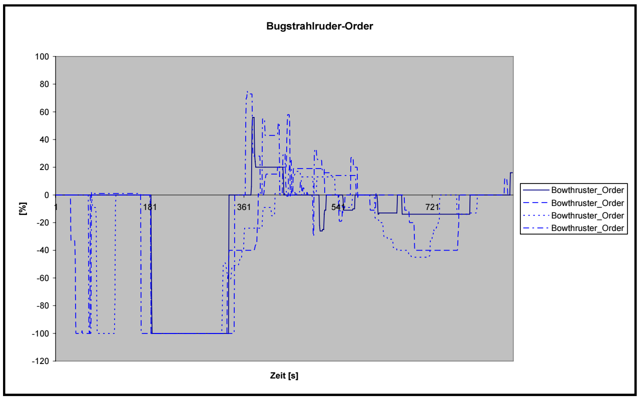
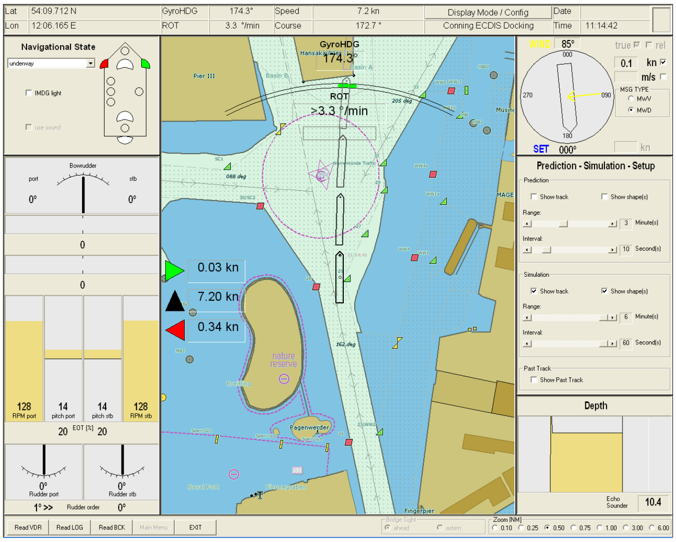


Fig. 30: Course of ordered Bow thruster power during Simulation trials

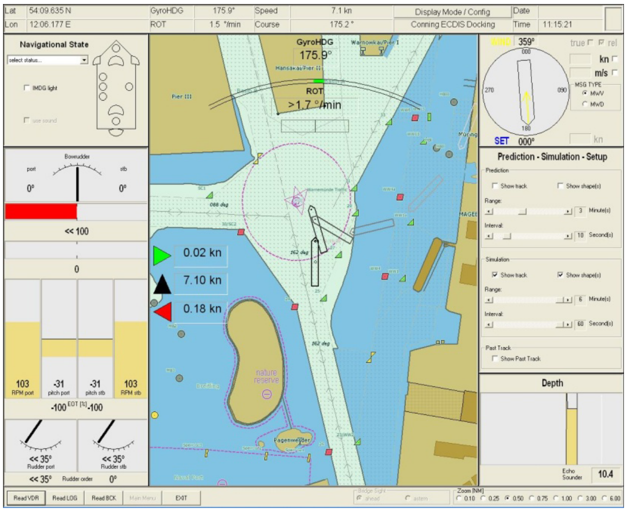
After passing buoy 25/28 the course was changed to starboard, to give more space for turning the vessel to port.



Lat 54:09.712 N | GyroHDG 174.3° | Speed 7.2 kn | Display Mode / Config | Date
Lon 12:06.165 E | ROT 3.3 °/min | Course 172.7 ° | Conning ECDIS Docking | Time 11:14:42

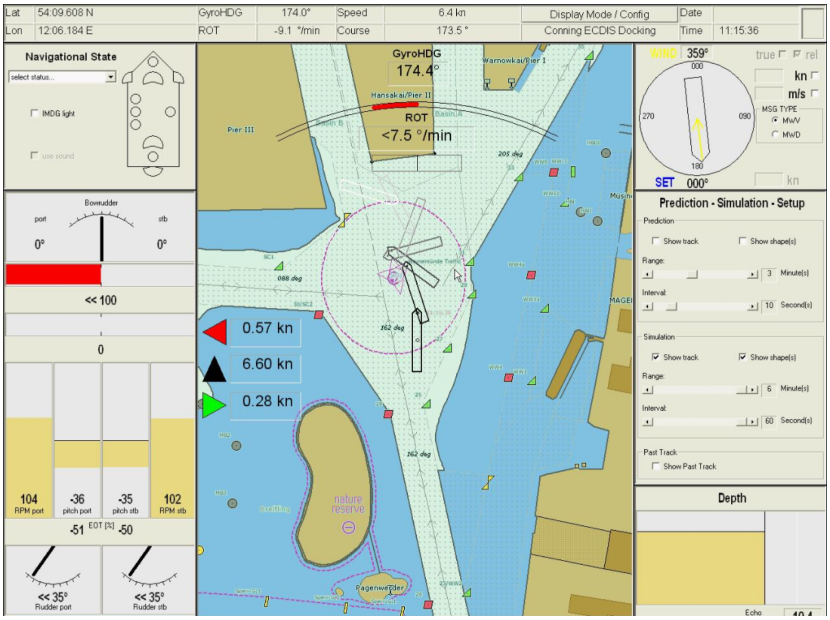
Fig. 31: Approaching the turning basin

After approaching the turning basin, in the first attempt the rudders are set to hard to port, both engines are ordered to „full astern“, as such the bow thruster is set to port direction. The Track of the Dynamic Predictor with a prediction time of up to 10 minutes shows that these settings will not succeed (Fig. 30). Due this, the settings should be manipulated, which can be online done. The Dynamic Predictor immediately shows the changes for the handles in terms of the predicted change of Track. In that manner the track can be “adjusted”, so that the set orders achieve the maneuver aim. Particularly here it is the reduction of the engine order, which is set to a lower state. This process is illustrated in the following figures 32 to 34.



Lat 54:09.635 N | GyroHDG 175.9° | Speed 7.1 kn | Display Mode / Config | Date
Lon 12:06.177 E | ROT 1.5 °/min | Course 175.2 ° | Conning ECDIS Docking | Time 11:15:21

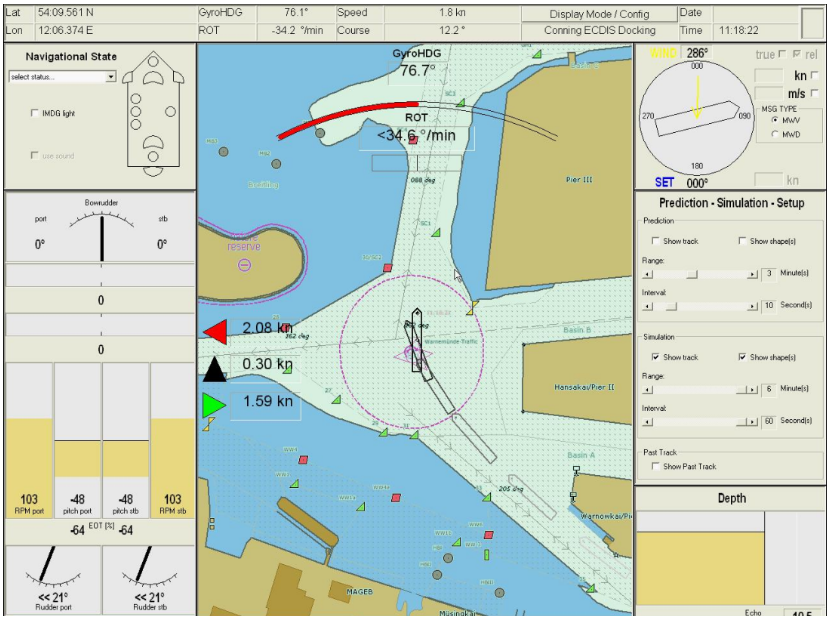
Fig. 32: Turning in the turning basin using Prediction (1) – here with still too much EOT astern



Lat 54:09.608 N
Lon 12:06.184 E
GyroHDG 174.0°
ROT -9.1 °/min
Speed 6.4 kn
Course 173.5 °
Display Mode / Config
Conning ECDIS Docking
Date
Time 11:15:36

Prediction - Simulation - Setup
Prediction: ☐ Show track ☐ Show shape(s); Range: 3 Minute(s); Interval: 10 Second(s)
Simulation: ☑ Show track ☑ Show shape(s); Range: 6 Minute(s); Interval: 60 Second(s)
Past Track: ☐ Show Past Track

Fig. 33:Turning in the turning basin using Prediction (2) – here with appropriate EOT astern while turning



Lat 54:09.561 N
Lon 12:06.374 E
GyroHDG 76.1°
ROT -34.2 °/min
Speed 1.8 kn
Course 12.2 °
Display Mode / Config
Conning ECDIS Docking
Date
Time 11:18:22

Prediction - Simulation - Setup
Prediction: ☐ Show track ☐ Show shape(s); Range: 3 Minute(s); Interval: 10 Second(s)
Simulation: ☑ Show track ☑ Show shape(s); Range: 6 Minute(s); Interval: 60 Second(s)
Past Track: ☐ Show Past Track

Fig. 34: Leaving turning basin using Prediction (3) – end of turn maneuver

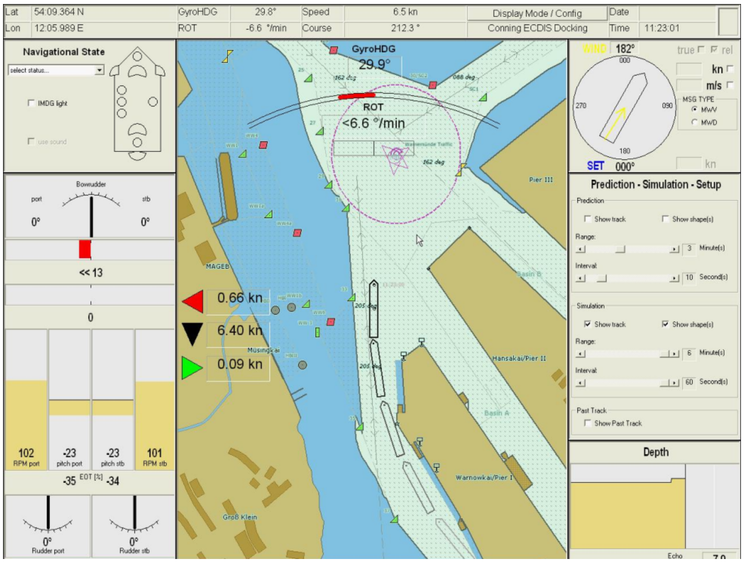


Fig. 35: Going astern with prediction – approach to berth

3.4 Conclusions from simulation trials for alternative concept and outlook

The simulation trial approved the feasibility for a change in the maneuver strategy when entering Port of Rostock with MV “Mecklenburg-Vorpommern”. The performed maneuvers differ greatly compared to those presently in use, but are safe throughout of course.

During the simulation experiments it was discovered that a complete stop in the turning basin is not necessary in order to turn the vessel. Additionally to that, an increased rate of turn can be achieved. The options of the steering equipment to maneuver the ferry in the harbor basins are not fully used. Consequently the possibility to cope with harsher environmental influences still remains.

The total time required for the three experimental trials was:

- 14:36 minutes (simulation run 1),
- 14:32 minutes (simulation run 2),
- 13:32 minutes (simulation run 3)

This means that there is a potential to save one up to six minutes when comparing the proposed maneuvers to the current practice. It is assumed that a further increase can be achieved through further training and improvement of the HMI.

Focusing only on the second phase (turning), there is about one to 3 minutes to save. Another fourth simulation run was performed to investigate the potential for time saving by using a higher the rate of turn (see figure 36).

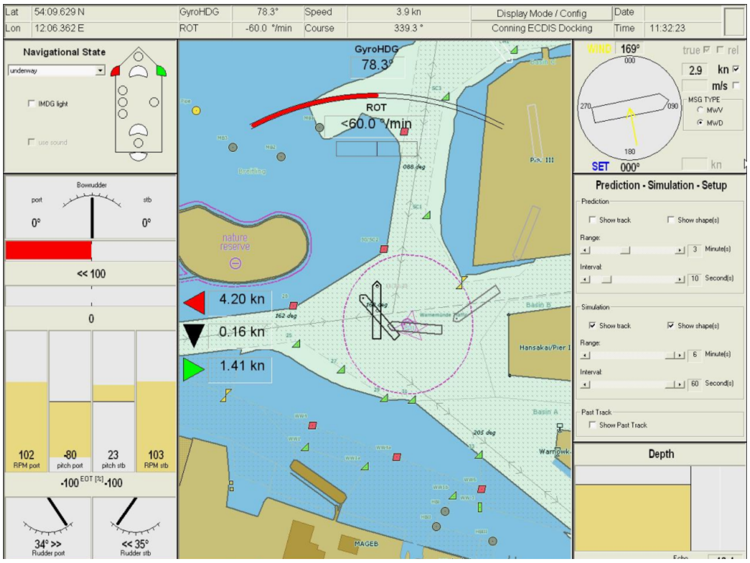


Fig. 36: Test for increasing rate of turn up to 60°/min by separate rudder use

During the fourth simulation run the turning maneuver was initiated applying the standard manner as it is currently practiced. While turning to portside, the rudders were turned to each other (Port rudder to Stb and Stb rudder to port), and the portside engine is set to slow ahead. The achieved rate of turn due to the special settings of the controls was 60°/min maximum.

Especially in the context of ferry operations the potential for time savings of three to five minutes is crucial. Ferries have to keep their time schedules. According to today's time scheduling company based analysis have shown that once a delay occurs during one of the turns there is no realistic chance to compensate this delay during the following voyages of the day, even the delay was suffered during early voyages of the day. This statement was proved by own spotlight investigations of ferry connections in the Baltic Sea. A public statement of a Captain of a Danish ferry mentioned at the e-Navigation underway conference that "*... the compensation of just a seven minutes delay on a trip between Copenhagen and Oslo needs seven tons of additional fuel to keep the given time schedule.*" This statement clearly underlines the potential that alternative maneuvering strategies and the use of enhanced Maneuvering Assistance Systems provide for time and cost savings and moreover the reduction of GHG emissions.

It is clearly demonstrated that there is a further potential for improvement by separating the use of the rudders, which should be investigated in the next phase with continuative simulation studies.

4 HMI design for Maneuvering assistance

4.1 Introduction and theoretical background

In considering the drive towards a greener, more environmentally friendly international shipping industry, it is important to understand both error and resilience, and to consider the role of the human interacting in the 'socio-technical' system of the ship operating in the global maritime complex. After considering this broadest of perspectives, the main aim of this chapter is to examine the issue much more narrowly, considering the human-machine interface with respect to maneuvering assistance. The sub-aims of the chapter are as follows:

- To investigate the main human element issues and design strategies associated with developing Human-Machine-Interfaces;
- To consider as it relates to automation in a range of transportation domains; and
- To investigate the potential of Maneuvering Assistance Module (MAM) for "green ship operation".

The figure below represents the complex socio-technical relationships encountered in the maritime domain. Shipboard factors are shown to have immediate impact on maritime safety, whilst extrinsic factors, largely being of organizational origin, have indirect influence on crew performance. Any design should be developed with respect to this complex interaction of relationships. While there are established principles in ergonomics for the good design of hardware and software, many systems fail to achieve their goals because of a lack of understanding of the socio-technical system they must exist within. The maritime industry is no exception to this, and, potentially the most complex of all forms of mass transportation. Riding on the back of this complexity is the complex nature of the human condition, with all its ability to comprehend and maintain complex systems whilst at the same time being subject to the constraints associated with issues like memory, fatigue and stress. It is to these issues our direction now turns.

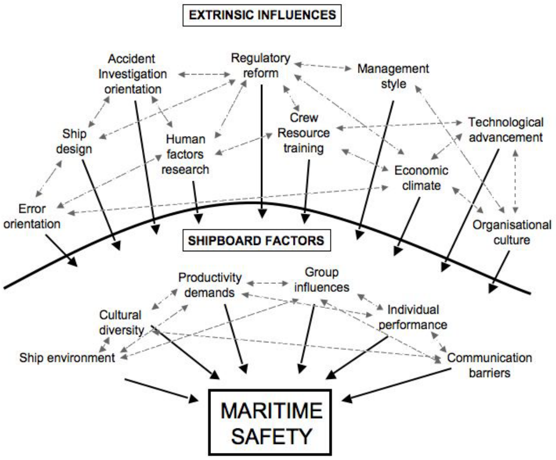


Fig. 37: Socio-technical relationships in the maritime domain (Grech et.al. 2008)

4.2 Background Issues: Human Factors

4.2.1 Human Factors Issues

Human Factors, put simply, is the science of people at work. Human Factors is primarily concerned with understanding human capabilities, and then applying this knowledge to the design of equipment, tools, systems, and processes of work. Accordingly, Human Factors examines the interaction between humans, and the broader systems with which they work (Wickens et al., 1998). Chapanis (1996) provides this definition:

> *Human Factors is a body of information about human abilities, human limitations, and other human characteristics that are relevant to design… Human Factors engineering is the application of human factors information to the design of tools, machines, systems, tasks, jobs, and environments for safe, comfortable, and effective human use.*

Human Factors therefore desires to be integrated at the design stage, and through the iterative process of system design, although regularly human factors is used as a mechanism to diagnose problems with current designs in an effort to drive some change with respect to future design of maneuvering systems.

4.2.2 Relevance of Human Factors the ProGreenShipOperation-1 Project

Irrespective of who stands on the bridge of a ship, they are susceptible to all the limitations of the human condition, and blessed with all the benefits associated with expertise that comes from being a trained seafarer. In the design of any man-machine interface, the designer should make every effort to meet the four main goals of human factors (Wickens et al., 1998):

- Reducing error: This includes removing ambiguity in the interface to avoid errors, including “forcing functions” to prevent erroneous input, ensuring all essential information is provided to the user, ensuring any error is visible to the user and ensuring any error can be recovered from or “reversed”.

- Increasing productivity; This includes mapping task sequences and measuring performance, removing unnecessary steps from a task, creating a more efficient work-space layout, building better tools and equipment and selecting personnel with greater aptitude for the task. In the current context productivity also relates to efficiency and the desire to promote greener, less energy intensive approaches to shipping.

- Enhancing safety: Including functions such as monitoring human performance, building defenses against frequent forms of error, reducing the occurrence of error through training, removing environmental stressors, managing task design to reduce workload and increasing or reducing the information provided to operators.

- Enhancing Comfort: Includes redesigning the workspace to meet changing anthropometric characteristics; building a more intuitive interface; maintaining comfortable temperature and noise levels; increasing/reducing light levels; redesigning the roster to reduce fatigue.

4.2.3 Human Factors ‘Interventions’

The field of Human Factors focuses its attention of five primary areas (Chapanis, 1996, Wickens et al., 1998). This is not a hierarchy (and therefore different to the OHS ‘hierarchy of control’) but might be considered more as a ‘toolkit’ to be combined as appropriate.

- Personnel Selection
- Personnel Training
- Equipment and Machine Design
- Job and Task Design
- Environmental Design

These are what we call the main areas of human factors intervention – these are the types of areas in which a human factors practitioner might identify and institute some form of change. The iemphasis of this project is directed towards design issues, and might reasonably be considered an emphasis on ‘equipment and machinery design. Having said this, in order to design equipment that meets the needs of the human, it is necessary to address the environment and the job/task (not part of this report) and to address any subsequent training and selection requirements.

4.3 Key Areas of Human Factors Relevant To Interface Design

This section includes brief summaries of issues important to the design of a manoeuvring assistance interface. They are presented as brief ‘literature reviews’ followed by short commentary on the relevance to the current design issue.

4.3.1 Decision-Making

Several theories describing cognitive constructs including attention, knowledge acquisition and problem solving are important to understand behavioral responses on the ship bridge. *Classical decision making theory* holds that people analyze the value of each alternative to inform their selection of preferred solution (Meso, Troutt, & Rudnicka, 2002). However, behaviorists such as Simon (1965) challenged the ecological validity of this perspective, and favored a more practical and adaptable explanation.
Behavioral decision making models purport that rational analysis of all possible choices is too effortful and that in operational environments, humans simplify decision making to preserve limited cognitive resources to respond to any future threats that may present (Adelman et.al., 1996; Klein et.al., 2005; Endsley, 1995). The human capacity for adaptation and efficient performance has been variously termed *bounded rationality, local optimization, satisfying, cognitive minimization* and the *thoroughness-efficiency compromise*, and while it usually facilitates successful outcomes, it also represents a source of error vulnerability (Wickens & Hollands, 2000; Cooper, 2000).
Naturalistic decision making models propose that expertise is context specific. Rasmussen (1997) identified that inexperienced operators, lacking a store of previous solutions, need to thoroughly analyze salient information, which leads to high attention demands. Conversely, skilled operators have less need to manipulate hypotheses and can assess situational cues more economically. Similarly, several theorists discuss the effect of cognitive heuristics, thought to simplify information laden decision making, which are clearly desirable in high risk operations and emergency situations. The *representativeness heuristic* involves matching similarities with a previously stored reference; the *availability heuristic* involves readily accessible solutions; and the *anchoring heuristic* uses an initial estimation without adjustment for later information (Bjork, 1999; Lipshitz, Klein, Orasanu, & Salas, 2001; Schneider, 1985; Flin, Slaven, & Stewart, 1996).

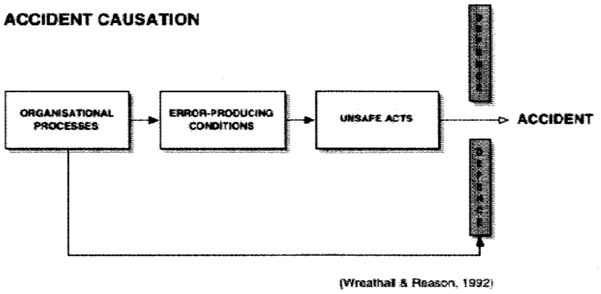
While stored knowledge structures reduce cognitive complexity, over-utilization of heuristics may compromise problem solving effectiveness. Sarter and Woods (1995) found that when under threat or in doubt, humans tend to default to habitual responses. C*onfirmation bias* is the tendency to fixate on a particular hypothesis, to interpret ambiguous evidence as supportive and to ignore falsifying information; *frequency gambling bias* explains selection of the most commonly employed solution; and e*xpectation bias* could be responsible should a seafarer fail to detect that the signals on a familiar channel marker have altered (Tversky & Kahneman, 1981; Schustack & Sternberg, 1981; Mumaw, Roth, Vicente, & Burns, 2000; Woods & Cook, 2002; Hunt, 1997). Although decision-making biases represent another source of human fallibility, understanding human tendencies in the operational context can inform intervention to reduce risk of these effects.

The evolution of decision-making theory has progressively identified the highly conditional nature of human performance. Contextual influences are thought to mediate individual performance, giving rise to Dekker's (2006) suggestion that organizational practices may be more amenable to adjustment and improvement than certain cognitive capacities. This leads to a conclusion that improvements in design of maneuvering assistance interface must acknowledge the strengths and limitations of cognitive capacities of the user and the context in which they are embedded. Decision-making analysis, particularly under circumstances that are highly novel (such as unforeseen emergencies) can also be a very effective design tool and this is discussed further in the section on automation and design. The cognitive apparatus is also only one component of decision-making (the other is the affective apparatus that deals with emotional responses to situations). This issue is explored further in the section on emotional design.

4.3.2 Human Error

Error is a ubiquitous and natural part of everyday life. Indeed, error can be described as a defining element of the human condition and it is accepted that we will all make errors every day of our lives. Already, we all have an intuitive understanding of the term error, and regularly use a wide range of words in order to describe our errors and their outcomes. For instance, frequently our actions lead to unintended outcomes or our plans are simply mistaken or wrong. A calculation we make might be inaccurate or incorrect, or we might forget an important step in a task. While each of these examples are classified as errors, we need more robust definitions in order to understand better the nature of human error and develop mechanisms for effective error management.

As Wreathall and Reason (1992) put so elegantly, "the history of accidents and their analysis is also the history of human contribution to accidents". Illustrated in the Figure 38 below, it is the unsafe acts of human operators that are often primary factors in accident causation. However, rather than treating the variety of error events, captured by the term "unsafe acts", as aberrant mental processes which need to be eradicated, it has become accepted that systems-based approaches to human error management offer the greatest potential from the perspective of safety management in high risk industries. The systems-based approaches to error management employ countermeasures that are based on the assumption that though we cannot change the human condition, we can change the conditions under which humans work. Expanding this perspective, error management has two components: 1) limiting the incidence of dangerous errors; and 2) creating systems that are better able to tolerate the occurrence of errors and contain their damaging effects (Reason, 2000).



(Wreathall & Reason, 1992)

Fig. 38: Accident Causation Wreathall and Reason (1992)

As error is such a ubiquitous element of the human condition, the equipment and systems we design frequently embed error detection devices that will provide warning or override our actions if an error occurs. Any new piece of technology built today has been designed with at least some understanding of human error. From the kettle to the automatic teller and the most modern computer, our new technology often includes functions that will detect erroneous input and provide us with messages or warnings to alert us to any error. A simple warning-tone to indicate that our car's headlights are still on when we remove the key from the ignition is a classic example of a system designed to respond to a common error, and without doubt has saved hundreds of thousands of people from significant frustration and expense due to a flat car battery. Thankfully, industrial designers have taken into consideration our natural propensity for error and the equipment we use will often warn us when we make an error. However it is fair to say that the greater the requirement for reliability, the more detailed and sophisticated our design efforts need to be to address error.

Through the classification of error, we risk creating an illusion of understanding the causal factors involved through a simplistic process of relabeling and grouping similar types of error. However, it is possible to build effective mechanisms for safety-related change through analyses of error that de-emphasize the construction of cause and focus on the identification of patterns in error occurrence. These "genotypical mechanisms of failure" elucidate the means by which operators create safety in practice, and map universal patterns of safety breakdown (Dekker, 2003).

The most common system for the classification for errors involves the differentiation between errors committed in the planning of actions, and errors committed in the execution of actions.

The term mistake is used to describe the errors that occur in the planning of actions and involve errors where the plan for specific action is deficient or fundamentally flawed. In this instance, an operator might execute a plan of action flawlessly, but not achieve the desired outcome due to an inherent problem with the plan of action itself. As Reason (1990) suggests, mistakes frequently occur through the failures of higher-order cognitive processes involved in judging the available information, setting objectives, and deciding on the means to achieve a desired outcome. This type of error relates directly to Rasmussen's (1986) knowledge-based behaviors, which involve conscious reasoning during problem-solving activities. Accordingly, these errors are frequently referred to as knowledge-based mistakes.

However, mistakes are frequently also observed with respect to less conscious or deliberate planning processes. Termed rule-based mistakes, these forms of error involve the incorrect initiation of actions in response to existing behavioral routines. Frequently, rule-based mistakes involve an automatic response to misdiagnosed problem, or the automatic misdiagnosis of a situation. Rule-based mistakes occur through the interference of biases or quasi-automatic intervention of more familiar rules, and can occur in relation to both the identification of a situation and the selection of action (Rizzo et al., 1995).

Similarly, two broad types of error can be categorized at the execution stage. Firstly, slips involve unintentional actions or active failures in the execution of a plan. In these situations, the intended action is appropriate, but due to low level attentional failures in highly practiced and automatic behaviors, incorrect action is executed (Norman, 1981). For instance, simple errors in psychomotor performance such as moving a lever forward instead of backward typify slips.

Secondly, lapses are defined as errors that occur as a result of memory failures, and most frequently involve forgetting a procedural step or planned action. For instance, a task, or individual task step, is omitted through a failure in memory processes. Again, it has been suggested that attentional failures, or diversion of attention through distraction, are important mechanisms in the production of lapses.

The design of any interface needs to acknowledge the ubiquitous nature of human error and be designed to assist with error detection, diagnosis and recovery. The section on automation and design considers this further by exploring design approaches through examination of 'imagined' future incidents by multi-disciplinary teams.

4.3.3 Information Processing and Cognition

The sophistication of human information processing activity, or cognition, is perhaps the one thing that sets us apart from the rest of the animal kingdom. However, our information processing is not without its limitations and peculiarities. An understanding of the basic cognitive processes, and the areas in which they are vulnerable, forms a critical underpinning for Human Factors knowledge. Ulrich Neisser (1967) defined cognition as:

> *"all processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used. It is concerned with these processes even when they operate in the absence of relevant stimulation, as in images and hallucinations"*

From a human factors perspective, there are a number of important features of our cognition that warrant particular attention. These can be grouped under the headings of Perception, Central Processing & Response. Perception addresses visual, auditory, tactile, haptic (touch) and vestibular (spatial orientation) concepts. Central processing addresses issues such as attention, processing capacities, memory and learning. Response relates to decision-making and has been addressed earlier.

It is likely that the development of a vessel interface for port waters will lead to some change in Mental Workload. This concept can be understood in terms of the difference between the amount of metal resources available to a person, and the amount of mental resources demanded by the task or situation (Sanders & McCormick, 1987). Mental workload is a function of a number of interacting elements of information processing. These include, among others:

- Attentional Demands – whereby the demands of having to pay attention to increasing amounts of information increase overall workload;
- Multiple Competing Tasks – whereby increasing the number of concurrent tasks that are required to be performed increase overall workload;
- Expertise – whereby tasks undertaken by a novice requires significantly more metal resources than the "automatised" tasks undertaken by an expert; and
- Physiological Interference – whereby factors such as fatigue and stress reduce the available cognitive resources.

Another important distinction to make when considering cognition from a human factors perspective involves the distinctions between skill-based, rule-based, and knowledge-based behaviours. This framework was developed in order to reflect the changes in performance associated with expertise, and explore the relationship between the level of cognitive control over a task, and the types of error that can occur (Rasmussen, 1986).

- Skill-Based Behavior – refers to behaviors that are largely "automated" as a function of expertise. At this level behavior is governed by pre-programmed action sequences that are simply triggered by appropriate sensory input. There is little conscious processing of information, problem-identification, diagnosis or decision-making involved.

- Rule-Based Behavior – refers to behaviors that require some level of conscious processing to select the appropriate action from a set of possible “rules”. This typically reflects the performance at an intermediate level between novice and expert.

- Knowledge-Based Behavior – refers to behavior that must be consciously controlled by the operator. This involves analyzing the information present at a conceptual level, in order to choose the correct action. This level of behavior places the most demands on working memory.

This Skill-Rule-Knowledge (SRK) framework has significant intuitive appeal in describing the behavioral differences between experts and novices, and also the behavioral differences between frequently encountered and novel situations. It is important to note that, as expertise or familiarity with a task, increases, the demands on conscious processing of information in the working memory decreases. In turn, valuable working memory capacity is “freed-up” for other functions, such as executive monitoring functions, which are typically seen in experts. The design of an interface needs to be cognizant of changes in workload, and in particular mental workload, and acknowledge how aspects of operation are likely to require different levels and types of cognitive control. The SRK framework is both useful to define the limitations of human performance buy also look at which aspects might be able to be automated.

4.3.4 Occupational Stress

Although it’s difficult to quantify risk exposure to health and safety and environmental incidents internationally, seafarer fatigue and stress have been identified as causative factors in both. In the literature fatigue is often regarded as a stressor and not distinguished separately. It is frequently pointed out in the literature that work generically is a significant factor in stress causation in white collar work as well as in blue collar occupations. The maritime transport sector is no exception particularly relative to long periods onboard. At the outset it is important to note that there are three main categories of stress; some of the sub categories are:

- Physical: relative to hot/ cold temperature/ climate/ levels of humidity: noise/ harmonic engine vibration; poor lighting; sea motion.

- Physiological: as a result of fatigue; inadequate rest and sleep between watches/ shifts; sleep loss/ disrupted sleep; irregular/ unpredictable working hours; irregular eating times due to shift work/ lifestyle issues such as diet/ alcohol/ prescription and illicit drugs.

- Psychological: milder forms of mental disorders; subjective experience of inability to cope with job requirements; impaired task management capacity; adverse impacts on social/ interpersonal relations (Kristiansen, 2005).

The effects of stress and their cumulative impact in the maritime sector are well known and have been researched for decades. More recently a study by Parker et al (1998) points to environmental hardships on shipboard such as heat, humidity and noise with a substantial impact on engineers and crews (relative reporting frequency 15.4%). According to Parker et al these stressors contribute to fatigue, neurotic syndromes, arterial hypertension and gastric and duodenal ulcers (Parker et al in Kristiansen, 2005). Specifically to seafarers, the industry specific sources of occupational stress are (in percentages reported by main value); Hardships at sea, 10.5%; Weather, 6.2 %; Missing home, 11.8 %; Broken rest, 10.2 %; Long hours, 10.2%; and significantly, Industry change, 77.8% (Parker et al in Kristiansen, 2005).

4.3.5 Fatigue

According to a report of an international comparative study conducted by Andy Smith, Cardiff University in 2007:

> *Global concern with the extent of seafarer fatigue is widely evident everywhere in the shipping industry. Maritime regulators, ship owners, trade unions and P & I clubs are all alert to the fact that in some ship types, a combination of minimal manning, sequences of rapid turnarounds and short sea passages, adverse weather and traffic conditions, may find seafarers working long hours with insufficient recuperative rest. A holistic view is needed of the effects of stress and health factors associated with long periods away from home, limited communication and consistently high workloads on seafarers. In these circumstances fatigue and reduced performance may lead to environmental damage, ill-health and reduced life-span among highly skilled seafarers who are in short supply.*

Attributable to fatigue Smith reports that:

> *Within the maritime industry Folkard (1997) found that collisions between ships at sea were more likely to occur during early morning hours with a peak between 0600 and 0700. These data were derived from a sample of 123 collision claims made between 1987 and 1991 (UK P &I Club, 1992, cited by Folkard, 1997). Marine pilotage accidents have also been found to show circadian variation, with two peaks occurring between 0400 and 1000, and 1600 and 2400 (Smith and Owen, 1989). Thus, it appears that high performance demands during the night may pose safety and occupational health hazards within the maritime industry. It should be noted that reported accidents may be just the observable portion of a much greater number of unsafe behaviours and mishaps. While collisions occur more frequently in the early morning, fatal injuries to seafarers are more likely to occur during the day, reflecting the greater likelihood of seafarers working on the decks during daylight hours (Smith, 2007).*

Smith's report found that the evidence reviewed in this demonstrates that seafarers' fatigue is common and widespread. Consequently there are serious risks and consequences inherent in allowing vessels to be manned by fatigued seafarers. According to Smith they can be summarized as follows: Potential for more environmental disasters; Economic costs due to fines for accidents, losses, and increased insurance premiums, and; Serious health and safety implications for seafarers (Smith, 2007).

Smith claims that recent estimates based on research suggest that 20% of the general working population experience symptoms that would fall into the category of extreme fatigue, but that estimates can vary comprehensively from 7% to 45% in different studies depending on how fatigue is defined and the samples studied. Smith also substantiates that risk factors for fatigue have been widely documented and can be split into factors reflecting the organization of work including; working hours, task demands, the physical environment and characteristics of the individual. According to Smith many of the established risk factors for fatigue are also applicable to seafarers: lack of sleep; poor quality sleep; insufficient rest time between work periods; excessive workload; poor quality of rest; lack of social support; boring or repetitive work; noise or vibration; motion; dehydration; medical conditions; illnesses; long distance travel to and from work. Clearly, stress and fatigue have many factors in common. Many of these potential problems reflect organizational defects such as inadequate manning or the use of fatigue and stress inducing shift work patterns. What is important to recognize is the crucial combination of risk factors with fatigue may be most readily observed when a large number of these are present (Smith 2007).

DNV, the international provider of risk management services, claims that a well designed fatigue management strategy as part of a Safety Management System (SMS) has the capacity to reduce the risk of OHS and environmental incidents in piloting (AMSA, 2001).

4.3.6 Situational Awareness

In maritime navigation, Situational Awareness (SA) refers to the mariner’s ability to recognize and comprehend the state of the ship’s systems, the state of the marine environment, the relative positions and behaviors of other vessels and hazards (Walker, Stanton, & Young, 2008) as well as predicting how these components will interact or change in the near future (Shebilske, Goettl, & Garland, 2000**) .** It is essential for the mariner to “observe, integrate and remember” (Sarter & Woods, 1991, p. 47) and then use all of this information to correctly position the ship into the future.

In other words the seafarer is continually scanning and taking in the information flow from all around him and using that to understand what is going on to enable him to place the ship in a safe space. The potential for conflicts in this information flow can be represented by reference to situations where the seafarer, in the course of managing the navigation, guidance, and control of the ship, is also simultaneously receiving information presented by the ship systems. The seafarer then interprets that information to help in identifying the cause of the conflict and then chooses an appropriate response. (Adams, Tenney, & Pew, 1995)

The real test of SA though, is when emergency situations arise and it is here that the currency of a seafarers’ SA in regards to his view of the state of the ship, its systems and environment are critical to their ability to make decisions, revise plans and manage the ship (Adams, et al., 1995). It follows then that one of the “principal benefit of achieving SA is that the operator (marine pilot) is better prepared to deal with upcoming events” (Adams, et al., 1995, p. 91) and is thus able to stay ahead of the game (M. Endsley, Farley, Jones, Midkiff, & Hansman, 1998).

The maritime industry has a particular combination of demands such as “fatigue, stress, work pressure, communications, environmental factors …” (Hetherington, Flin, & Mearns, 2006, p. 402) which could be termed as potential error inducing hazards. Most of the worlds maritime authorities have found that human error is a dominant factor in a great number of maritime accidents (Grech, Horberry, & Smith, 2002).

A number of these human errors can be described a being caused by SA problems and the application of SA in the safety critical areas where management of complex systems such as those existing in the maritime, aviation and automobile fields is required (Schager, 2008). Jones, et al (2004, p. 693) found that SA problems “are faced by complex systems in a variety of domains”.

Many studies have found that SA problems lead to accidents. For example Hartel, Smith and Prince (1991) in their review of military aviation accidents found that SA problems were a leading causal factor, Endsley (1995c) also found the same in her investigation of aircraft accidents involving major air carriers. In the field of automobile accidents, Shinar (1993) found that the most common causes were due to errors in judgment caused by SA recognition failures such as inattention and external distractions.

From the maritime side, Grech et al (2002), in their study of maritime accidents found that SA errors were a major causal factor in many maritime accidents, Stalberg and Schroder (2006) in their study of maritime accidents found that the most common factor of human error was a lack of SA and a failure to interpret available information, the American Bureau of Shipping (2004) found that there were failures in SA in many cases and Baker and McCafferty (2005) also found that a major causal factor in the majority of accidents was due to failures of SA and situation assessments.

For all this, it is apparent that there is still little discussion on SA problems being a causal part of the accident. It is often inferred such as being caused by the pilot becoming disorientated in the fog (Australian Transport Safety Bureau, 1998, p. 17), or by the fact that the "communication on the bridge during the pilotage was minimal, did not encourage 'challenge and response' and also resulted in the bridge team not developing a 'shared mental model" (Australian Transport Safety Bureau, 2007, p. 44) or there was inadequate monitoring causing "an inattentive 'state of the bridge' at a critical phase of the passage" (Australian Transport Safety Bureau, 2007, p. 44). The grounding of the Bunga Teratai Satu was caused when the Mate "allowed himself to become distracted … from the navigation of the ship" due to a telephone call (Australian Transport Safety Bureau, 2001, p. 36) but there is no real acknowledgement that a loss of SA has occurred and at what level.

Part of the above problem is due to what Grech (2005, p. 62) points out is the overuse of the term the "loss of situation awareness was a leading cause of human error in accidents". This has led to circular reasoning (Flach, 1995) arguments which goes as follows: there was a loss of SA and an accident occurred, how do know there was a loss of SA , because there was an accident. This in turn has led to a diminishing of the concept of SA.

4.3.7 The Three Level Model of Situational Awareness

"The three level model is an information processing approach that describes SA as a state of knowledge or product that is separate to the processes used to achieve it" (Stanton, et al., 2005, p. 213) and is meant to describe human information processes using psychological constructs such as attention and short term memory (Uhlarik & Comerford, 2002). The three level model of SA is built around three linear levels which are based upon Endsley's (1988b, p. 792) definition of SA which is "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future". This is shown in Figure 39.

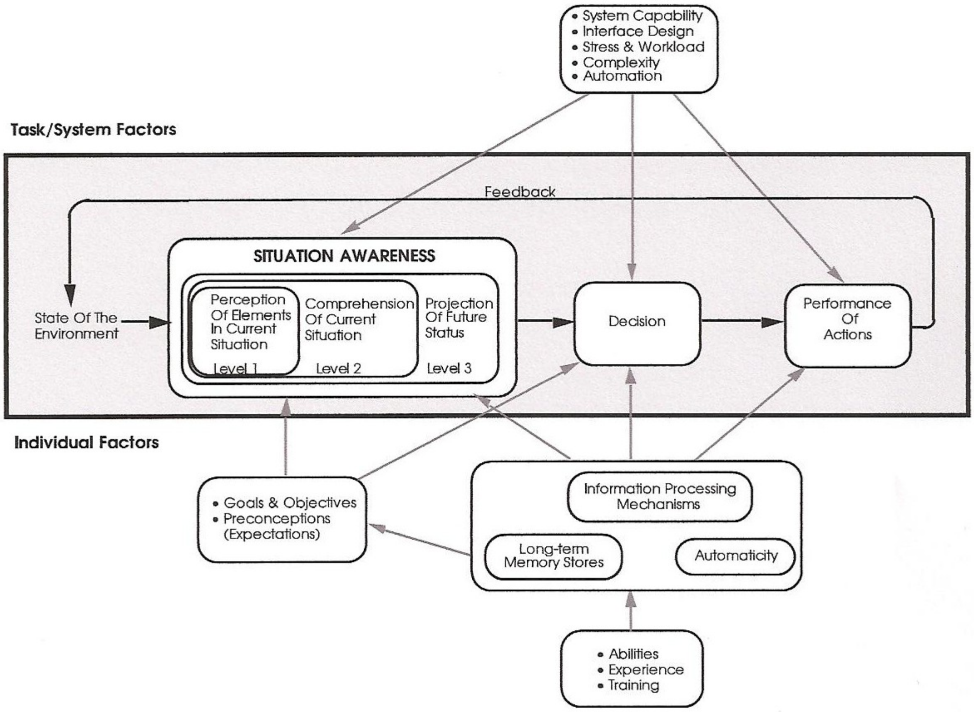


Fig. 39: The Three Level Model (M Endsley, 1995b)

In using this model in maritime navigation, where the mariner is for example approaching a difficult part of the passage the following would occur. Approaching the difficult part of the passage in Endsley's (1995b) model would be considered to be a task factor and represents the state of the environment. If the mariner recognizes the difficult part of the passage in the current situation (Level 1 SA) from cues provided by visual aids such as beacons or electronic aids such as radar and then compares this new information against the contents of both working and long-term memory to update the situation and from that recognizes this part of the passage is difficult then the mariner has comprehended (Level 2 SA) the situation. Furthermore if the mariner is able to use his Level 1 and 2 SA to determine what action to take (for example plot the position of the vessel more frequently due to danger) upon reaching this point in the passage he has projected the future status of the situation (Level 3 SA).
Salmon et al (2008, p. 300) describe Endsley's three-level model as one that "describes SA as an internally held product comprising three hierarchical levels that is separate from the process (termed situation assessment) used to achieve it." They go on to say, "the model depicts SA as a component of information processing that follows perception and leads to decision making and action execution."

4.4 Key Design Concepts

4.4.1 Human Centered Design (HCD) & Usability

"Usability is now widely recognized as critical to the success of an interactive system or product" (Maguire, 2001, p.587). Maguire summarizes the benefits of designing a usable system as follows:

- "Increased productivity. A system designed following usability principles, and tailored to the user's preferred way of working, will allow them to operate electively rather than lose time struggling with a complex set of functions and an unhelpful user interface. A usable system will allow the user to concentrate on the task rather than the tool.

- Reduced errors. A significant proportion of human error' can often be attributed to a poorly designed user interface. Avoiding inconsistencies, ambiguities or other interface design faults will reduce user error.
- Reduced training and support. A well-designed and usable system can reinforce learning, thus reducing training time and the need for human support.
- Improved acceptance. Improved user acceptance is often an indirect outcome from the design of a usable system. Most users would rather use, and would be more likely to trust, a well-designed system which provides information that can be easily accessed and presented in a format which is easy to assimilate and use.
- Enhanced reputation. A well-designed system will promote a positive user and customer response, and enhance the developing company's reputation in the marketplace".

These benefits can be seen to be closely aligned with the four central goals of human factors described earlier – the reduction of error and risk, improved reliability and comfort. It is important to note that the HCD approach should be considered complementary to software/artifact development methods rather than a replacement for them. The key principles of HCD are as follows.

- "The active involvement of users and clear understanding of user and task requirements: One of the key strengths of human-centered design is the active involvement of end-users who have knowledge of the context in which the system will be used. Involving end-users can also enhance the acceptance of and commitment to the new software, as staff come to feel that the system is being designed in consultation with them rather than being imposed on them. Strategies for achieving user involvement are discussed by Damodaran (1996).
- An appropriate allocation of function between user and system: It is important to determine which aspects of a job or task should be handled by people and which can be handled by software and hardware. This division of labor should be based on an appreciation of human capabilities, their limitations and a thorough grasp of the particular demands of the task.
- Iteration of design solutions: Iterative software design entails receiving feedback from end-users following their use of early design solutions. These may range from simple paper mock-ups of screen layouts to software prototypes with greater fidelity. The users attempt to accomplish "real world" tasks using the prototype. The feedback from this exercise is used to develop the design further.
- Multi-disciplinary design teams: Human-centered system development is a collaborative process which benefits from the active involvement of various parties, each of whom have insights and expertise to share. It is therefore important that the development team be made up of experts with technical skills and those with a "stake" in the proposed software. The team might thus include managers, usability specialists, end-users, software engineers, graphic designers, interaction designers, training and support staff and task experts".

The achievement of usability within system design requires a combination of the following:

- Careful planning of human-centered design processes.

- Understanding the context of use for the system as a basis for identifying requirements and evaluating the system.
- Understanding and specifying user requirements in a clear manner which can be assessed for achievement.
- System and user interface development based on a flexible and iterative approach.
- Usability evaluation based on both expert and user testing at appropriate points.

These aspects of usability have been integrated into design processes most notably in the ISO standard 13407.

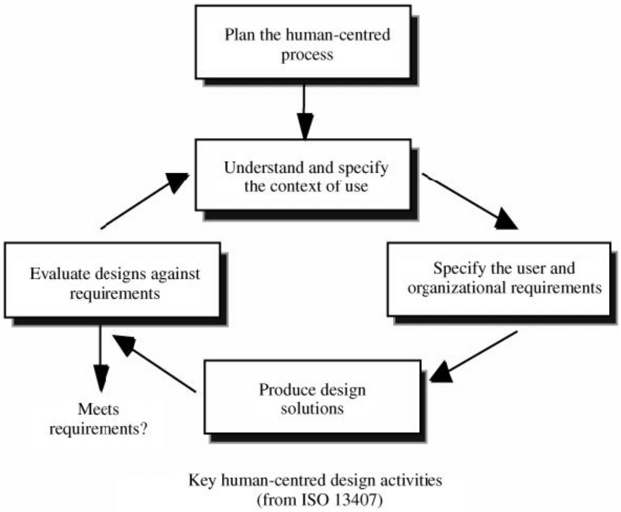


Fig. 40: The Human Centered Design Cycle (Maguire, 2001, p.589)

In June 2011, IMO NAV57 recognized that: "the development of guidelines for usability evaluation of navigational equipment should continue during the preparation of the e-navigation strategy implementation plan". Further to this issue, "In considering the use of the modular concept to enable scalability and implementation, INS could be considered to be the dominant factor for the development of e-navigation on board". During this Sub-Committee Japan also presented two Information papers on the issue of usability. In this chapter, we accept the role of usability assessment, but consider that the evaluation of usability needs to be cognizant of the dominant measurement techniques available for assessing usability.

In 1998 ISO 9241 – originally titled *Ergonomic requirements for office work with visual display terminals (VDTs)* – in its part 11 (guidance on usability) defined usability with the extent to which a product can be used by specified users to achieve specified goals with effectiveness (accuracy and completeness of task completion by users), efficiency (time and effort expended to accomplish tasks) and satisfaction (comfort and acceptability of use by users) in a specified context of use (users, tasks, specific equipment & environments). From 2006, ISO 9241 was renamed *"Ergonomics of Human System Interaction"* Part 10 (dialogue principles of Visual Display Terminals) was withdrawn by ISO 9241-110. "Dialogues" are meant to be between humans and information systems. An Integrated Navigation System (INS) with an embedded Manoeuvring Assistance Module (MAM) can be considered a "navigation information system".

USABILITY (ISO 9241-11:1998 and ISO/IEC 25010:2011) actually identifies the extent to which a product can be used by specified users to achieve specified goals with:

- effectiveness

- efficiency
- user satisfaction - in a specified context of use

There is general consistency between the definitions of usability given in ISO 9241-11 and in the recent ISO/IEC 25010:2011 *(Systems and software engineering - Systems and Software Quality Requirements and Evaluation (SQuaRE) - System and software quality models).* The difference is only in the user satisfaction component. ISO 9241-11's user satisfaction is meant in terms of comfort and acceptability of use, whereas ISO/IEC 25010's user satisfaction refers to pragmatic and hedonic user's goals. The hedonic goals are related to emotions. The current approach taken to assessing usability (Di Lieto & Lemon, 2012) is described in the figure below.

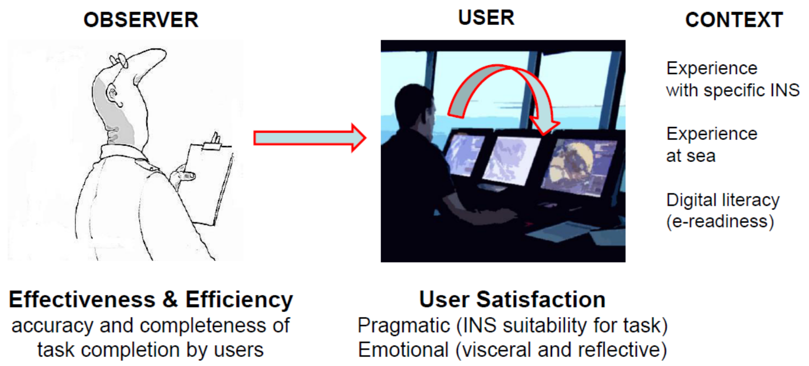


Fig. 41: Model of Usability Assessment for INS

The principle is to measure INS usability by observing and rating users performance, and at the same time by letting users express their satisfaction (pragmatically and emotionally). Observers are highly qualified INS instructors. Users are trainees (both experts and novices). The context is captured ANONYMOUSLY in terms of experience with specific INS, experience at sea and also digital literacy (e-readiness).

4.4.2 Emotional Design

Norman (2004) in his book 'Emotional Design' talks about three different aspects of design:

- Visceral design concerns itself with appearances.
- Behavioral design has to do with the pleasure and effectiveness of use.
- Reflective design considers the rationalization and intellectualization of a product. (p.5)

There is a common tendency to consider emotions to be irrational, illogical and even animalistic. From such a perspective emotions are out-of-place in modern society and certainly in the design of sophisticated technological solutions to the issue of a terrestrial vessel interface. Norman (2004) responds:

> *"Nonsense! Emotions are inseparable from and a necessary part of cognition. Everything we do, everything we think is tinged with emotion, much of it subconscious. In turn, our emotions change the way we think, and serve as constant guides to appropriate behaviour, steering us away from the bad, guiding us towards the good (p.7)."*

It is important to note that psychologists talk about 'affect' not just emotion when referring to good design principles in this area. Affect is an information processing system like cognition that deals with likes dislikes, good bad, safe or unsafe. This information processing system makes judgments either at a conscious or subconscious level. "Emotion is the conscious experience of affect, complete with attribution of its cause and identification of its object" (Norman, 2004, p.11).

The role of affect in decision-making is so important that without emotions people can be rendered incapable of making decisions. The studies by Antonio Damasio on people who had injured the emotional centre of their brain found just this. People with such an Acquired Brain Injury could describe exactly how they **should** be functioning, but couldn't determine where to live, what to eat and what products to buy and use. The conclusion is that the affective system provides critical assistance to decision-makers by helping them make rapid decisions, and therefore reduces the information that needs to be processed. Good design can use the affective system to its advantage. Designs that create negative affect-dominated feedback loops are less likely to succeed and tend to increase error and therefore reduce safety, reduce productivity and decrease our levels of comfort.

We are now aware that affect corresponds with changes at neuro-physiological levels. The affective system controls muscle function via a group of chemical neurotransmitters, and changes how the brain functions. The evaluative system that encompasses affect is as important as the process of sense-making we call cognition. In the design of a vessel interface we ignore this element at our peril.

4.4.3 Automation and System Design

In Dekker's (2005) book 'Ten Questions about Human Error" he asks a question that is fundamental to the current project: "Can we automate human error out of the system?"

> *If people cannot be counted on to follow procedures, should we not simply marginalize human work? Can automation get rid of human unreliability and error? Automation extends our capabilities in many, if not all, transportation modes. In fact, automation is often presented and implemented precisely because it helps systems and people perform better. It may even make operational lives easier: reducing task load, increasing access to information, helping the prioritization of attention, providing reminders, doing work for us where we cannot. What about reducing human error? (p.151)*

The short answer to the question is no, we cannot automate human error out of the system. Automation cannot do away with human error, because it does not do away with human work. There is still work for people to do in the system. It is not that the same kinds of errors occur in automated systems as in manual systems. Automation does however change:

- the expression of expertise and error;
- the context in which people can perform well;
- how their performance breaks down, (if and when it does);
- opportunities for error recovery, and;
- the visibility of the consequences of errors

As a result of this, new forms of coordination breakdowns and accidents have emerged. Key issues with respect to addressing and managing the changed expression of human error within the system include data overload. The reasons for data overload once aspects of the system are removed from the human are that automation typically creates new types of monitoring and memory tasks.

The good news is that workload reduction solutions have been successful in reducing data overload in highly reliable transportation systems. Some of the best examples have come from the development of aviation warning systems and fault management. Current systems in commercial aviation vary significantly – from those that do little at all, to prioritization and sorting of warnings, to automated responses. "Airbus A320 and MD-11 solutions to the workload bottleneck problem really seem to pay off. Performance benefits really accrue with a system that sorts through the failures, shows them selectively, and guides the pilot in what to do next" (Dekker, 2005, p.155).

The implications for the current project are that it will be necessary to look closely at how the automation of any part of a task previously conducted by a human shift the role of the human and therefore changes the likely expression of human error within the system. Put simply, changes to the role and the interface associated with a Maneuvering Assistance Module (MAM) and an emphasis on 'green shipping' has the potential to both minimize and create different types of errors and in order to minimise the risk the design needs to be able to predict the types of errors and find solutions to build in redundancies and other forms of error mitigation.

4.4.4 MABA-MABA Lists

MABA-MABA Lists have traditionally been used by technology designers based on the premise that there are some things Machines-Are-Better-At, and there are some things that Men-Are-Better-At (or humans to be more politically correct). The lists therefore attempt to elucidate the areas of the system that are strengths for the machine and human strengths and design on that basis, automating tasks that are machine strengths and not automating tasks associated with human strengths. "The process of function allocation as guided by such lists sounds straightforward, but is actually fraught with difficulty and often unexamined assumptions" (Dekker, 2005, p.161).

For example, as discussed earlier, automation typically shifts the expression of human error within a system. But MABA-MABA lists reply on the presumption that fixed human and machine strengths and weaknesses. But automation is much more than the replacement of the human. "The really interesting issues from a human performance standpoint emerge after such a replacement has taken place" (Dekker, 2005, p.162).

A number of conclusions can be drawn about the automation of aspects of a system:

- Automation creates new human strengths and weaknesses, often in unanticipated ways;
- Automation exacerbates the systems reliance on the human strength to deal with the 'context' in which the automation occurs;
- Automation creates new functions that need to be examined and understood.

What does this all mean for the design of a system and the principles being considered for the VIPW Project? Dekker (2005) suggests that the role of the system designer is not just the creation of an 'artifact' but the recognition of the need to understand the nature of human practice in the marine pilotage and wider port authority domain. This makes it particularly important to acknowledge the Detailed Design Brief as represented in this document. As Dekker (2005, p.164) indicates:

- Design Concepts represent hypotheses or beliefs about the relationship between technology and human cognition and collaboration
- They need to be subject these beliefs to empirical jeopardy by a search for disconfirming and confirming evidence.
- These beliefs about what would be useful have to be tentative and open to revision as they learn more about the mutual shaping that goes on between artifacts and actors in a field of practice.

Historically, this process was performed through validation and verification studies that applied limited tests to small, limited versions of systems. These tests also occurred once the design was substantially settled; leading to the problem that by the time test results become available a substantial commitment to the current design is already in place. The design team are quite often 'anchored' to this design and any significant change is usual resisted for these reasons alone.

However this by itself leads to a problem, best identified by quoting Dekker in full:

> *Such constraints through commitment can be avoided if human factors can say meaningful things early on in a design process. What if the system of interest has not been designed or fielded yet? Are there ways in which we can anticipate whether automation, and the human role changes it implies, will create new error problems rather than simply solving old ones?*
>
> *This has been described as Newell's catch: In order for human factors to say meaningful things about a new design, the design needs to be all but finished. Although data can then be generated,*

> *they are no longer of use, because the design is basically locked. No changes as a result of the insight created by human factors data are possible anymore. Are there ways around this catch?*

Human Factors practitioners have identified solutions to these problems. Dekker and Woods (1999) looked at the issue in the context of system change in air traffic control using a technique called ***'Future Incident Studies'***. They trained multi-disciplinary teams (controllers, pilots and dispatchers) in the new methods and rules for the system, and then asked them to solve complex future airspace problems presented to them in several different scenarios. Scenarios included aircraft decompression, emergency descents and so forth, and could reasonably be translated into the maritime domain to include fires in cargo holds, rudder failures and engine failures. For a Maneuvering Assistance Module (MAM) we are potentially more interested in navigational failures that lead to problems in fuel efficiency and as such breach the goals associated with 'green shipping'.

The point is not to test the performance of one group against the other but to determine where the future system is likely to break down, but to perform this using a multiple stakeholder viewpoint, while anchored in the task details of a concrete problem. Validity is derived from both the ecological validity of the scenario (does it reflect situations that happen in reality) and from the way in which the problem-solving expertise is brought to bear by the study participants.

4.5 Relevant Projects and Design Solutions from Other Domains

4.5.1 The Human Project

The object of the HUMAN Project was to develop a methodology with techniques and prototypical tools supporting the prediction of human errors in ways that are usable and practical for human-centered design of systems operating in complex aviation cockpit environments.

Previously, the typical approach of analyzing systems was error prone as well as costly and time-consuming (based on engineering judgment, operational feedback from similar aircraft, and simulator-based experiments). The HUMAN methodology allowed researchers and industry partners to detect potential pilot errors more accurately and earlier (in the design) and with reduced effort.

The detection of errors is achieved by developing and validating a cognitive model of crew behavior. Cognitive models are a means to make knowledge about characteristic human capabilities and limitations readily available to designers in an executable form. They have the potential to automate parts of the analysis of human errors because they offer the opportunity to simulate the interaction with cockpit systems under various conditions and to predict cognitive processes like the assessment of situations and the resulting choice of actions including erroneous actions. In this way they can be used as a partial "substitute" for human pilots in early development stages when design changes are still feasible and affordable.

Model- and simulation-based approaches are already well-established for many aspects of the study, design and manufacture of a modern airliner (e.g., aerodynamics, aircraft systems, engines), for the very same objective of detecting potential problems earlier and reducing the amount of testing required at a later stage. HUMAN extends the modeling approach to the interaction of flight crews with cockpit systems.

It should be noted that the focus of this project has not been the full automation of the transport mode, but the use of simulation to predict the effect that prototypical tools would have on the frequency and severity of human error. The approach of developing cognitive models is considered a useful one and is likely to provide a key aspect for the development of a human-system integration approach to a Maneuvering Assistance Module (MAM) design. One approach therefore is to model the actions of the human with respect to the system to establish which elements might reasonably be automated, where errors are likely to occur and so forth.

4.5.2 The DCoS Project

The Designing Dynamic Distributed Cooperative Human-Machine Systems Project is a project within the Artemis Joint Undertaking, Sub-Programme 8. This project gives some indication of competition within this area of automated systems globally, or at least provides an indication of the type of industry driven research occurring in this area. The project began in March, 2011, led by colleagues at OFFIS, Oldenburg, Germany, collaborating with a number of European partners.

The project is predicated on the need for market penetration of these systems. The project intends to develop affordable methods, techniques and tools which go beyond assistance systems and consequently address the specification, development and evaluation of cooperative systems from a multi-agent perspective where human and machine agents are in charge of common tasks, assigned to the system as a whole. A high quality user interface notably is inevitable to meet user expectations and to gain market acceptance of cooperative systems with increased levels of automation. Already today the development of the user interface of Embedded Systems is a substantial cost driver that is constantly increasing.

The project proposes to strive to boost cost efficiency of highly innovative DCoS with several interactive Embedded Systems. This will be achieved by supporting and closing the industrial development process chain from (1) DCoS composition over (2) interaction design to (3) interface design, taking care of requirements capture, specification, development and evaluation at all steps, and by allowing to evaluate the overall system safety, efficiency and effectiveness already in early process phases. An Innovation Eco System for cooperative embedded HMI will be established during the project and will be maintained afterwards. This is relevant to the current project as a model for the actual commercial development of a Maneuvering Assistance Module (MAM), although it is apparent that such an approach may not yet be feasible.

4.5.3 Automation in Train Control

A number of recent train control technologies have been developed that are designed to provide an increased level of train control through more effective transfer of information to the train and from the train to the controller (or control system). As such they are relevant for considering changes in the dynamic between ship and shore, although the complexity of the maritime environment is obviously much greater. Systems such as the European Rail Track Management System (ERTMS), Electronic Train Management System (ETMS), Advanced Train Management Systems (ATMS) and the Incremental Train Control System (ICTS) represent advances in this area. These systems effectively perform the same key functions, with a few slight differences in how these functions are achieved operationally (Bearman and McCusker, 2008).

4.5.3.1 The Future of Train Control – System specifications

Bearman and McCusker (2008) identify a range of system specifications that are based around a combination of GPS and wireless transmission of stored information from a route database.

Wireless transmission of information from trackside transmitters, in correlation with GPS technology can provide accurate data informing the driver/signalers of track configuration and geometry, switch position, signal indication, authority limits, train direction and makeup, current speeds, max speed, distance to enforcement (speed restrictions), time to enforcement (speed restrictions), geographical location and text messages (describing any enforcement action in progress, condition advisement or required action) (Hartong, Goel & Wijesekra, 2006). In addition, each technology includes an Automatic Train Control function where the on-board computer continuously calculates the above factors for all trains present on the track and generates a warning of potentially hazardous conditions ahead, generally through speed restrictions. If the driver does not respond to these enforced restrictions, the computer will automatically apply the train's emergency breaking system (Hartong, Goel & Wijesekra, 2006; Kane, Shockley & Hickenlooper, 2005). The Automatic emergency *breaking system is also implemented in technologies that utilise trackside wireless transmitters if the system is unavailable for any reason (Hartong, Goel & Wijesekra, 2006). (all cited in Bearman and McCusker, 2008)*

4.5.3.2 The Effect of Automating Train Systems

Across different transportation modes, the way that drivers, pilots or other operators interact with technology has created issues both for the design of technology and the role of the human. As Bearman and McCusker (2008) identify: "When a new technology is introduced the driver is required to understand how it works in order to be able to utilize that technology effectively. For the driver to be able to develop an effective understanding (or mental model) of how the technology works it is necessary to provide training"

However Bearman and McCusker (2008) note that:

- Basic training is unlikely to provide the driver with a comprehensive understanding,
- These gaps in driver understanding and a lack of adequate feedback create the opportunity for fixation on the technology
- This leads to the conclusion that the system should supply a good quality and optimum quantity of information about its current functioning to assist the driver in developing a good understanding of what the system is currently doing. This cannot occur independent of valid and sufficient training.

Bearman and McCusker (2008) suggest that the actual human factors implications of the train control technologies will depend on how they are implemented:

> *Aspects of the particular context, such as the type of train (freight, passenger) and the particular skill sets that the drivers and controllers possess will to some extent determine the human factors issues that are faced. Issues such as the level of feedback of the system, the extent to which the system is intrusive and ergonomic considerations (such as reaching and grasping, posture and gaze pattern issues) can vary depending on the operational specifications laid down by the operators (Bearman and McCusker, 2008).*

These issues are also likely to be important for any future development of a maneuvering assistance interface on the bridge of a ship.

4.5.4 Adaptive Cruise Control in Cars

Adaptive Cruise Control Systems (ACCs) are functionally equivalent to a conventional cruise control except with two added components. They are based on a range sensor and a distance control system linked to the conventional cruise control that allows the vehicle to 'follow' another vehicle based on a time-distance separation. ACCs have been studied in some detail and provide some insight into the effect that automation has on a range of human-related variables such as perceived control, situational awareness, stress and trust in the automated system. This is relevant both to the current situation in the use of maneuvering assistance interfaces embedded in INS, as well as any potential developments or changes to such systems into the future.

Hoedemaeker and Brookhuis (1998) also studied driver behavior with respect to ACC. This simulator-based study identified behavioral adaptations with an ACC in terms of higher speed, smaller minimum time headway and larger brake force. All these adaptations have the potential to increase driving risk, and the authors encouraged caution about the potential safety of such systems.

Stanton and Young (2005) studied 110 drivers and assigned them to different experimental conditions in a fixed-base driving simulator based on a Jaguar XK8. The independent variables were automation level, workload and feedback, with the researchers collecting data on driving behavior, and six psychological variables (locus of control, trust, workload, stress, mental models and situational awareness). The most important findings associated with this research included that ACC led to a reduction in workload in normal operations and that situational awareness was highest when the information on the status of the ACC was presented in the instrument cluster of the car, even though the team trialed a more sophisticated Heads Up Display as well. As the authors go on to mention:

> *The irony here is that the design considerations that optimize situational awareness, may well have a negative effect on workload and visa versa. For instance if an interface is simplified to improve situational awareness, this may also have the effect of reducing workload. Depending on the context of performance, reductions in workload may not be advisable (p.1310).*

Stanton and Young (2005) go on to examine the issue of driver situational awareness in more depth, recognizing that ACCs currently transmit no ‘predictive’ data (about the future expected state of the system) to the driver even though they process much of this information already. Given that ability to predict future events is a key aspect of situational awareness, they suggest that:

> *The ACC system of the future may require a new kind of display, to help drivers identify cues in the world to which they should attend, and offer predictions about their future trajectory in relation to their own vehicle.*
>
> *Ideally, the design of the interface would need to reduce the reliance on drivers to make calculations and make comprehension and prediction easier (p.1311).*

There are some interesting implications for a Maneuvering Assistance Module (MAM) and these are considered in more detail in the Conclusions to this report. If a key design goal of a MAM is to provide the seafarer with a situational awareness of the efficiency with which the ship is moving from ‘point a to point b’ then it would need to take account of the three levels of situational awareness and build this information into the interface. In order to realize the goal of identifying the current situation and predicting the future, integration of navigational and engine performance data would be necessary. As discussed earlier in terms of the effect of automation on systems, and noting the outcomes of the study by Hoedemaeker and Brookhuis (1998), it is important to understand how any changes in automation or in the man-machine interface are likely to create changes in other parts of the system.

4.6 Human Element Analyzing Process (HEAP)

One approach to considering the design of any component of a system to be embedded in a maritime context is to use the Human Element Analyzing Process (HEAP). MSC/Circ.878 MEPC/Circ.346 (1998) defines the HEAP a practical tool designed to address the human element, to be used for consideration of maritime safety and environmental issues at IMO. The steps outlined in the flowchart list a series of questions that should be considered to appropriately address the human element in the regulatory development process.

According to MSC/Circ.1022 (Guidance on the use of Human Element Analyzing Process and Formal Safety Assessment in the IMO rule making process), the HEAP "is a method developed by IMO for the use of IMO and should be seen as a practical and non-scientific checklist to assist regulators in ensuring that human element aspects related to the ship and its equipment, training, the master and the crew, management ashore and on-board and work environment conditions have been taken into consideration when introducing or amending IMO instruments.” While this therefore has a predominantly non-scientific and regulatory focus, the concept of considering the full range of human factors issues when introducing changes to large socio-technical systems remains relevant.

Yet there are some significant concerns about the current version of HEAP, the most significant of those being that the approach is not in line with current approaches to safety management. Historically, safety analyses have considered human error as an undesirable and wrongful manifestation of human behavior. Recent operational research for the aviation industry has provided a different perspective proving that human error is a normal component of human behavior. Human error is inevitable, ubiquitous, is impossible to be completely eradicated and can potentially generate negative consequences. Countermeasures to error, including training interventions, should not be restricted to avoiding errors, but rather to making them visible and trapped, before they produce negative consequences. This is the essence of error management: *human error is unavoidable but manageable* ICAO (2002).

With this in mind Di Lieto et.al.,(2011) reconfigured the HEAP to align the process more consistently with a threat and error management understanding of safety management systems. This approach appeared in Annex 3 of the report of the e-navigation Correspondence Group on e-navigation to IMO COMSAR Sub-Committee in 2011. While this approach has been specifically derived to address e-navigation related issues, the table of specific human elements to consider while developing guidelines and regulations related to practical implementation of bridge systems is still relevant to the development of a Maneuvering Assistance Module (MAM).

For the development of a Maneuvering Assistance Module (MAM) it would be necessary to consider how any changes might influence:

- Human Attention,
- Mental Workload,
- Decision-making, and therefore
- All levels of situational awareness.
- Teamwork may well be a consideration particularly if interaction between bridge teams and engineering teams becomes significant in addressing the relationship between navigational and engine/propulsion systems.

Obviously both software and hardware ergonomic issues will need to be considered, including issues such as the visual interface, the amount, style, presentation of information, alarm types and combinations (visual, auditory) as well as the comfort of the user in terms of meeting anthropometric standards. Finally, any change to an interface may lead to modifications in the skill-based training of seafarers. These issues are considered further with respect to the NACOS INS case study below.

Table "R"

OPERATIONAL LEVEL interactions between humans and the operational environment	TECHNICAL LEVEL human-technology interaction	REGULATORY regulatory style	TRAINING human-element oriented training
OPR1 - Human attention	TCH1 - Software ergonomics	REG1 - Prescriptive	TRN1 - Bridge Team Management training (BTM)
OPR2 - Mental workload	TCH2 - Hardware ergonomics	REG2 - Performance based	TRN2 - Shore-based Team Management training (STM)
OPR3 - Decision Making	TCH9 - Others (specify)	REG3 - Deregulated	TRN3 - Bridge-Shore Teams management (BSTM)
OPR4 - Situation Awareness Lev 1 (Perception of external cues)		REG4 - Industry self regulated	TRN4 - Skill-based training
OPR5 - Situation Awareness Lev 2 (Understanding of current state)		REG9 - Others (specify)	TRN5 - Knowledge-based training
OPR6 - Situation Awareness Lev 3 (Projection of current state in future)			TRN9 - Others (specify)
OPR7 - Cooperation (Team work)			
OPR8 - Language differences (communication breakdowns)			
OPR9 - Others (specify)			

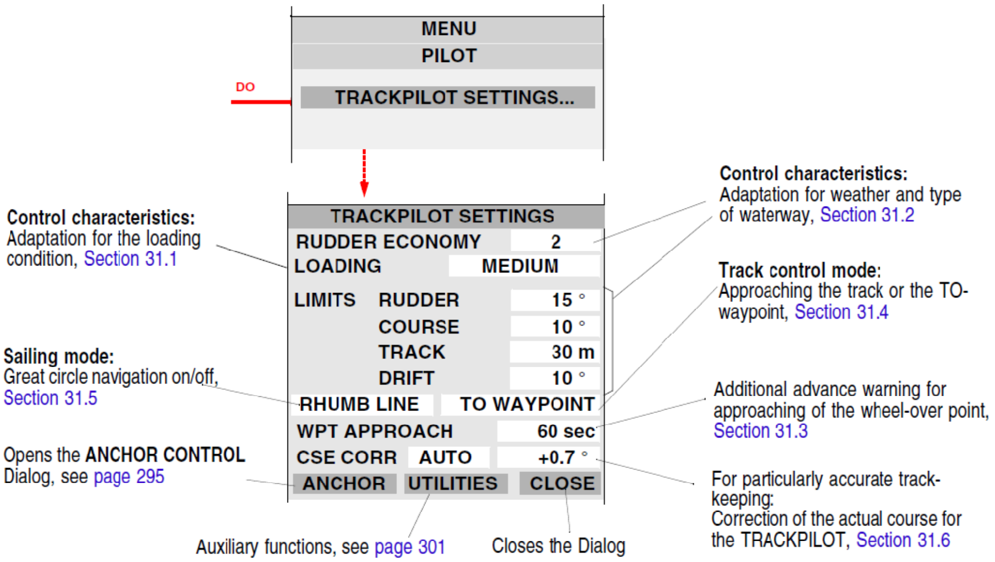
4.7 *NACOS -an INS Case Study*

A key assumption made in this chapter is that the 'state of the art' in current maneuvering assistance can be found in Integrated Navigation Systems and specifically relates to the track control system and adaptive autopilots. This chapter briefly considers the control parameters in a commercial version of that system,

In the SAM Electronics NACOS INS, the MULTIPILOT 1100 (2008) "combines all of the main operating and display functions for traffic surveillance, collision avoidance and for nautical ship-handling in a unit of equipment. This is important for automated ship handling in particular, for which a large number of parameters and system statuses have to be observed together with the nautical situation" (p.17).

The MULTIPILOT is normally connected to all of the important navigation units and other units used for ship-handling purposes, thus forming a system. The MULTIPILOT acts as the operating and display unit for ARPA radar, Automatic Identification System (AIS), ECDIS, Chart Radar, Conning Display, Autopilot/Track Control System, Speed Controller, Alarm Management and the Voyage Data Recorder.

> *On the MULTIPILOT, it is also possible to operate the optional **TRACKPILOT 1100**. The TRACKPILOT is a **track control system**, which can also be operated as a conventional adaptive **autopilot***
>
> *- in **Heading mode** without automatic drift-correction, or*
> *- in **Course mode** with automatic drift-correction but with which, in contrast to a conventional autopilot,*
> *- in **Track mode** the ship can automatically be kept on a pre-planned track with great accuracy.*
>
> *Furthermore, it is possible based on the installation to maintain the ship's heading during anchoring. The operating procedure for the TRACKPILOT is completely integrated within the MULTIPILOT, and can take place in all display modes. Systems which are equipped with a TRACKPILOT are called **NACOS** (**Na**vigation and **Co**mmand **S**ystem). Usually, the TRACKPILOT can be operated from various radar workplaces of the NACOS (RADARPILOT, CHARTRADAR and MULTIPILOT), whichever is selected. The decision as to which indicator is to be used as the operating unit of the TRACKPILOT is made by simply pressing a key on the unit concerned.*



RUDDER ECONOMY 2
LOADING MEDIUM
LIMITS RUDDER 15 °
COURSE 10 °
TRACK 30 m
DRIFT 10 °
RHUMB LINE TO WAYPOINT
WPT APPROACH 60 sec
CSE CORR AUTO +0.7 °

Control characteristics: Adaptation for the loading condition, Section 31.1

Sailing mode: Great circle navigation on/off, Section 31.5

Opens the **ANCHOR CONTROL** Dialog, see page 295

Auxiliary functions, see page 301

Closes the Dialog

Control characteristics: Adaptation for weather and type of waterway, Section 31.2

Track control mode: Approaching the track or the TO-waypoint, Section 31.4

Additional advance warning for approaching of the wheel-over point, Section 31.3

For particularly accurate track-keeping: Correction of the actual course for the TRACKPILOT, Section 31.6

Fig. 42: Track Pilot Settings Dialogue Box

In order to consider the most efficient movement of a vessel between two ports via maneuvering assistance it is important to understand the specific control characteristics of the TRACKPILOT. For example, the Rudder Economy setting considers:

> *Economically advantageous optimization between precise track keeping and frequency of changing of the rudder angle, depending on sea state and wind, is achieved by means of the "rudder economy" parameter. This is comparable to a combination of the control variables "rudder", "counter rudder" and "yaw" of a conventional autopilot.*

The higher the rudder economy value, the more 'tolerant' the system is and this reflects a response to navigation in poorer weather/sea states. Incorrect setting of any of the control parameters leads to the steering gear working too frequently, the course sailed fluctuating continuously around the set course (with the wake forming a meandering line), a low accuracy in the course achieved, deviations from the track that are too large, and when the ship performs corrective steering to return to the set track, it either overshoots the set track or takes too long to reach it (SAM Electronics, 2008). Each of these problems has implications for the efficiency of navigation/transit and therefore for the use of fuel by the engine. Effective management of these parameters either manually or semi-autonomously can lead to greener shipping.

Returning to some of the key human factors issues associated with interfaces and identified in the section on HEAP, it is clear that the seafarer needs effective training in the application of the trackpilot settings in order to operate the vessel efficiently in this mode. Misunderstanding of how to apply the control parameters is likely to lead to a longer route and a decreased efficiency of the ship and therefore not promote the principles of green ship operation.

As indicated in Figure 43, a significant amount of information appears on the screen of the NACOS INS. The trackpilot settings are readily apparent however it is possible that the screen as a whole is moving towards a level of clutter that might be considered unacceptable under certain circumstances. In particular types of emergencies when the individual needs to quickly access and interpret information, the more information on the screen the more difficult it is to locate that information and assimilate it. More specifically, in ‘out-of-the-loop control problems when the seafarer moves quickly from an autopilot to a manual control it is necessary to quickly acquire a mental model of the situation, this directly increases attention, mental workload, and decision-making and may be completed within the context of needing to manage and later team dynamics.

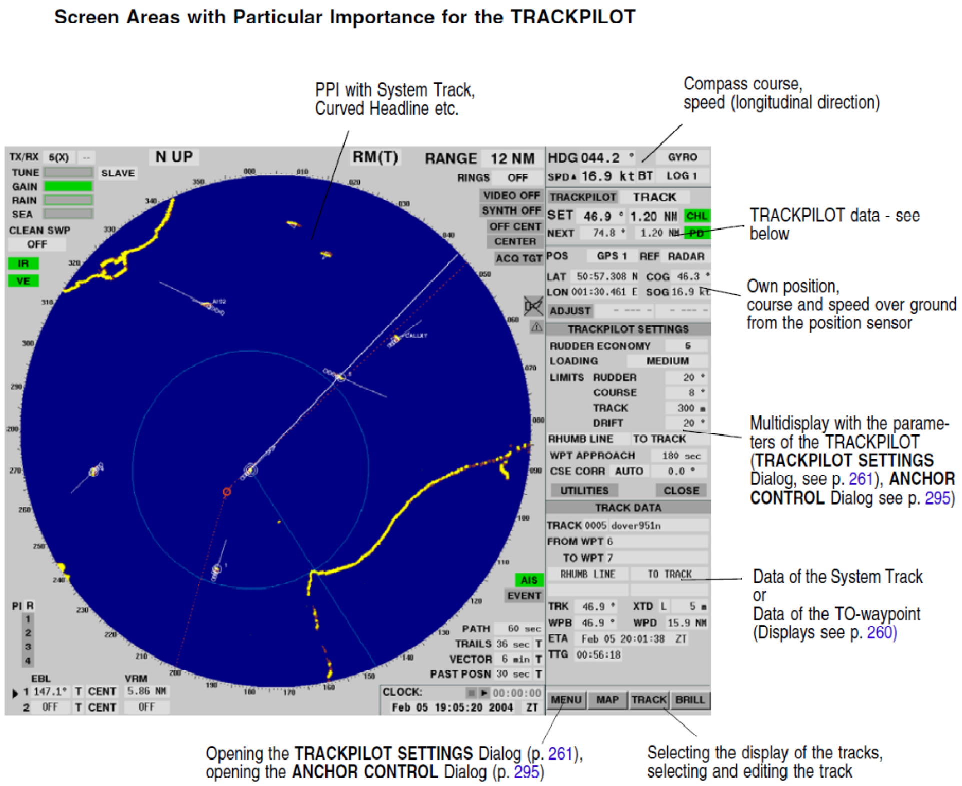


Fig. 43: Screen Areas with Particular Importance for TRACKPILOT

4.8 Decision-Support Systems for Energy Efficiency

Decision-support systems are computerized software/hardware tools that use a range of input variables to both report results and are also typically used to predict and change performance into the future. The push towards increased energy efficiency has seen these devices increasingly installed on ships bridges, particularly for ship types such as container vessels.

Maersk Maritime Technology’s Vessel Performance Management Service (VPMS) is a decision support service for monitoring and controlling fuel efficiency. The service is based on the ship’s daily reporting of operational data. Maersk Maritime Technology provides Vessel Performance Management Services for more than 300 different vessels. Based on more than 30 years of experience, the service is designed to optimize the operation and technical management of hull, propeller and main engine performance and voyage efficiency. There is the potential within the systems, and the very real goal for shipping companies to use the data to plan optimum routes for vessels based on the collection of this data.

The system provides daily reporting on a range of performance metrics including Hull & Propeller Performance, Lubrication Oil performance, Voyage abstracts and statistics and the vessel's operational efficiency. Key metrics such as main engine SFOC performance, main engine load profile, fuel consumption, and emissions are all calculated dynamically and in real-time.

Such activity, however, is made without the dynamic input of the trackpilot variables identified above. This leads the author to consider whether it is possible to merge the control parameters from the Trackpilot with data on engine parameters in a vessel performance decision-support system in order to produce an overall system for the efficient operation of a vessel. If it is possible to produce this in real-time, then it may also be possible to develop an algorithm using the combination of those parameters to predict how efficiency is likely to change as the ship moves along its track.

From a human factors perspective, there are many issues to be considered here. Would this approach 'dumb-down' the interface and 'hide' valuable information from the user? Would it be effective under all operating contexts of the Trackpilot and in all environmental conditions? Where would it be located on the screen and how would it be represented – as a single value, as a virtual 'gauge', or in another format? What level of efficiency constraint might be set and what type of alarm would be used to identify to the bridge team that they were exceeding the efficiency parameter?

All these issues can be considered within the context of the usability design approach identified earlier, assessing all these issues and also assessing underlying human factors concepts such as situational awareness, workload and stress.

4.9 Conclusion for the Design of HMIs related to support energy efficient ship operation

The world is quite aware that it must become 'greener' to address the issues associated with climate change, and this awareness extends to the need to make transportation more efficient and less reliant on fossil fuels. This chapter has explored the human-on-the-bridge aspect of this problem, identifying a broad range of human factors issues that impinge on the redesign of a Maneuvering Assistance Module (MAM) to support greener shipping.

It has taken the approach that the current aim to be greener must relate to the maintaining the most efficient transit of a ship from 'point a to point b', but recognizing that under certain environmental conditions the efficiency is likely to be understood differently – as indicated with rudder economy settings above.
A key assumption made in this chapter is that the 'state of the art' in current maneuvering assistance can be found in Integrated Navigation Systems and specifically relates to the track control system and adaptive autopilots and the potential to link these with engine data via the types of decision support systems that are currently available.

Currently these systems do little in terms of integrating engine performance and navigational performance data. The systems don't 'speak' to each other, and may be located some distance from each other. On this basis they also do not provide either Level 2 situational awareness (an idea of the current state) or predict that efficiency of the ship into the future. There is much more that can be done to give the seafarer on the bridge of the ship the tools needed to achieve the 'greenest' ship operation possible in the context of the available performance envelope, however it would appear that the most significant issue is a lack of integration of bridge hardware/software for this purpose, rather than the lack of the systems themselves.

In future there may be the desire to derive a single measure of efficiency in real time and use this to predict future efficiency, thus improving what we might call 'green-operation situational awareness – Level 3' which is simply the ability to predict the future efficiency of the ship based on engine performance and track control parameters. This may not be a single metric, but a clever interface that allows the seafarer to quickly and efficiently build their own ‘mental model’ of this issue, and adjust parameters as necessary. In order to design such a system and embed it within a current INS, usability studies are necessary, and those studies need to be cognizant of the socio-technical system within which they operate.

There is more research to be performed with respect to this issue – the integration of the technologies identified above needs further examination. We need better tools for testing such interfaces in simulation facilities – particularly tools that will assess human performance. Ultimately there is also further work to be done to ‘prepare’ the socio-technical system that is maritime transport to recognise the importance of moving in this direction. This would seem to require a fundamental market trigger that internalizes the cost of carbon pollution and supports the impetus for this sort of innovation to occur.

5 Conceptual design of a simulation based training module

5.1 Draft IMO Model Course on "Energy-efficient Operation of Ships"

From the research conducted in the frame of the" ProGreenShipOperation" project so far it can clearly concluded and stated that the approach of introducing sophisticated assistance tools for enhanced maneuvering planning can significantly contribute to more energy-efficient ship operation in the harbor areas. On the other hand, as demonstrated in the simulations studies (see chapter 3), there is clear potential for time and fuel savings and consequently the reduction of GHG emissions.

These results are in accordance with IMO's intention to contribute to green shipping. One of IMO's latest initiatives is the development of a model course for "Energy-efficient Operation of Ships". The first draft of this model course contained a suggestion for a one week (five days) training course for ships technical and nautical crew and shore-based personnel as well.

As a core element the drafted course framework provided a wide range of and room for practical exercise in order to learn about best practices related to energy efficient operations of a ship. Five main subject areas for training have been defined. Especially section I and II are relevant for an integrated simulation based training module. Section I is entitled "Fuel efficient operations" and addresses e.g. the fields of voyage planning, weather routing as well as "Just-in-time" operations and others.

The subject "Improved voyage planning" is foremost dedicated to the appropriate implementation of procedures according to IMO resolution A.893(21) (25 November 1999) on voyage planning as this resolution provides essential guidance for the ship's crew and voyage planners. It is mentioned that the optimum route and improved efficiency can be achieved through careful planning and execution of voyages. Thorough voyage planning needs time, but a number of different software tools are available for planning purposes.

Another main topic integrated in the draft model course is "Weather routing". It is highlighted that it has a high potential for efficiency savings on specific routes. Professional service is provided and is commercially available for all types of ship and for many trade areas. Significant savings can be achieved, but conversely weather routing may also increase fuel consumption for a given voyage.

With respect to the investigations of this project voyage planning and weather routing are seen as the "macro (planning) level" for rather strategic decisions whereas maneuvering planning is seen as the micro (planning) level belonging to tactical decisions of the ship navigation process.

Further in the first section of IMO's draft model course also "Just-in-time" practices are described. Emphasize is given to good early communication with the next port. This should be an aim in order to give maximum notice of berth availability and facilitate the use of optimum speed where port operational procedures support this approach. Optimized port operation could involve a change in procedures involving different handling arrangements in ports. Port authorities should be encouraged to maximize efficiency and minimize delay.

Moreover "Speed optimization" and "Optimized Shaft power" are topics of section I. The training modules should consider that speed optimization and optimized shaft power can produce significant savings. However, optimum speed means the speed at which the fuel used per ton mile is at a minimum level for that voyage. It does not mean minimum speed; in fact sailing at less than optimum speed will consume more fuel rather than less. Reference should be made to the engine manufacturer's power/consumption curve and the ship's propeller curve. Possible adverse consequences of slow speed operation may include increased vibration and sooting and these should be taken into account.

As part of the speed optimization process, due account may need to be taken of the need to coordinate arrival times with the availability of loading/discharge berths etc. The number of ships engaged in a particular trade route may need to be taken into account when considering speed optimization.

The second section of the draft model course is entitled "Optimized ship handling" and should address optimum trim and ballasting but also optimum propeller and propeller inflow considerations and optimal use of rudder and heading control systems. These items have impact on maneuvering performance on both the planning levels too and therefore are also relevant for the development of simulation-based training modules of such a training course.

5.2 Systematic approach for the development of a simulation-based training module

As a general approach to develop a training module on energy efficient ship operation proven theory and guidance will be applied. According to STCW, simulator training must clearly identify the objectives of education and training, the standards of competence and the levels of knowledge, understanding and skill. This means that simulator training should comprise the following:

- one or more scenarios (in accordance with STCW); and
- an assessment standard, stating the assessment criteria by which the performance of the trainee can be appraised.

Both, the scenarios and the assessment standard have to be developed, prior to the training. The following figure, originally developed under the MASSTER project of the European framework program on research and technological development, shows schematically the various processes which are involved.

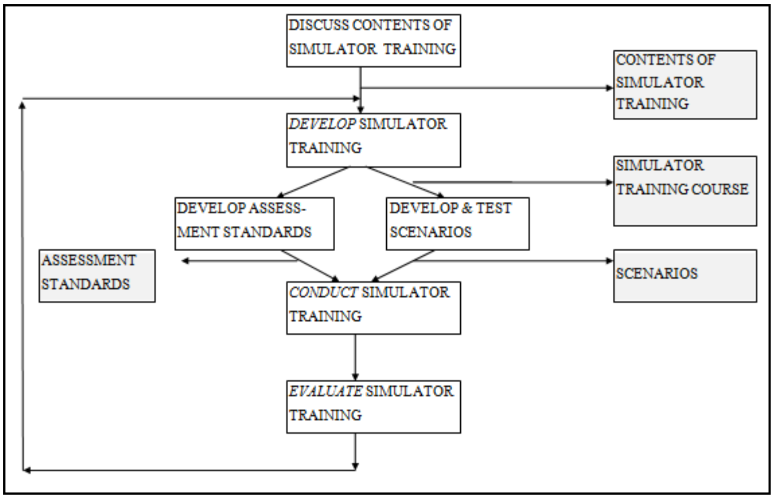


Fig. 44: Principal approach to develop simulator training

In this figure the shaded boxes contain documents or written results. The other boxes are about a certain process. The three main processes are

- the development,
- the conducting (including briefing and debriefing) and
- the evaluation of the simulator training.

With respect to scenario development in the following figure that part of the above figure is shown in more detail that specifically refers to the development of scenarios.

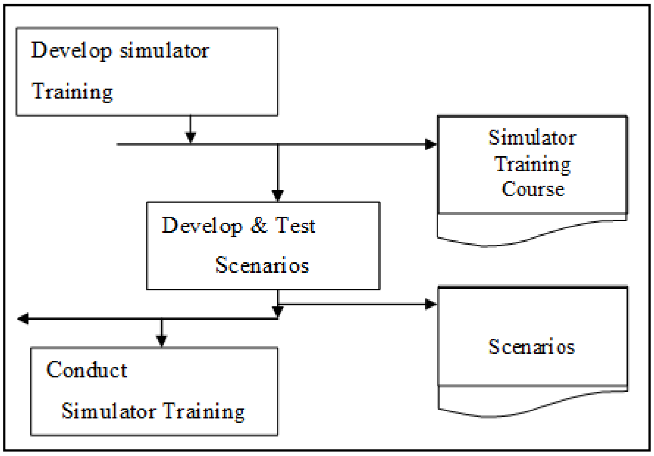


Fig. 45: Structure of the scenario development process

In this figure the development and testing are shown as one process. In reality this, by nature, is very much an interactive process, which must be concluded by a final test on the scenario. For now, let us take a closer look at the development of the scenario thereby adhering to the STCW scenario-definition.

The first step in the scenario development process is to establish the training objectives from the two documents "statement on contents simulator training" and "simulator training course" (figure 44 and 45). These two documents describe the aim of the training more generally. Together with the establishment of the training objectives within the general training aim, the question which simulator tool should be used, must be answered. It is important to reach an agreement on the training objectives (and appropriate simulator tool) that are to be used. This agreement should be reached between the simulator centre and the customer in case the customer is a company that requires training as a part of certification by national law or simply because of certain company regulations. Alternatively the agreement should be reached within a MET institution between the simulator centre and the responsible authority which approves the training. Most likely the training in question will also be part of training for certification under national law.

The following steps of the process of the scenario development are about the establishment of all relevant scenario elements. During this part of the process, the division into main training themes can be useful, in order to make the decisions about the scenario elements as in STCW.

For the sake of completeness the other scenario elements are given hereafter:

- simulator tool
- standard of competence
- own ship's configuration
- traffic situation, if applicable
- time of day, if applicable
- current, if applicable
- environment, if applicable
- duration
- visibility, if applicable
- area
- description of sequence of events

With respect to energy-efficient operation special attention is drawn to the description of the events and the sequence these are in. This element is very closely related to the training objectives and the standard of competence. Most probably there will be more than one description of sequence of events suitable for the same training objectives with the same standard of competence.

5.3 Scenario development for simulation exercises

5.3.1 Stages and processes

The following figure visualizes the central part of the scenario-development process. There are feedback links from the training objectives to the general training aim and from the sequence of events to the training objectives. The first feedback loop, covering AIM and THEMES, takes place between the simulator operator and the 'customer'. The second and third feedback loops are about the question whether the sequence of events is appropriate for the training objectives within that theme. These two development stages take place within the MET institute.

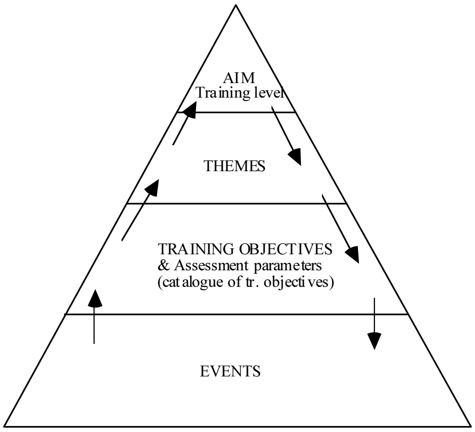


Fig. 46: Core elements of the scenario development process

As mentioned before, the definition of the scenario elements is an interactive process. Different sequences of events can be used to reach the same set of training objectives. Important questions during the development process are:

- With which event or sequence of events can a particular training objective be reached?
- Which event or which sequence of events, in terms of effectiveness and efficiency, is best suited to reach the training objective?

Basically, by keeping a close look at the training objectives and the general aim or theme of the entire training, the events will follow naturally. The most important pitfalls in the development process of the scenario are:

1. Going to EVENTS directly without specifying the AIM;
2. Going too quickly from AIM to EVENTS without properly working out the layers in-between;
3. Absence of validation through FEEDBACK LOOPS;

As the feedback loops (arrows pointing upwards in the figure) are so important it is advised strongly that more than one person is involved in the validation and the verification of the outcome at each stage. At the highest stage this must be done in concert with the ‘customer’. For working out the training objectives into events, given by a certain theme, the simulator operator must incorporate proper procedures to ensure the correctness of the process.

5.3.2 Methods for Scenario Development and Scenario Parameter

In general there are two different approaches which might be chosen for the scenario development:

- First one on the basic of the training objective,
- Second one on the basic of accidents, near misses and situations, met in real life.

Both approaches require a clear definition of the different parameters involved as given below.

Scenario – Exercise:
The scenario, often called exercise, consists of the own ship and three main parameters:

1. The training objective which is defined according to STCW95 or requirements detected according to the gaps and shortcomings,
2. The description of events in a form of a sequence which shall lead to the required result, the training aim,
3. The training area and the environmental conditions.

Definition: The word scenario describes the entity of a training exercise.
The scenario has to be taken as a part of a training program, which represents an overall general training objective and detailed objectives as part of a syllabus within a group of scenarios. The “Own ships”, involved in the training, depend on the availability in the library of the simulation facility.

Training objective and training aim:
Every simulation exercise is carried out to reach a defined goal. Therefore it is of great importance within a training program to define the general objectives in a clear way. This has to be done by checking the qualification of the trainee, collecting the requirements and comparing the qualification and the requirements. The balance shows what has to be trained.
Definition: The training objective is derived from the balance between the qualification of the trainee and the requirements to reach a training aim and/or a certain level of qualification.
Every training objective has to be divided into a number of detailed objectives. This can be done in the way of the ”top down-method” as well the ”bottom-up-method”.

Event description:
In a scenario a sequence of events is prepared in the way to reach the training aim, which is defined in accordance with the training objective, at the end of the exercise. The sequence consists of events, which shall force the trainee to follow the planned way according to a given schedule, and of objects to produce events. Every event and object is positioned in the sequence. Each sequence is an individual unit, which exists only in this way. Any change within the sequence, e.g. a change of the position of the event or objects or their functions, defines a new sequence.
Definition: The description of events represents the plan or sequence of different events which shall guide the trainee through the scenario and lead to the training aim.
The sequence needs to be described and it contains the starting situation with all details such as time, environmental conditions, objects and the functions of these details. The fact of "What is going on in this exercise" has to be said in the description of the sequence. This has to be a part of the whole documentation of the exercise.

Events:
The events are parts of the description of the sequence. The position within the sequence is of great importance for the result. The purpose of the events is to induce reactions of the trainees in order to get a required result. Events will be very different in their character. They depend on the simulator equipment and the instructor’s skill, knowledge, flexibility, proficiency and attitude.
Some very different examples may demonstrate the variety of events:

- A change of visibility by fog requires action.

- The agent’s telephone-call regarding the question of the ETA of the vessel needs an answer.
- Weather forecast announces critical wind forces that requires review of maneuver plan
- A navigational warning requires the attention of the trainee.

Objects:
The objects can be part of the events but not every object must raise an event. This depends on the trainee and his knowledge, experience, attention and vigilance. On the way it is presented within the simulation by the instructor.
Some examples for some objects:

- Ships,
- Floating objects,
- Flying objects such as helicopter.

Of course, there are further objects, which can be integrated in any simulation exercise, as for example rain areas and fog patches, which influence the visibility or wind areas, which influence the maneuverability of the ship, as well as tide and current. With respect to a simulation scenario for to be integrated into a model course on energy-efficient ship operation such objects have to be carefully chosen in respect to the defined training objective mainly.

Training area:
The general words used for describing the area often give a clue as to where the exercise will take place. It offers the space for running an exercise. In the scenario definition the training area is described in a generic way:

- open sea
- near/in TSS
- coastal waters
- close navigable waters
- near/in harbors.

These words describe the space available for carrying out ship’s maneuver in abstract form only. Performing the simulation the training area has to be defined in a more concrete way.
Definition: The training area represents the morphology, the aids to navigation and characteristics of a geographical zone for carrying out a simulation exercise. In the following some general data are given in respect to the different terms:

Table 5-1: Overview - general data for training scenario

Training objective	**Level / Qualification**
training objective / identification number level of education / qualification function within the STCW	identification number function according STCW
Events	**Objects**
events / identification number position in the sequence function of the event object/ part of the event	objects/ identification number function of the object object control position of the object in the sequence object class dimensions / detailed data

Training Area	**Sequence of Events**
name of area / identification number	name of description of sequence
general info such as	identification number
open sea	description of sequence
near/in a TSS	function of the events
coastal waters	status at starting time
close navigable waters	changes during exercise
near/in harbors	events in the sequence
geo data such as latitude and longitude	objects in sequence
morphology	functions of objects in the sequence
aids to navigation	

Applying the described systematic approach for the development of an integrated simulation-based exercise on energy-efficient ship operation will ensure also efficient preparation and conduction of model courses with integrated practical exercises.

5.4 Draft sample scenarios for training of energy-efficient ship operation

As described above, modern comprehensive improved voyage planning nowadays can be performed by using dedicated software system providing processed information regarding e.g. currents, tidal streams, and impact of shallow water as well as weather and related and sea state. However systems depend on reasonable and intelligent use of the provided functions taking into account the actual and forecasted prevailing circumstances.

On the other hand experienced navigators are also using manuals containing graphs indicating the performance parameter information as e.g. about pitch handling, power, speed and fuel consumption under different loading conditions and for the two main types of fairways (deep and shallow water). A practical exercise on fuel efficient operation integrated into a course framework should make use of simulators or otherwise suitable equipped laboratories providing specific assistance systems as standalone version or integrated into a complex ship-handling simulator even connected to ship engine simulator.

In addition, there are also game-based simulators available enabling demonstrating relationships between power, speed, fuel consumption and CO_2 emissions and furthermore allows savings that can be made when the power is adjusted to ETA, instead of sailing 100% to the destination and anchoring to avoid arriving too early.

By applying the described methodology the principle framework of a practical simulation-based exercise on fuel efficient ship operation is structured as exemplarily shown in the following tables. The framework allows for flexible integration of the suggested exercises into an applied IMO model course.

Draft sample exercise scenario I	
Identifier	**Fuel efficient ship operation I** Improved voyage planning
Training objective(s)	i.a. / e.g. • Perform comprehensive voyage planning according to IMO Res. A.893 (21) and Weather routing acc. to IMO Res. A.528 (13) • Speed optimization • Use different methods for determination of optimal route (incl. weather routing) taking into account efficiency indexes and optimal fuel consumption • Draft a berth to berth voyage plan
Simulator tool	Master office / shore-based company office
Standard of competence	Master, chief mate (management level) and navigating officers, Environmental officer, chief engineers and shore based operators
Configuration	e.g. Container feeder vessel (L_{oa} = 188 m; draught = 8,24 m; service speed = 22 kn)
Traffic situation	Varying
Time of day	Daylight
Current	n/a
Environment	Wind: moderate, < 2 Bf, Sea state: low, average high of wave ~ 0,5 m
Duration	Long, > 45 min
Visibility	More than 8 nm
Area	n/a
Event-description	• Charter party requirements delivered to ship management, crew to gather all relevant information for planning and • Heavy weather conditions forecasted with corresponding wind / wave conditions • Team determines optimal route from two/three alternative suggestions • Detailed berth-to-berth voyage planning including also the pilotage areas • Definition of monitoring parameter and criteria • Shore office to be contacted in order to coordinate decisions

Draft sample exercise scenario II

Identifier	**Fuel efficient ship operation - II** response actions to changing environmental conditions
Training objective	i.a. / e.g. • Speed optimization for just-in-time arrival and maneuvering in shallow water • Use of publications on tides and currents • Ballast / trim operations • Use of a weather routing system
Simulator tool	Full mission ship handling simulator
Standard of competence	Master, chief mate (management level) and navigating officers
Configuration	e.g. VLCC (L_{oa} = 340 m; draught = 22,03 m; service speed = 22 kn)
Traffic situation	Moderate (about 4 ships per 10 min)
Time of day	Daylight
Current	Realistic (regarding area)
Environment	Wind: moderate, < 6 BF Sea state: low to moderate, average high of wave ~ 2,5 m
Duration	Long, > 45 min
Visibility	More than 8 nm
Area	Open sea
Event-description	• The own ship is navigating in open sea and approaching shallow water area • Effect of “squat” on underkeel clearance power, speed and fuel consumption in shallow water, tides and currents has to be calculated in preparing the passage and presented by a nautical officer • At xx:yy hours – updated weather forecast informs about increasing wind (e.g. also intensifying tidal streams) • Situation assessment including trim operation and speed adaptation • Own ship sailing plan has to be adapted according to ETA • Falling tide • During incoming (high) tide further actions to be taken

5.5 Draft simulation module for planning of energy-efficient maneuvering in harbor approaches and basin

It is suggested to integrate practical activities to support optimized ship handling to demonstrate effects of such actions regarding fuel saving, reduction of GHG emissions etc. and on the other hand to perform actions/tasks in simulation environment.

Practical activities on this subject can range from performing manual or desktop calculation exercises of specific case studies up to full-mission simulation exercises.

As a sample exercise the ship operation when approaching a berth in a harbor is suggested. A potential frame for the sequence of events and tasks of such an exercise is given in the following table.

The emphasis of the simulation exercise is laid on planning of energy efficient maneuvering taking into account optimized use of engine, propeller, thruster etc. and by using available sources of information and taking into account different trim and ballast conditions.

Draft sample exercise scenario III

Identifier	**Optimized ship handling I** Maneuver planning for harbor basin and berthing operation
Training objective	i.a. / e.g. • Maneuvering in shallow water areas of harbor basin • Optimum use of steering and control systems • Use of tools for planning and monitoring ship operation considering different trim / ballast conditions
Simulator tool	Full mission ship handling simulator
Standard of competence	Master, chief mate (management level) and navigating officers
Configuration	e.g. RoRo Ferry (L_{oa} = 200 m; draught = 6,0 m; service speed = 24 kn)
Traffic situation	Moderate (about 3 ships per 10 min)
Time of day	Daylight
Current	Realistic (regarding area)
Environment	Wind: moderate, < 4 BF Sea state: low to moderate, average high of wave ~ 2,5 m
Duration	Long, > 45 min
Visibility	More than 8 nm
Area	Harbor area
Event-description	• Ferry/Passenger vessel (i.a. equipped with two propellers, bow thruster) is approaching a harbor area for berthing operation, • Communication with shore-based VTS station • Passage to berth includes several rudder/engine maneuver, also use of thruster is necessary • Passage planning to berth including pre-planning of maneuvering up to berthing • Combined rudder/engine maneuvers possible to save time while simultaneously keeping safety limits • Effects of “squat” on under keel clearance power, speed and fuel consumption in shallow water • Situation assessment (including trim operation and speed adaptation)

Such an exercise can be implemented to full-mission ship handling simulators preferably directly connected to a ship engine room simulator to cover the onboard regime of ship operation more completely. The sample exercises developed here are suggested for integration into the final draft of the IMO model course and were forwarded accordingly.

The simulation runs performed at the Maritime Simulation Centre in Rostock-Warnemuende during the course of this project can be converted accordingly in order to develop a detailed scenario description for specific training purposes. The scenario framework is open for the integration of the models provided in chapter 2 and the further development of the HMI for the maneuvering assistance system according to the investigation and their results presented in chapter 4.

6 Summary and conclusion

Within the project "ProGreenShipOperation I" basic investigations into potential contributions of ships to reduce greenhouse gas emissions have been performed. The focus of the investigations in the first phase of the project was laid on operation of ferries and the introduction of enhanced maneuvering assistance in the view of enhancements of MET by taking into account the challenges connected to IMO's aims.

The main objective of the first part of the project was to perform investigations into the development of the basics for a simulation based training module that supports optimized ship operation by means of enhanced integrated maneuvering planning to assist captains, pilots and navigating officers when entering port entrances and maneuvering in harbor areas in a way that time saving will allow for reducing greenhouse gas emissions by reducing fuel consumption while simultaneously keeping the economic constraints of the voyage's time schedule. For this purpose a prototyped maneuvering assistance system was integrated into a full-mission simulation environment and tested with respect to potentials for time and energy savings. Recordings of real harbor entrance maneuvers and berthing actions have been analyzed followed by a comparing simulation study. In the studies potentials of enhanced maneuvering assistance for time savings and energy and fuel efficient ship operation in port areas and harbor basins has been identified.

Regarding the design of the interface of the assistance system a comprehensive state of the art study is done. Basic concepts are developed and principle requirements are derived from the human factors point of view. Functional and technical requirements are considered by referring, i.a., to the present developments of e-Navigation and modular structured integrated navigation systems (INS).

A detailed study into effects of time savings has been performed and a model for the calculation of the NO_x and CO_2 emissions from the ships during port operations is provided together with the establishment of some interesting conclusions for the reduction of the mentioned emissions which would help the maritime industry to move towards the GREEN SHIP concept.

A framework for the development of a dedicated simulation exercise to train and demonstrate energy-efficient ship operation in port and harbor areas was developed and applied for the design of sample exercises. The development of the framework especially took into account the demands and needs of the draft IMO model course on "Energy-efficient Operation of Ships".

In conclusion is very well recognized, that best results regarding maritime safety and efficiency is basing on well-trained crews. Same is valid with respect to green ship operation. Only mariners who have background knowledge and who know how they can contribute in the best way to energy efficient and environmentally-friendly ship operation will be able to contribute to the ambitious aims. Therefore a concept for maneuver training using enhanced technology has been drafted.

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