IAMU 2012 Research Project
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Simulation-based training module to promote green energy-efficient ship operation Part II: Application (ProGreenShipOperation-II)

By

World Maritime University (WMU)

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Abstract: *Within the twofold project "ProGreenShipOperation" basic investigations into potential contributions of ships to reduce greenhouse gas emissions and investigations into the development of corresponding training material have been performed. This research project is a continuation of the research on "Simulation-based training module to promote green energy-efficient ship operation – Basics Part I" in which basic investigations have been carried out to develop a profound database and provide the necessary prerequisites for the application of simulation based training modules for integration into related training programmes.*

In this connection Part II of the project, again, deals with enhancement of MET by taking into account the specific challenges connected to IMO's aims in reducing greenhouse gas emissions when operating a ship. The objective of the research in the second period of the project 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.

A learning objective oriented approach will be used in order to develop a training scenario relevant for planning optimal manoeuvring sequences to minimize the Greenhouse gas emissions and reduce fuel consumption. Requirements of the latest Manila amendments of the STCW (2010)convention will be taken into account.

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

1 Introduction

1.1 Recall of the project's overall subject

The research project "Simulation-based training module to promote green energy-efficient ship operation" brought together four recognized IAMU institutions by merging and combining their research competencies on specific subject areas related to environmentally friendly shipping. Under the leadership of World Maritime University (WMU) the partners commonly developed their ideas for the 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 was divided into two phases. This report belongs to the project's second phase, which deals with the continued investigations to describe the potentials for energy-efficient ship operation identified in the first phase of the project and focuses on the completion of those studies and the application and transfer of the research outcomes into the development of training materials for a flexible training module on energy-efficient ship operation with a dedicated simulation-based exercise.

The project started from earlier investigations providing evidence that shipping significantly contributes to air pollution especially in coastal zones and harbor areas where many people are concerned. As already referred to in the final report of phase I among others from measurements carried out in the south Sweden region it is 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).

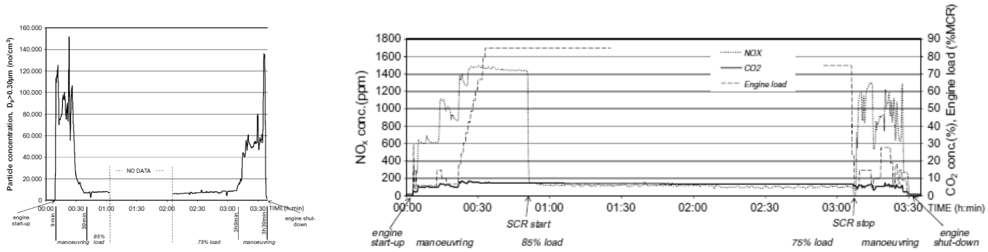


Fig. 1: Particle concentration (left), NO_x and CO_x emissions during different maneuvering phases of a ferry (source: H. Winnes & E. Fridell (2010))

Taking this into account the project started with the basic assumption that optimized maneuvering regimes contribute to decrease Greenhouse gas emissions and reduce fuel consumption, one aspect that has not been addressed sufficiently yet.

In this respect Part II of the project, again, deals with enhancement of MET by taking into account the specific challenges connected to IMO's aims in reducing greenhouse gas emissions when operating a ship. The objective of the research in the second period of the project is to continue and complete the research of phase I and investigate approaches to apply the concept for simulation-based exercises and to integrate and to demonstrate it in a simulation environment of a ship-handling simulator.

A learning objective oriented approach will be used in order to develop a training scenario relevant for planning optimal manoeuvring sequences to minimize the Greenhouse gas emissions and reduce fuel consumption. Requirements of the latest amendments of the STCW convention will be taken into account.

The second part of the research project is specifically dedicated to apply a simulation based - training module and implement simulation exercises for integration into existing maritime education and training schemes of nautical students and cadets and moreover into professional development courses of captains, pilots and navigating officers. Further the project is concentrating on the detailed development and implementation of simulation-based methods for manoeuvring planning to train environmentally friendly ship-handling in harbour areas and coastal zones. Teaching materials will be drafted. Training effects will be researched basically in the frame of a test trail.

1.2 Project aims and objectives and methodological approach

The main objective of both the phases of the project work 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 was integrated into a full-mission simulation environment in order to research how to provide situation dependent recommendation for optimal maneuvering strategies to save time.

The main objective of this research project is to perform investigations into the implementation of the results of the previous basic research into the development of a simulation based training module that supports optimised ship operation by means of enhanced integrated manoeuvring planning.

The work in the project was organized and structured in the following work packages:

- WP 1: Investigations into the transfer of the concept into a application of a learning objective-oriented training module for "green ship operation",
- WP 2: Design and implementation of a simulation exercise for training and demonstration of "green ship operation",
- WP 3: investigations into the development of related training materials for simulation-based training modules dedicated to for environmentally-friendly ship-handling,
- WP 4: Investigation into the development of an approach for the assessment of "green ship operation" and
- WP 5: Demonstration and test trail as well as development of integrated components for SEEMP IMO model course.

The second phase of the project starts with a collection and review of existing training programs, courses. This work especially focussed on content of training exercises and the use of simulators for training purposes.

In order to realize the aims and objectives the partners have been performed several working activities. The following activities and tasks were performed and are accomplished:

- Review and development of a methodology to apply a learning objective-oriented training module for "green ship operation". Therefore information on existing training programs and courses was gathered and has been reviewed. Emphasis was laid on content of training exercises and the integrated use of simulators.
- Secondly, in order to support the implementation of a practical exercise into a full-mission simulation environment, the partners investigated and adapted a framework for the harmonized design of a simulation exercise for training and demonstration of energy-efficient ship operation. A concrete simulation exercise has been designed and prepared for implementation.

- Thirdly, the partners drafted a set of training materials (draft lecture notes and presentation, scenario script) for use in training sessions related to energy-efficient ship operation with integrated simulation exercises dedicated to environmentally-friendly ship manoeuvring.

- Basic investigations were performed into to potential approaches how to support the assesment of dedicated simulation exercises.

- Parts of the developed training module and the produced training material were adpated for integrated use in various related maritime training and education courses dedicated to support and to promote green ship operation. For the purpose of studying the acceptance and usefuleness a presentation of parts of the preliminary module were integrated and tested in the frame of IMO's Greenhouse Gas Emission Train-the-trainer course.

The most important deliverable from the project is this final report document. During the course of the project's work a number of preliminary results and outcomes were produced. On the basis of those interim project results several presentations has been given and research papers were prepared and submitted to peer reviewed journals but also presented on prestigious conferences during the course of the project.

Furthermore, an interim report of the project phase II was prepared and a paper has been presented during IAMU's Annual General Assembly in St. John's, Canada in October 2012. The slides are attached to this final report as a separate appendix.

The project aims at researching and technical developments in order to produce and deliver a comprehensive description of a simulation exercise as one training module able to be potentially integrated into student courses and professional development course respectively. This module will be exemplarily implemented in a ship-handling training scenario and potentially distribution to further IAMU member institutes.

1.3 Research activities and distribution of results

The principle project work of the second project phase followed the above mentioned work packages.

For coordination of the partners' activities virtual (skype conference) meetings and email correspondence was used. Meetings were held periodically either as phone meetings or as workshop-like technical meetings.

The project leader World Maritime University has coordinated the work of the involved partners and their common activities. Furthermore, in the course of the project, there were also some travel activities. The trips were used for face-to-face meetings at conferences (as e.g. the IAMU's Annual General Assembly and Conference) and to present the project and selected interim results. The working meetings were also used to coordinate and monitor the partners work as well as to also ensure sufficient information exchange between them.

The main meeting and travel activities were:

- Barcelona, Spain, 27th -29th June, 2012, joint working meeting at the 5th International Conference on Maritime Transport;
- Rostock-Warnemuende 3rd - 7th September 2012, working meeting at 17th INSLC; St. John's, Newfoundland and Labrador, Canada, 15th -17th October 2012;
- joint partner progress meeting at IAMU AGA13 and conference as well as
- Rostock-Warnemuende 13th - 16th November 2012, 24th - 25th January and 25th February 2013 working meetings at Maritime Simulation Centre

During the course of the project the following papers referring to work done and results gained in the ProGreenShip project have been delivered:

1. Michael Baldauf, Knud Benedict, German de Melo, Ben Brooks (2012) ‘Energy-efficient ship operations through advanced manoeuvring planning’, in Maritime Transport V – Technological, Innovation and Research, Fransesc Xavier Martinez de Osés & Marcel la Castells i Sanabra [Eds.] IDP: Barcelona, pp 1056 - 1074

2. Takeshi Nakazawa, Michael Baldauf, Knud Benedict, Sandro Fischer, Michelé Schaub (2012): Development of a Model Course for energy efficient Operation of Ships and Application of a Simulation-based Training Exercise. . In K. Benedict (editor): Proceeding of the INSLC'17, Hochschule Wismar, University of Applied Sciences, Technology, Business and Design. Department of Maritime Studies Rostock-Warnemuende, pp 222 - 231

3. M. Baldauf, S. Klaes, K. Benedict, S. Fischer, M. Gluch, M. Kirchhoff, M. Schaub: (2012) Application of e-Navigation for Ship Operation Support in Emergency and Routine Situations. European Journal of Navigation; (2012), Volume 10 (2): 4 - 13.

4. Additionally to the papers published in peer reviewed journals and in conference proceedings as listed above, the following presentations have been delivered:

5. Baldauf, M.; Brooks, B.; de Melo, G.; Benedict, K.; Fischer, S.; M.; Schaub, M.: Simulation-based training module to promote green energy-efficient ship operation. Paper presented at the 13th Annual General Assembly of IAMU Expanding Frontiers – Challenges and Opportunities in Maritime Education and Training. St. John's Newfoundland, Canada, October 2012

6. Baldauf, M.; Benedict, K.; Fischer, S.; Gluch, M.; Kirchhoff, M.; Schaub, M.: Green Ships – Research for environmentally-friendly Shipping. Paper presented at Schweriner Wissenschaftswoche 2012: Sustainable Research – Future-Project Earth. Schwerin, October 2012

7. M. Baldauf, R. Baumler, T. Nakazawa; K. Benedict, S. Fischer, M. Schaub: Environmentally-friendly Sea Transportation - new Challenges for maritime Training and Education. Paper presented at 18th Schifffahrtskolleg: Preservation and Extension of maritime Competence. Rostock-Warnemuende, November 2012

As the papers and presentations were based partly on outcomes of work performed in the frame of the ProGreenShip project, the chapters are reflecting the content of these papers.

Moreover, the first draft version of the training module has been delivered as one contribution to the ongoing development of IMO's Greenhouse gas-Emission Train-the-Trainer course.

1.4 Research results and structure of the report

Chapter 2 contains the work performed in continuation of the related research carried out by partner UPC during phase I with respect to theoretical background and basics of effects of time savings by providing a method to empirically calculate different kinds of emissions taking into account different types of fuels. A series of calculations, some of which already presented in the first report, but further developed and further scenarios included as well and following the methodology along the same lines. With this method it is possible to determine both fuel consumption, and emissions of CO_2 and NO_x taking into account the

different regimes for a vessel of this type as there are: navigation, maneuvering and staying in port or hoteling.
The following third chapter summarizes the work performed, by Hochschule Wismar and World Maritime University, to integrate simulation augmented manoeuvring technologies into training. The chapter reports about the potential of a software package specifically designed for manoeuvring support for planning, monitoring and training to efficiently manoeuvre ships in different environments and under varying environmental conditions. Its integration into training exercises and for onboard use is described as well.

Chapter four, elaborated by Dr Benjamin Brooks, Dr Michelle Grech and Capt. Peter Dann of AMC, is dedicated to the human element aspects in energy-efficient ship operation and summarizes the studies carried out to complete the investigations of the first project period. The design of dedicated HMIs is researched and discussed in detail. The main aim of this chapter is to examine how possible human-machine interfaces to support energy efficiency can be assessed effectively. Two approaches to this issue – the assessment of situational awareness and the assessment of human error are considered and a discussion of the training implications is given. These implications are currently theoretical, as the type of integrated energy efficiency interface envisioned by this project is currently not commercially available yet.

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 final chapter contains the overall summary and provides conclusions and an outlook for further work on the subject of energy-efficient ship operation.

2 Measures towards green ship operation – Background and theoretical Underpinnings

2.1 Introduction

Select rigorously tested mathematical models that allow us to empirically calculate the different emissions for the different fuels and production processes provide the fundamental basis of the calculations for the studies presented in this chapter.

The calculation models referred to, were described in the final report of the previous project phase and therefore will not be repeated herein.
The purpose of the investigations described here is to try to define the parameters and identify trends which could guide us to adapt our production processes to improve the environmental performance of ships.

For this, as in the previous report, we started our data analysis for a Sorolla ship - vessel combining RoRo cargo transport and passenger traffic. The following are a series of calculations, some already present in the previous study while others are made directly for the consideration in this phase, though following along the same lines, in order to determine both fuel consumption and CO_2 and NOx emissions of in different regimes for a vessel of such type.

Although in recent years, the greenhouse effect, the destruction of the ozone layer, pollution and other contaminant issues are real and being legislated for regarding the control and reduction of all such and harmful emissions, we must bear in mind that in their construction and operations , our ships, ports and shipping lines have not been designed according to these parameters. This is not to say that all these parameters have been ignored; not at all, we all know the efforts that both shipyards and equipment manufacturers have been making in recent years, with the intention of reducing emissions by engines and equipping the ship with additional elements in the exhaust gas duct that can reduce these emissions.

But we must go a step further. The idea is to reduce emissions, which is the commitment of all to adapt equipment to the requirements of the permissible maximum emissions that have been set as standards (Euro Standards, Tier ....). What is proposed here is whether structural design, operation, routes and environmental aspects will predominate when we design our vessels, transport and maritime traffic as a whole, without losing sight of the main purpose for which they were designed.

To guide us in this regard, we offer study results that depict small variations in the current settings,

- For example the case of valuing what speed variations would result in emission parameters of a sailing ship.
- Check if the effects, beneficial or not, would have the same impact on the manoeuvres and be positive, see if these settings be viable, while maintaining the highest levels of safety.
- Study whether navigation times in port are advisable, and along with these the lines between ports defined. If possible, reduce waiting times; see how they affect driving significant reductions motivated by their own routes or operating conditions of the ports.
- Determine if the installed capacity of the survey vessel, both propulsive and auxiliary level, corresponds to the power actually required to perform the services provided.
- View other configurations of power that could allow us to maintain operational standards and reduce recorded emissions.
- Study the feasibility of alternative energy supplies as replacing dual motor gas engines, the use of alternative energy or power supply ground as measures of efficiency and therefore reducing parallel pollutants.

Once the lines of study are determined and the ships relevant to our study identified, it seems interesting to extrapolate these results to the fleet of Ro-Pax, with similar benefits as the Port of Barcelona annually hosts the fleet and for the ships that daily cross the Baltic Sea. The measures carried out as a whole would result in a more relevant and significant reduction of total emissions emitted by these vessels.

To perform such a comparative analysis, we used for the reference data, results of a previous study on all the ships that frequented the Port of Barcelona in 2011. The study collected the different scales we refer to - the main and auxiliary power installed on each ship, average manoeuvring times and registered their emissions. . It received information about these ships and about those that sail the Baltic Sea through various software and computer tools.

2.2 NOx and CO_2 Emissions calculation for a RO-PAX passenger ship.

As explained in the previous project phase, the ships, during their normal operation, generate different kinds of pollutants and emit the same into the atmosphere. We are going to use the previous calculations and perform and make some approximations that allow us to determine the parameters that contribute towards reducing emissions.

2.2.1 Ship's particulars

Described below are the most relevant data from the Sorolla ship and its crew.
Marked in orange are those features that have been taken as a basis for further calculations.

Fig. 2. Ro-Pax Sorolla

Name and owners	***Sorolla*** ACCIONA Trasmediterránea
Type	Passenger/RoRo Ship (vehicles)
Year of build	2001
AShipyard	hijos de J. Barreras S. A. Vigo (Spain)
Number of built	1.580
State of the vessel	In Service
Port of Register	Santa Cruz de Tenerife Register of Canary Island
Identification	IMO – 9217125
MMSI	224600000
Call sign	EBRI
Clasification Society	Bureau Veritas
Clasification	+ I3/3 E - FERRY - DEEP SEA - AUT-PORT - F (RIN)
Number of decks	9 + ceiling of bridge (RIN)
Place of engine room	Stern
Light *Displacement*	11.568 t
Summer *Displacement*	**16.555 t**
Deadweight	5.000 t
GT - NT	26.916 t - 14.308 t
Overall lenght	172,00 m
Lenght bpp	157,00 m
Molded breadth / depth	26,20 m - 9,20 m
Puntal a cubierta superior	14,84 m

Summer draft	6,200 m
Vehicle capacity	80 trucks and 336 cars or 98 trucks and 165 cars
habilitation	1.100 passangers plus crew in 202 cabins with 744 beds and 356 on deck. Crew: 71
Propulsión power	28.960 kW (39.372 bhp)
Speed	23 Knots
Propulsors	4 engines Wärtsilä 46A, 4 stoke, 8 cilynders at 500 r.p.m. Built by Wärtsilä Diesel S.A. - Bermeo Coupled two to two
Nmber of axes	2
Propulsion propeller	2 cc propellers lips, 4.600 mm diameter and four blades type "high skew".
Maneovering propeller	2 propeller, Rolls-Royce Marine type 250 TV, 1.000 kW at 320 r.p.m.
Auxiliary engines	3 generators Leroy Somer LSAM53M85 C6/6 AREP, 1.962 kVA - 380 V - 50 hz, driven for 3 engines Wärtsilä 20, 1.620 kW at 1.000 r.p.m. 2 tail shaft generators Leroy Somer LSAM53M85 C6/6 AREP 1.962 kVA - 380 V - 50 hz PTO.
Emergency engine	1 of 250 kW at 1.500 r.p.m. driven for an engine MAN D2866 LXE
Boilers	2 boilers Aalborg Industries type Mission OS 2.800 kg/h at 7 bar. 2 exhaust gas bolier Aalborg Industries type AQ-7 2.500 kg/h.
Type of fuel	Heavy fuel-oil IFO 380

Fig. 3: Sorolla ship details

The goal is not only to consider whether the ships are appropriate according to the environmental considerations , but also to consider the criteria of port operation and function as limiting or enhancing agents that place certain requirements on some of our ships so that they cannot give a better environmental response.

We will therefore also study the common routes for this type of a vessel.

Bcn-Ibiza-Mahon	17:30-23:00, Port of Barcelona stay 23:30 -5:30, sailing Bcn- Mahon 5:30- 8:30, Port of Mahón stay 8:00- 17:30 Sailing Mahon-Bcn 17:30-23:00, Port of Barcelona stay 23:30 -5:30, sailing Bcn- Ibiza 5:30- 8:30, Port of Ibiza stay 8:00- 17:30 sailing Ibiza-Bcn

Fig. 4.Sorolla routes 2012

Almeria - Melilla-Malaga-Algeciras	17:00 Algeciras 7:30 Melilla 19:00 Malaga 8:00 Melilla 20:00 Almeria 8:00 Melilla

Fig. 5. Sorolla routes 2013

2.2.2 Configuration and current condition.

The initial parameters of vessel operation for the analysis we have taken into consideration, have been explained in the previous study:

Sailing fuel consumption and thus emissions will be associated with:
- The operation of the 4 main propulsion engines.
- The operation of at least one auxiliary. The tail generator available and consumption can be assumed that this is already integrated in the previous section.
- The auxiliary boiler will stop usually used for the production of steam and hot water, recovery boilers fed by the exhaust gases of the main engines.

In port, we will define two main situations:

In manoeuvring where fuel consumption and emissions will play a role.

- The 4 main engines, responsible for supplying the ship's propulsive capacity to perform the manoeuvers for both entering and exiting the port.
- The electricity generated and needed for both the operational aspects and to provide for the ship's other services (hoteling).

Docked in port

- Electrical energy necessary to maintain ship's services. Both of operation for loading and unloading and those for hosting and ensuring the comfort of all on board.
- Use of auxiliary boiler, due to the non-availability of the service recovery boilers to guarantee the necessary hot water service.

In this work, unlike the previous, most of the calculations are measured per hour, so that this assessment can be extended to the study of any route or stay.

2.2.2.1 Power consumption and emissions of the propulsion installation during the navigation in port.

A universally accepted mathematical model - Admiralty formula [27] was used to calculate the IhP and the SFOC curve provided by the engines for the usual working loading ranges (WARSILA-2010b) for knowing NOx emissions and the CO_2 emission factor for the main engine of the model ship. Therefore a medium speed of 4- stroke and burning IFO (Intermediate Fuel Oil) is, in accordance with IMO GHG study of 2009, 3,19 kg of CO_2/ kg of fuel to arrive at the total amount of CO_2 emissions in navigation in port as we concluded from the investigations in the first project phase.

FEATURES	CONSUMPTION	NOx EMISSIONS	CO_2 EMISSIONS
in navigation in port MMEE estimated summer draft, 4 MMEE running 6knots maneuver average 1,5h	914kg	41kg	2915,66kg

Fig. 6. Sorolla Main engines emissions in manoeuvering

2.2.2.2 Power, consumption and emissions of the main source of electric power during the navigation in port and berthing/unberthing

Considering that the power required from the main source of electric power for maneuvers will be 20 or 30% greater than the power required for navigation in the open sea, due to the starting and the running of the necessary services for the manoeuvers (auxiliary blowers, bow thruster, mooring equipment) the SFOC curve provided by the auxiliary engines marks the usual working load ranges (WARTSILA 9L20C) for knowing the NOx emissions and the CO_2 emissions from the main source of electric power at berthing and unberthing and the emissions from the auxiliary boiler. We then have a consumption and total emission of:

FEATURES	CONSUMPTION	NOx EMISSIONS	CO_2 EMISSIONS
in navigation in port AAEE 2 AAEE working 65% maneuver average 1,5h	608,32kg	31kg	1940,50kg
in navigation in port auxiliar boiler			405kg

Fig. 7. Sorolla. Emissions of auxiliaries equipment in manoeuvring

2.2.2.3 Power, consumption and emissions from the main source of electric power at berth

These calculations, also present in previous sub-chapter are made following the same pattern as the previous section. The only difference is that in this case the calculation has been made for the period of one hour and not for an average stay of three hours, which allows for an easier way to extrapolate this value to different stages in port.

FEATURES	CONSUMPTION	NOx EMISSIONS	CO_2 EMISSIONS
at berth AAEE 2 auxiliar working 50%, 1h	322kg	16,9kg	1027,18kg
at berth auxiliar boiler, 1h			269,7kg

Fig. 8. Sorolla Emissions - berthed

2.2.2.4 Consumption and emissions of the propulsion installation in normal navigation. Speed 23 knots

We shall now proceed to perform the calculations for the speed of the ship pertaining to its design. From the Admiralty coefficient CA = 336 with which we have been working for this type of a ship, we will calculate both fuel consumption and emissions in navigation, using the curves provided by the engine manufacturer.

Consumption Calculation for navigation at 23 knots.
Considering the Admiralty coefficient and the total installed propulsive power on the ship, its four engines would work under a load very close to 80%,

$P= \Delta^{2/3}. V^3 / C_A$

P = Indicated power – IHP
Δ = Ship's displacement – Long T (1 Long T= 1,016 t)

v = Ship speed – kn

C A = Admiralty Coefficient. Value 336.

$P= 16306^{2/3}. 23^3 / 336 =23285{,}1$ IHP

Assuming that boat propeller teams have 28968kW MCR, and mechanical efficiency of these is 0.98,
$P_I= P_B/\eta_m= 28960/ 0{,}98 = 29551$ IHP
The relationship between the power developed by sailing 23 knots relative to the vessel's total propulsive power is;
23285,1/ 29551 = 78,8% (80% than usual as this is the speed of service)

For deriving the values for a period of 1 hour, we used the SFOC curve, provided by the engines maker for the usual working load ranges (WARSILA-2010b).

Knowing the charge rate of the engines determines the fuel consumption at 23 knots.

$$C_{fuel\ 23\ navig} = (0{,}0093 \cdot L^2 - 1{,}412 \cdot L + 223{,}5) \cdot P_{23\ navig} \cdot t_{23\ navig} \cdot n$$

Where:
$C_{fuel23\ navig}$: Total main engine fuel oil consumption during the navigation (kg).

L : Main engine load (% of MCR).

$P_{23navig}$: Brake power of the main engine during navigation (kW).

t_{navig} : time (1 h).

n : Number of main engines running.

As the estimates for these values:

L = 78,8%

$P_{23\ navig}$ = 5705 kW (78,8% de MCR)

$t_{23\ navig}$ = 1 h

$n = 4$

So:

$$C f_{23\ navig} = \frac{\left(0{,}0093 \cdot L^2 - 1{,}412 \cdot L + 223{,}5\right) \cdot P_{23navig} \cdot t_{23navig} \cdot n}{1000} = \frac{170 \cdot 5705 \cdot 1 \cdot 4}{1000} = 3879 kg$$

Calculating the level of NOx and CO_2 emissions covered at 23 knots.
Once the fuel oil consumption is determined, the emission factors corresponding to the engine type with which the ship is provided are applied and the NOx emissions and the CO_2 emissions for the main engine are obtained.
So, applying the main engine emission formula, we calculate the NOx quantity emitted from the main engine during 1hour of navigation at 23knots.

$E\ NOx - ME = FE - NOx \cdot CME$

$E\ NOx - ME$: NOx emissions from the main engine during the navigation (kg)

$FE - NOx$: NOx emission factor (kg NOx/t fuel)

CME : Main engine total fuel oil consumption during 1 hour navigation.

$E\ NOx - ME = FE - NOx \cdot CME$

$$E\ NO_x - ME = (-0{,}002 \cdot L + 0{,}5351 \cdot L + 39{,}714) \cdot CME = 60{,}46 \cdot 3879/1000 = 269{,}4 kg$$

The emissions from the main engines in 1 hour navigation is **269,4 kg of NOx**.

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

Given that CO_2 emissions for this fuel IFO (Intermediate Fuel Oil) are 3.13 kg CO_2 / kg of fuel, according to IMO GHG Study 2009.

Emission		Emission factor (kg emitted/tonne of fuel)	Guideline reference
CO		7.4	CORINAIR
NMVOC		2.4	CORINAIR
CH_4		0.3	IPPC 2006/CORINAIR
N_2O		0.08	IPPC 2006/CORINAIR
CO_2	*Residual fuel oil*	3,130	IPPC 2006
	Marine diesel oil	3,190	IPPC 2006
SO_2	*Residual fuel oil (2.7% S)*	54	CORINAIR
	Marine diesel oil (0.5% S)	10	CORINAIR
NO_x	*Slow-speed diesel engines*	90 \ 78 (85)*	–
	Medium-speed diesel engines	60 \ 51 (56)*	–
	Boilers	7	–
PM_{10}	*Residual fuel oil*	6.7	CORINAIR
	Marine diesel oil	1.1	CORINAIR

* NO_x Emission factors: non-regulated\subject to IMO NO_x regulation (2007 average emission factor).

The emissions from the main engine are therefore **12.180,9 kg of CO_2**.

FEATURES	CONSUMPTION	NOx EMISSIONS	CO_2 EMISSIONS
navigation MMEE 23knos	3879kg	269,4kg	12141,27kg

Fig. 9. Sorolla Consumption of fuel and Emissions MMEE sailing at 23 Kn

2.2.2.5 Power, consumption and emissions of the main source of electric power during the navigation.

In general, it is a common practice to keep only one generator running during the normal navigation. It will work more or less 90% if shaft generators are not working.

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, only one main generator is connected during the navigation.
The load approximately is 90% of MCR,

$C\ AAEE-Ng$: (0,0064 · L^2 - 1,1242 · L+239,15) · $PAAEE-Ng$ · n · $t\ maneuv$

$C\ AAEE-Ng$: Fuel oil consumption for the main generator plant during the navigation (kg).

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

$PAAEE-Ng$: Brake power of each AAEE during the navigation (kW).

n : Number of AAEE's running.

$t\ maneuv$: Time spent during the navigation (h).

Being the conditions in this situation:

$L = 90\%$

$PAAEE-Ng = 1458\ kW$

$n = 1$

And doing the calculations for 1h sailing.

$t\ maneuv = 1h$

$$C\ AAEE\text{-}Ng = \frac{190 \cdot 1458 \cdot 1 \cdot 1}{1000} = 277kg$$

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, thus obtaining the NOx emissions from the AAEE's in the indicated period.

Thus, the NOx emissions from the main source of electric power during the normal navigation:

$$E\ NOx-AAEE-_{Ng} = FE-_{Nox} \cdot C\ AAEE-Ng$$

$E\ NOx-AAEE-Ng$: NOx emissions from the main source of electric power during the navigation (kg).
$FE-NOx$: NOx emission factor (kg/t fuel).

$C\ AAEE-Ng$: Main generator plant fuel oil consumption during the navigation (t).

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

$$E\ NOx-AAEE-_{Ng} = (0{,}0004 \cdot L^2 - 0{,}1386 \cdot L + 58{,}299) \cdot C\ AAEE-Ng / 1000 =$$
$$= 41{,}07 \cdot 277/1000 = 13{,}6\ kg$$

The main source of electric power emissions are **13,6 kg of NOx** during the navigation stage in port.

Given that CO2 emissions and the fuel consumption in this type of engine have a ratio of 3.19 kg CO 2 / kg fuel, according to IMO GHG Study 2009.

$E_{CO2} = 277_{kgcombustible} \cdot 3{,}19_{kg\ de\ CO2\ /Kg\ combustible} = 883{,}63\ Kg\ CO_2$

The main source of electric power emissions are **883,63 kg of CO_2** during the navigation stage in port. The vessel does not need additional boilers during navigation.

FEATURES	CONSUMPTION	NOx EMISSIONS	CO_2 EMISSIONS
sailing AAEE 1 engine running 80%, 1h	277kg	13,6kg	883,63kg

Fig. 10- Sorolla Consumption of fuel and emissions of auxiliary Equipment during sailing

2.2.3 Calculation of fuel consumption and emissions at other speeds

In the previous chapter we've studied the three most common ship operations for which it was designed - navigation, manoeuvring and when docked in port.
Following the same mathematical models and approximations made for the conditions of normal use, the focus in this section is to study other systems and other configurations that may indicate a pattern of operation that involves some improvement from the environmental point of view.

2.2.3.1 Table of consumption and emissions by speed (14-23 knots)

As we made the calculation of emissions from consumption and main propulsion of sailing the ship at 23 knots, we proceeded to perform the same approximations for the speeds of 14-22 knots.

The data together with that already obtained for navigation at 23 knots appears in the following table.

SPEED	knots	14	15	16	17	18	19	20	21	22	23	24
MMEE LOAD	%	18%	22%	27%	32%	38%	44%	52%	60%	69%	79%	90%
CONSUMPTION	kg	875	1076	1306	1566	1859	2187	2551	2953	3395	3879	4408
NO_x	kg	51,6	63,5	77,1	92,4	109,7	129,0	150,5	174,2	200,3	228,9	260,0
CO_2	kg	2747,2	3378,9	4100,7	4918,6	5838,7	6866,9	8009,2	9271,6	10660,2	12181,0	13839,9

Fig. 11 Consumption and emissions of MMEE of ship Sorolla at differents speeds

The chart below shows the trend in both the consumption and the emissions of NOx and CO_2 in relation to the increase in speed.

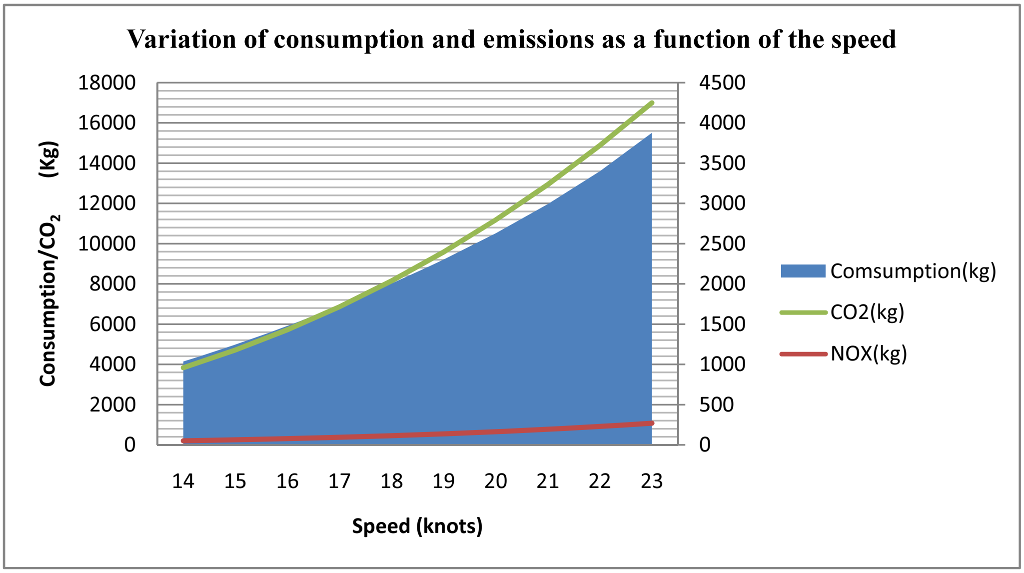


Fig. 12 Sorolla - variation of consumption and emissions as a function of speed

Analyzing these results shows that an increase in speed per knot, increases the consumption by more than 15%, and along with this the increase in the NOx and CO_2 emissions.

To increase from 14 to 15 knots			**a 16**	**a 17**	**a 18**	**a 19**	**a 20**	**a 21**	**a 22**	**a 23**
increase	**C(kg)**	20%	19%	17%	16%	15%	14%	14%	14%	14%
increase	**NOx(kg)**	25%	23%	22%	21%	20%	19%	18%	18%	18%
increase	**CO_2(kg)**	23%	21%	20%	19%	18%	17%	16%	15%	14%

Fig. 13 Sorolla. Percentage of increasing consumption and emission for knots

.

However this is not directly comparable, as although we reduce the consumption per hour, the slow turn implies an increasing commuting time.
Attached is now a new table, which combines the fuel consumption and emissions calculations per hour obtained for each speed, with the additional time spent to reduce the speed.
So we have:
1.- Table that determines the navigation time needed for a specific route.
2.- Table of consumption and emissions per hour, obtained at the beginning of this section.
3.- Table of consumption per route and speed.
4.- Emissions table of NOx per route and speed
5.- Emissions table of CO_2 per route and speed

miles	Consumption of the travel as a function of the speed 14	15	16	17	18	19	20	21	22	23
160	10000,0	11477,3	13060,0	14738,8	16524,4	18416,8	20408,0	22499,0	24690,9	26984,3
150	9375,0	10760,0	12243,8	13817,6	15491,7	17265,8	19132,5	21092,9	23147,7	25297,8
140	8750,0	10042,7	11427,5	12896,5	14458,9	16114,7	17857,0	19686,7	21604,5	23611,3
130	8125,0	9325,3	10611,3	11975,3	13426,1	14963,7	16581,5	18280,5	20061,4	21924,8
110	6875,0	7890,7	8978,8	10132,9	11360,6	12661,6	14030,5	15468,1	16975,0	18551,7
100	6250,0	7173,3	8162,5	9211,8	10327,8	11510,5	12755,0	14061,9	15431,8	16865,2
90	5625,0	6456,0	7346,3	8290,6	9295,0	10359,5	11479,5	12655,7	13888,6	15178,7
80	5000,0	5738,7	6530,0	7369,4	8262,2	9208,4	10204,0	11249,5	12345,5	13492,2
70	4375,0	5021,3	5713,8	6448,2	7229,4	8057,4	8928,5	9843,3	10802,3	11805,7
60	3750,0	4304,0	4897,5	5527,1	6196,7	6906,3	7653,0	8437,1	9259,1	10119,1
50	3125,0	3586,7	4081,3	4605,9	5163,9	5755,3	6377,5	7031,0	7715,9	8432,6

miles	NOx emissions of the travel as a function of the speed 14	15	16	17	18	19	20	21	22	23
160	589,7	677,3	771,0	869,6	975,1	1086,3	1204,0	1327,2	1456,7	1592,3
150	552,9	635,0	722,8	815,3	914,2	1018,4	1128,8	1244,3	1365,7	1492,8
140	516,0	592,7	674,6	760,9	853,2	950,5	1053,5	1161,3	1274,6	1393,3
130	479,1	550,3	626,4	706,6	792,3	882,6	978,3	1078,4	1183,6	1293,8
110	405,4	465,7	530,1	597,9	670,4	746,8	827,8	912,5	1001,5	1094,7
100	368,6	423,3	481,9	543,5	609,4	678,9	752,5	829,5	910,5	995,2
90	331,7	381,0	433,7	489,2	548,5	611,1	677,3	746,6	819,4	895,7
80	294,9	338,7	385,5	434,8	487,6	543,2	602,0	663,6	728,4	796,2
70	258,0	296,3	337,3	380,5	426,6	475,3	526,8	580,7	637,3	696,7
60	221,1	254,0	289,1	326,1	365,7	407,4	451,5	497,7	546,3	597,1
50	184,3	211,7	240,9	271,8	304,7	339,5	376,3	414,8	455,2	497,6

miles	CO_2 emissions of the travel as a function of the speed 14	15	16	17	18	19	20	21	22	23
160	31396,6	36041,6	41007,0	46292,7	51899,6	57826,5	64073,6	70640,8	77528,7	84737,4
150	29434,3	33789,0	38444,1	43399,4	48655,8	54212,4	60069,0	66225,7	72683,2	79441,3
140	27472,0	31536,4	35881,1	40506,1	45412,1	50598,2	56064,4	61810,7	67837,6	74145,2
130	25509,7	29283,8	33318,2	37612,8	42168,4	46984,1	52059,8	57395,6	62992,1	68849,1
110	21585,1	24778,6	28192,3	31826,2	35680,9	39755,7	44050,6	48565,5	53301,0	58257,0
100	19622,9	22526,0	25629,4	28932,9	32437,2	36141,6	40046,0	44150,5	48455,5	52960,9
90	17660,6	20273,4	23066,4	26039,6	29193,5	32527,4	36041,4	39735,4	43609,9	47664,8
80	15698,3	18020,8	20503,5	23146,4	25949,8	28913,3	32036,8	35320,4	38764,4	42368,7
70	13736,0	15768,2	17940,6	20253,1	22706,1	25299,1	28032,2	30905,3	33918,8	37072,6
60	11773,7	13515,6	15377,6	17359,8	19462,3	21684,9	24027,6	26490,3	29073,3	31776,5
50	9811,4	11263,0	12814,7	14466,5	16218,6	18070,8	20023,0	22075,2	24227,7	26480,4

Fig. 14 Consumption and Emissions by trip and average speed.

Now we graphically represent the curve that depicts fuel consumption and NOx and CO_2 emissions for 150 miles of travel depending on the speed.

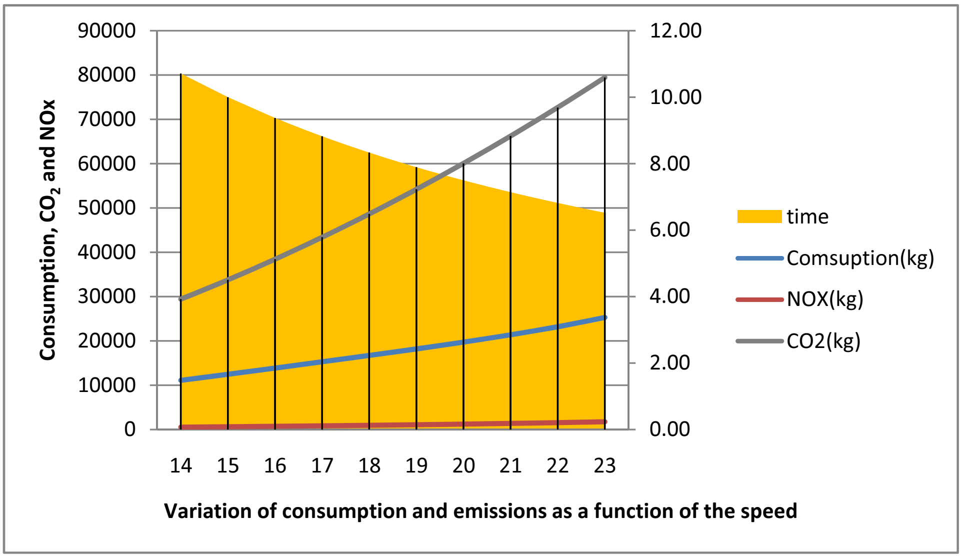


Fig. 15 Sorolla Variation of consumption and emissions as a function of the speed

From studying the graph we can conclude that as we increase the speed, travel time is reduced, but the consumption and emissions of both NOx and CO2 increase considerably.

	14 to 15kn	**15 to 16kn**	**16 to 17kn**	**17 to 18kn**	**18 to 19kn**	**19 to 20kn**	**20 to 21kn**	**21 to 22kn**	**22 to 23kn**
C(kg)	12%	11%	10%	9%	9%	8%	8%	9%	9%
NOx(kg)	17%	16%	15%	14%	14%	13%	13%	13%	13%
CO_2(kg)	15%	14%	13%	12%	11%	11%	10%	10%	9%

Fig. 16 Sorolla Percentage of increase in the emissions and the consumption for a travel of 150 mile

Sailing:
To reduce 1 knot ⇨ reduction from 13 to 15% of emissions of NOx.

To reduce 1 knot ⇨ reduction from 10 to 15% of emissions of CO_2

2.2.3.2 Consumption and emissions in speeds above the 23 knots

Given that the service speed of 23 knots is equivalent to approximately 80% of the load, it is interesting to see what happens with our study parameters, consumption, NOx and CO_2 emissions when we increase the speed and the engines are working at full load .
These would be the average values obtained for increasing speed.

Speed (Knots)	23	23,5	24	24,5
Consumption(kg)	3879,3	4137,8	4407,6	4688,9
NOx(kg)	228,9	244,1	260,0	276,6
CO_2(kg)	12181,0	12992,8	13839,9	14723,0

Fig. 17 Sorolla. Emissions at speeds higher to the speeds service

The representation of the evolution of the emission as a function of speed is shown in the graph below

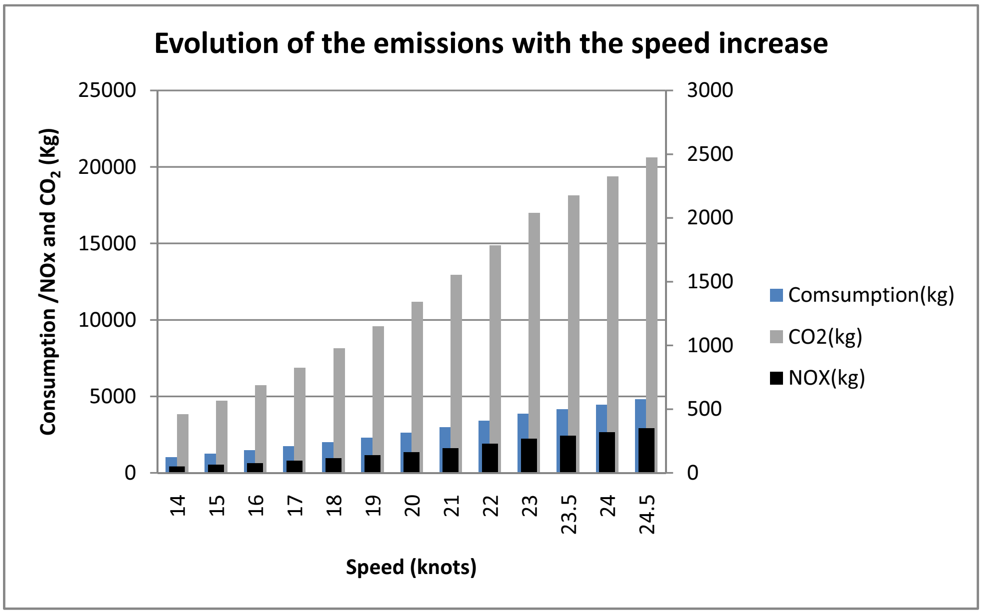


Fig. 18. Sorolla - Evolution of the Emissions with the speed increase

2.3 Awareness for reducing emissions

2.3.1 Navigation speed variations.

2.3.1.1 Example of vessel routes

In section 2.2.2.4 and 2.2.3.1, we clearly see that a reduction in speed is associated with a considerable reduction in consumption and emission. So we will now study the routes followed by the ships and the speed variations along these routes.

We have chosen a couple of routes followed usually by the Sorolla ship and the others in the Baltic Sea and the ships daily performance is very similar to this. Looking at the daily operation of these ships and after obtaining their actual speeds from the AIS equipment installed, we appreciate that there seems to be a common practice with them to sail at a high speed, perhaps due to some delay in the departure from a port and thereafter reducing the speed to tie up with the scheduled arrival in the following port.

And to a lesser extent, some vessels exhibit the contrary behavior, where they split the voyage and initially sail with reduced speeds, reaching high speeds only in the final hours of the journey.

Although in some cases this behavior can be justified due to weather forecast reasons, or traffic conditions. There is a sufficient level of agreement, to claim that these behaviors are more due to the organizational influence on the vessel to meet the timetables.

Represented below are the journeys made by these ships obtained from AIS.

The information on the average speed maintained according to information provided by the AIS is given alongside the usual paths in the images below.

ROUTE MELILLA - ALMERIA

We have as a first example, a route between Melilla and Almeria. It is a usual route for Sorolla, which alternates with routes like Almeria - Melilla, Melilla – Algeciras or Algeciras - Melilla.
Monitoring the ship in this way allowed us to develop speed record for the vessel. These are grouped according to their variations in three stages.
- A first in which the ship sails at 18 knots for 2h.
- A second where the ship is at an average speed of 19.2 knots.
- A third where the ship sails at 22.2 knots for 1h.

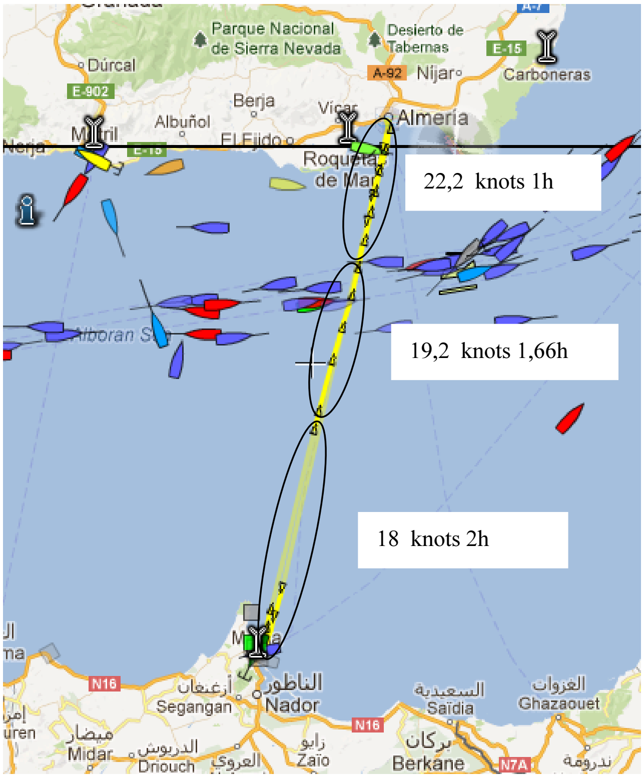


Fig. 19. Sorolla Route Almeria-Melilla

NOx and CO_2 emissions for each of the phases of the vessel's journey are calculated regardless of the manoeuvres. (See calculations in table below)

SPEED	TIME	NOx /h	NOx TOT	CO_2/h	CO_2 TOT	MILES
22	1	200,3	200,3	10660,2	10660,2	22
19	1,66	129,0	214,2	6866,9	11399,0	31,5
18	2	109,7	219,4	5838,7	11677,4	36
	4,66		**633,9**		**33736,7**	**89,5**

Fig. 20. Sorolla Calculation of emissions Almería-Melilla

Analyzing this journey, we see that the ship starts with a moderate speed and increases it at the last stage of the travel to maintain the planned ETA, which is a common practice for such ships for these types of journeys. Making a forecast for this route, we see that maintaining a constant speed of 19.2 knots, we could make the trip in the same time and reduce emissions.

SPEED (knots)	TIME (h)	NOx kg/h	NOx TOT (kg)	CO_2 Kg/h	CO_2 TOT (kg)	MILLAS
19,2	4,66	133,1	620,2	7086,0	33020,9	90
	5		**620,2**		**33020,9**	**90**

Fig. 21. Sorolla Calculation of emissions for a constant speed Almeria -Melilla

Based on this, we would cease to emit 14 kg of NOx and 700 kg of CO_2 into the atmosphere.
Being a bit more ambitious, we recalculated along these lines for 18 knots. This means an increase in the travel time by 20 minutes, but the environmental rewards are significant by leading to reduced emissions of 84 kg of NOx and 4000 kg of CO_2, a 13% decrease respectively.

The Table below shows the calculations of the emissions at 18 knots.

V (knots)	TIME (h)	NOx kg/h	NOx TOT (kg)	CO_2 Kg/h	CO_2 TOT (kg)	MILLAS
18	5	109,7	548,5	5838,7	29193,5	90
	5		**548,540495**		**29193,5111**	**90**

Fig. 22. Sorolla Calculation of emissions at reduced speed Almeria- Melilla

ROUTE BARCELONA - MAHON

The image now depicts a new route of Barcelona-Menorca.
This is normally undertaken by the ship Sorolla until it moves to the Malaga and Almeria zone depicted in Figure 19 above.

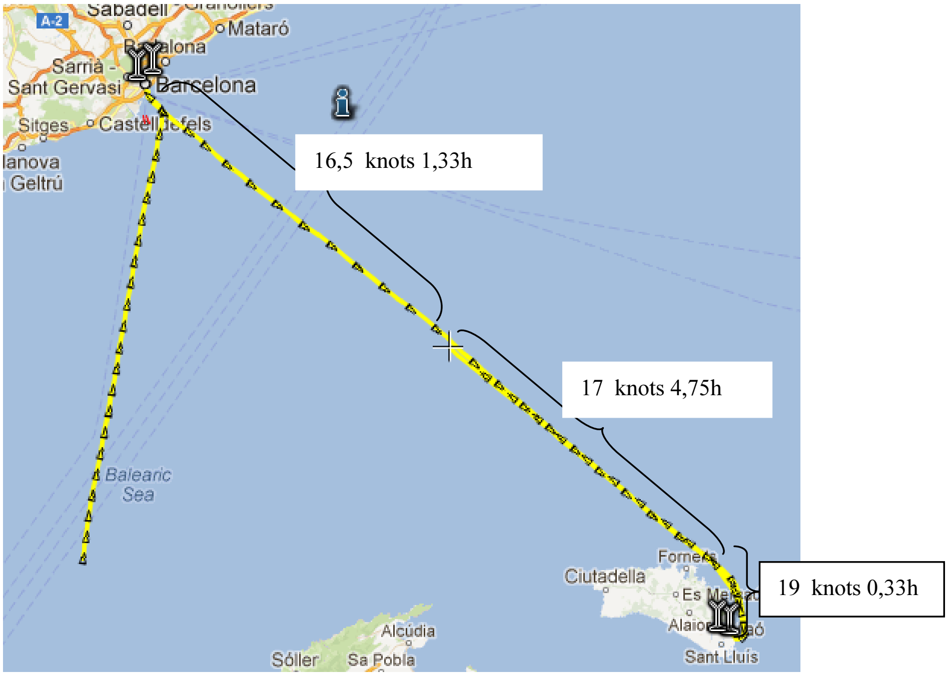


Fig. 23. Sorolla travel Barcelona- Menorca

Analyzing the route and taking the average of speeds, we found that there are three steps in this case:
- A first in which the ship is 16.5 knots for 1 hour 20 minutes.
- A second in which the ship sails at 17 knots for 4 hours 45 minutes.
- A third stage in which the ship sails at 19 knots for 20 minutes.

We see as in the previous case that the ship is sailing out at a reduced speed and increasing it at the end in order to meet the planned ETA.

Analysing along the same lines, the NOx and CO_2 emissions of the represented journey are 594 Kg of NOx and 31617 Kg CO_2.

SPEED (knots)	TIME (h)	NOx kg/h	NOx TOT (kg)	CO_2 Kg/h	CO_2 TOT (kg)	MILES
16,5	1,33	84,5	112,4	4497,28	5981,3824	21,9
17	4,75	92,4	439,0	4918,64	23363,54	80,8
19	0,33	129,0	42,6	6886,88	2272,6704	6,3
	6,41		**594,0**		**31617,5928**	**109**

Fig. 24.- Sorolla Calculation of emissions Barcelona-Menorca

For the same route the emissions are calculated for a constant speed of 17 knots. In this case we would, without altering the time necessary for the journey, reduce the emissions of NOx and CO_2.

SPEED (knots)	TIME (h)	NOx kg/h	NOx TOT (kg)	CO_2 Kg/h	CO_2 TOT (kg)	MILES
17	6,41	92,4	592,284	4918,64	31528	109
	6,41		**592,284**		**31528**	**109**

Fig. 25. Sorolla Calculation of emissions at constant speed Barcelona - Menorca

The following table depicts the emissions by decreasing this speed by a half knot:

SPEED (knots)	TIME (h)	NOx kg/h	NOx TOT (kg)	CO_2 Kg/h	CO_2 TOT (kg)	MILES
16,5	6,6	84,5	557,7	4497,28	29682,048	108,9
	6,6		**557,7**		**29682,048**	**108,9**

Fig. 26. Sorolla Calculation of emissions at reduced speed Barcelona-Menorca

Results show that we won't emit into the atmosphere 126kg of NOx and 8365.9 Kg of CO_2; a reduction of 21.5 and 19.5% respectively with only a delay of 12 minutes.

From above we get two important conclusions:

CONCLUSION 1: A travel plan reduces the level of emissions.

CONCLUSION 2: A reduction of one or half a knot of the speed reduces the emissions of NOx and CO_2 between 15 and 20 %, with a penalty time of between 12 and 20 minutes.

2.3.1.2 Navigation speed variations – Baltic Sea routes.

This image shows the Baltic region, where the blue arrows represent the daily running routes of Ro-Pax between ports, depicting mobility in the area.

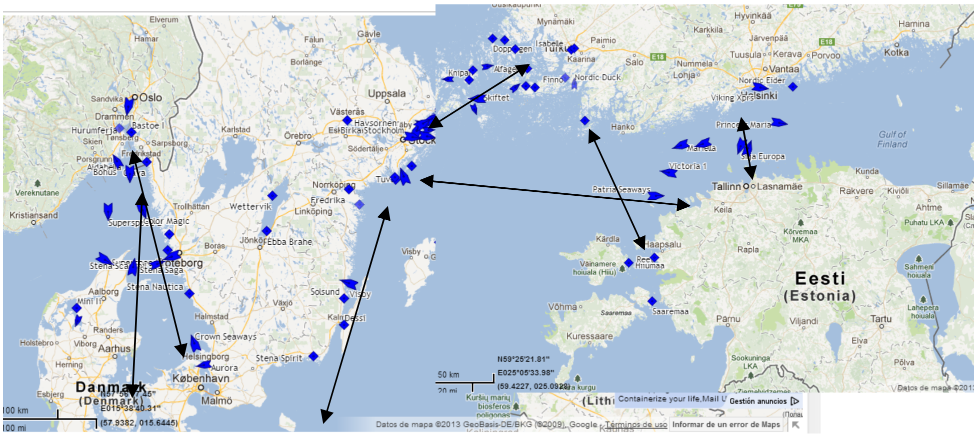


Fig. 27.- Main routes of Baltic sea

We have tried to study the more significant routes while also considering the availability of sufficient data to calculate the emissions of both NOx and CO_2 for each way.

Each plotted route is marked by different ovals corresponding to periods in which the ship has remained at the same speed, or a similar rate. Each box corresponding to the oval indicates the average speed for that step.

For this calculation we match the dimensions of the ship, its installed capacity and maximum speed of the ship design. From the Admiralty Formula we can determine the coefficient CA that calculates the engine load at different rates of speed, assuming in all cases that the ship is fully loaded.

Once the workloads are obtained for each of the speeds, and as all of these vessels have a diesel-based propulsion medium speed (medium speed engines), we applied the average specific consumption of between 170 and 200 g / kWh consumption for each of the stages. We have a calculation value of 200g/kWh.

To retrieve consumption, we have applied the NOx Emission Factor of 59 kg of NOx/t of fuel consumed to get the amount (in kg) of NOx released into the atmosphere. We applied the CO_2 emission factor of 3,14 kg of CO_2 / t of fuel for CO_2 emissions.

Accompanying each of the routes is a summary table of the main emissions, obtained from these calculations for each of these regimes.

1. ROUTE GOTEBORG -KIEL

SHIP : STENA SCANDINAVICA

Ro-Pax ship 31.409t displacement boat, propulsive power of 25920 kW, intended for an average speed of 22 knots. The table shows the consumption and emission values obtained for different speeds.

SPEED	knots	14	15	16	17	18	19	20	21	22	23	23,5
MMEE LOAD	%	21%	26%	32%	38%	45%	53%	62%	71%	82%	94%	100%
CONSUMPTION	kg	1096	1348	1636	1963	2330	2740	3196	3699	4254	4860	5184
NOx	Kg	64,7	79,5	96,5	115,8	137,5	161,7	188,5	218,3	251,0	286,8	305,9
CO_2	kg	3441,9	4233,3	5137,7	6162,5	7315,2	8603,4	10034,6	11616,3	13356,0	15261,3	16278,4

Fig. 28. Stena Scandinavica - Data of Consumption and emissions at different speeds

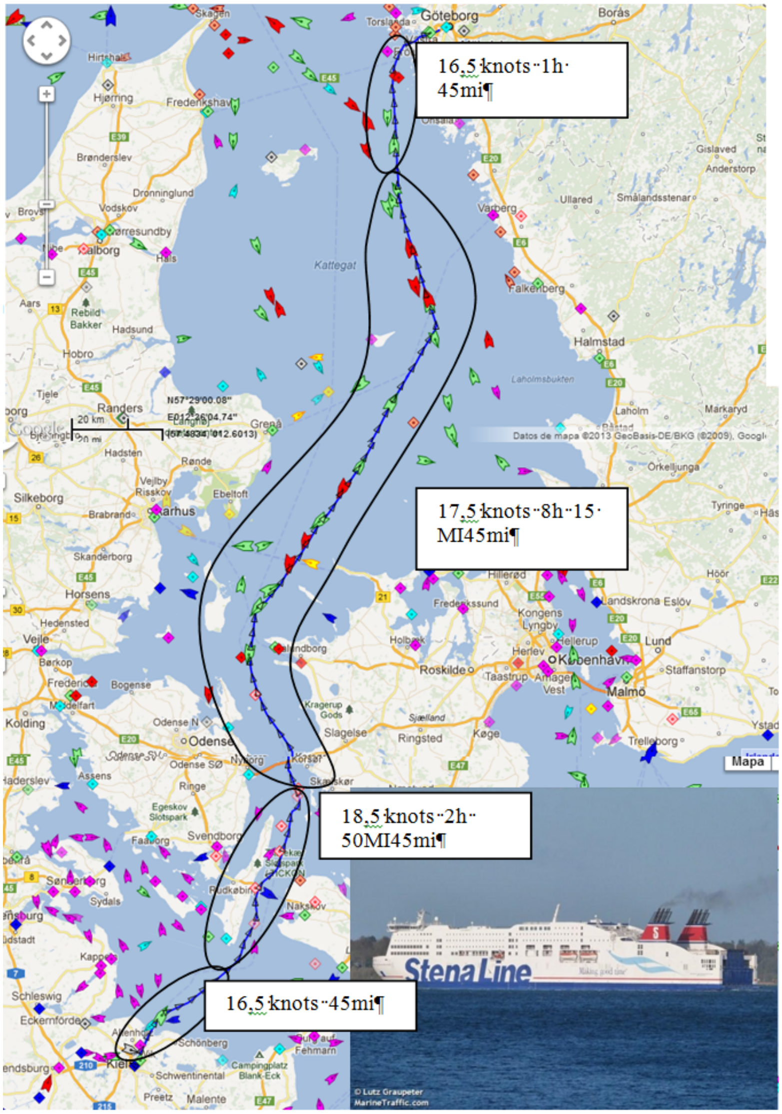


Fig. 29. Stena Scandinavica - Route Goteborg-Kiel

The following table shows, cruise emissions, calculated from the sections, speeds and times marked on the route: **1525.6 kg of NOx and 96332.7 kg of CO_2.**

time h	speed knots	F NOx/Knots Kg/h-knot	NOx kg
0,75	16,5	105,8	79,35
2	18,5	149,2	298,4
8,25	17,5	126,31	1042,1
1	16,5	105,8	105,8
			1525,6

h h	speed knots	F CO2/knots Kg/h-knots	CO2 kg
0,75	16,5	5634,6	4225,9
2	18,5	7941,9	15883,8
8,25	17,5	6722,4	55459,7
1	16,5	5634,6	5634,6
			81204,0

Fig. 30. Stena Scandinavica - Emissions of the route Goteborg-Kiel

As in the case of Sorolla ship, studied in the previous sections, with the average speed for this trip, of 17.5 knots, we see that we get a slight reduction in emissions.

time h	speed knots	F NOx/knots kg/h-knot	NOx kg
12	17,5	126,31	1515,7
h **h**	**speed** **knots**	**F** **CO2/knots** **kg/h-knot**	**CO2** **kg**
12	17,5	6722,4	80668,6

Fig. 31. Stena Scandinavica - Emissions at average speed

Reducing a single knot at this juncture, would reduce emissions even more, increasing the time of the journey by just 45 minutes.

time h	speed knots	F NOx/knots kg/h-knot	NOx kg
12,75	16,5	105,9	1350,2
Time **h**	**speed** **knots**	**F** **CO2/knots** **kg/h-knot**	**CO2** **kg**
12,75	16,5	5634,6	71840,8

Fig. 32. Stena Scandinavica - Emissions with reduction

The preliminary conclusions are:

CONCLUSION 1: Path planning reduces the level of emissions.

CONCLUSION 2: A 1 knot reduction in speed, in this case in a journey of 12h means significant emissions reductions, affecting the journey time by only 45minutes.

A further reflection;

CONCLUSION 3: The ship is carrying out all of its journeys at speeds well below the speed of design - 45-50% of its total propulsion.

2.- TRELLEBORG- SWINOUJSCIE

SHIP: WOLIN

Ro-Pax ship 31.409t displacement boat, 13.2000 kW propulsive power, designed for an average speed of 18 knots. The table shows the consumption and emission values obtained for different speeds.

Fig. 33. Wolin - Route Trelleborg- Swinoujscie

SPEED	knots	11	12	13	14	15	16	17	18	19	19,5
MMEE LOAD	%	18%	23%	30%	37%	46%	55%	66%	79%	93%	100%
CONSUMPTION	kg	474	615	782	977	1202	1459	1750	2077	2443	2641
NOx	kg	28,0	36,3	46,2	57,7	70,9	86,1	103,2	122,5	144,1	155,8
CO_2	kg	1765,6	2292,2	2914,4	3640,0	4477,0	5433,4	6517,2	7736,3	9098,6	9836,0

Fig. 34. Wolin - Consumption and Emissions as a function of the speed

Given the times and speeds recorded in this journey, emitting into the atmosphere are 321.3 kg of NOx and 17099,4 kg of CO_2.

time	speed	F NOx/knots	NOx
h	knots	kg/h-knot	kg
1	12,5	41	41
1,5	13	46,2	69,3
2,33	12,5	41	95,5
2,5	13	46,2	115,5
			321,3

time	speed	F CO2/knots	CO2
h	knots	kg/h-knot	kg
1	12,5	2184,0	2184,0
1,5	13	2456,7	3685,0
2,33	12,5	2184,0	5088,7
2,5	13	2456,7	6141,7
			17099,4

Fig. 35. Wollin - Emissions of the route

This run at a constant speed of 12.5 knots would already provide a small improvement in emissions, increasing the duration of the journey by only 10 minutes.

time	speed	F NOx/knots	NOx
h	knots	kg/h-knot	kg
7,5	12,5	41	307,5
h	speed	F CO_2/knots	CO2
h	knots	kg/h-knot	kg
7,5	12,5	2184,0	16379,8

Fig. 36. Wollin - Emissions at average speed

If we reduce this average speed by a half-knot, we see that the reduction affects us by increasing the travel time by half an hour.
The NOx emissions are reduced by about 12%. and CO_2 emissions are also reduced by 12%.

time	speed	F NOx/knots	NOx
h	knots	kg/h-knot	kg
7,8	12	36,3	283,1
Time	speed	F CO2/knots	CO2
h	knots	kg/h-knot	kg
7,8	12	1932,2	15071,5

Fig. 37. Wollin - Emissions with reduction of speed

Again we reach the same conclusions.

CONCLUSION 1: A constant speed all the way to reduce emissions without affecting its time

CONCLUSION 2: A ½ knot reductions leads to reducing emissions by 12%

CONCLUSION 3: Again we have an oversized ship with high installed propulsive power level in relation to the journey path.
The engine is operating at 25-30% of its charge. The optimal regimen therefore would work by 80%.

3.- SWINOUJSCIE - YSTAD

SHIP : KOPERNIK

Ro-Pax ship 9384t displacement boat, propulsive power of 8,826 kW, designed for an average speed of 17.5 knots. The table shows the consumption and emission values obtained for different speeds.

SPEED	knots	10	11	12	13	14	15	16	17	18	19	19,5
MMEE LOAD	%	13%	18%	23%	30%	37%	46%	55%	66%	79%	93%	100%
CONSUMPTION	kg	356	474	615	782	977	1202	1458	1749	2077	2442	2640
NOx	kg	21,0	28,0	36,3	46,2	57,6	70,9	86,1	103,2	122,5	144,1	155,8
CO2	kg	1118,1	1488,2	1932,0	2456,4	3068,0	3773,5	4579,6	5493,1	6520,6	7668,9	8290,4

Fig. 38. Kopernik - Consumption and Emissions at different speeds

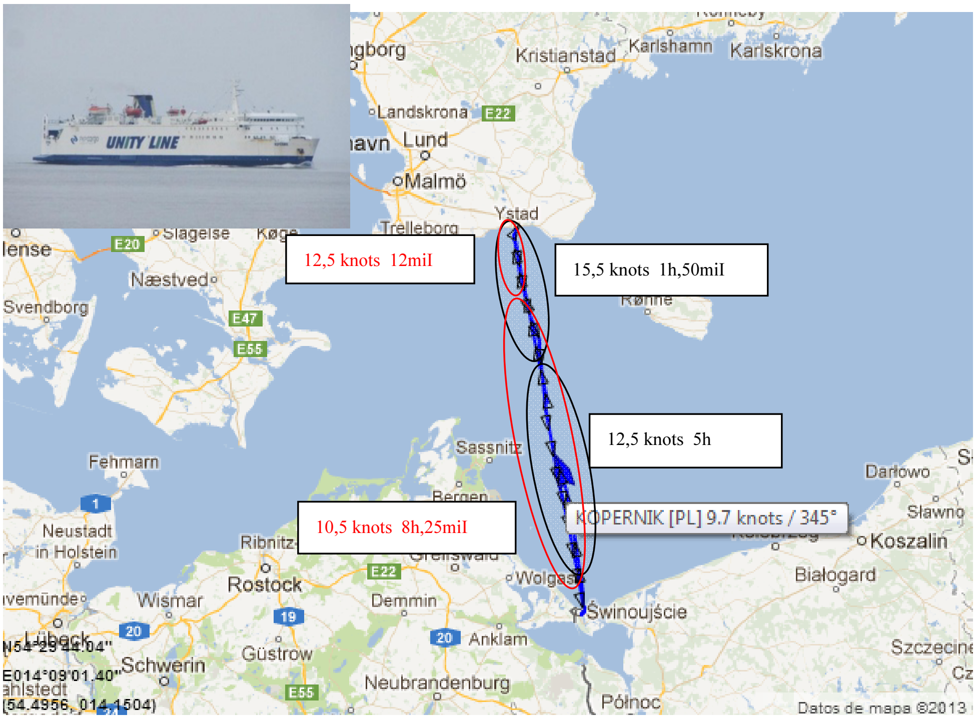


Fig. 39. Kopernik - Route Ystad – Swinoujscie, Swinoujscie – Ystad

In this case we will study the same journey in both directions, the one made from Ystad to Swinoujscie identified in black, and conversely made from Swinoujscie to Ystad identified in red.

Registered times and speeds are also identified in these same colors to left and the right of the path respectively. The colours have also been used to identify the to and from journey in the table.

Swinoujscie-Ystad				Ystad-Swinoujscie			
time h	speed knots	F NOx/Knots Kg/h-knot	NOx kg	time h	speed knots	F NOx/Knots Kg/h-knot	NOx kg
0,2	12,5	41	8,2	1,83	15,5	78,2	143,106
8,41	10,5	24,3	204,363	5	12,5	41	205
			212,6				348,1
time h	speed knots	F CO2/Knots Kg/h-knot	CO2 kg	time h	speed knots	F CO2/Knots Kg/h-knot	CO2 kg
0,2	12,5	2183,7	436,7	1,58	15,5	4163,6	6578,4
8,42	10,5	1294,3	10898,1	5	12,5	2183,7	10918,7
			11334,8				17497,1

Fig. 40. Kopernik - Calculation of emissions in both ways

As we can see at a glance, the journey along this route at 10.5 knots has great environmental rewards, but obviously in this case there is much change in time performance which is almost two hours apart. As in the previous examples, we could redo the calculations for the journey with average speeds in both directions, giving us a reduction in emissions.

We need to consider the reason for this difference between the two paths. This practice is repeated in many lines. Studying the data on the inputs and outputs of the ship in the various ports on the current path, we see that the Kopernik:

- Departure of Ystad daily between 9:35 and 9:45 in the morning.
- Navigate towards Swinoujscie for 5h 45mi. 6.5 h is the time stipulated by the company, counting and boarding maneuvers.
- Arrive at Swinoujscie at 15h.
- Departure of Swinoujscie at 20 h.
- Navigation towards Ystad. Between 8 and 9 am counting maneuvers.
- Arrival in Ystad between 4 and 5 am.

From the description it appears that the ship needs about 4.5 h for the operation of loading/unloading for both the ports.

The adjustment of routes appears to try and maintain a reasonable hour for the embarkation and disembarkation of passengers, bound for Swinoujscie embark on landing 8am to noon. Those traveling towards Ystad embark at 19h, staying on the boat and landing in the early hours of the morning.

Given that in both ports the ship needs for all its operations, an average of 4.5 h, and respecting that the ship needs to make the two paths in the same day, as is being currently done, 15 h are available for the back and forth journey.
Spreading these 15 hours for the two paths, we have an average of 7.5 hours each. An average speed of 12 knots, would allow us to make this journey in the 7 ½ hour period.
Calculating emissions for this new situation.

time	speed	F NOx/knots	NOx	IDA
h	knots	kg/h-knot	kg	VUELTA
7,6	11,95	36	271,8	
			271,8	543,6

time	speed	F CO2/knots	CO2	
h	knots	kg/h-knot	kg	
7,6	11,95	1908,0	14405,2	
			14405,2	28810,5

Fig. 41. Kopernik - Estimation of emissions at average speed

We see that this distribution between the two paths is practically at the point of balance, being almost at the same level of emissions generated to make the journey in two different times (6.5 and 8.5 h) to do both paths at 7.5 h.

You can aim for a much as positive conclusion, that despite the fact that usually route adjustment is done by assessing the commercial aspects, there are alternatives to these settings that have no environmental impact or further aggravate the situation. Companies should consider effective route planning and consider alternatives.

CONCLUSION 4: In many of the paths, the same premium cannot be achieved in terms of the environmental advantages. However schedules can be respected and customer expectations met. Good planning can meet these expectations without increasing emissions.

4 - MARIEHAMN - STOCKHOLM

SHIP: GABRIELLA
Another interesting route is made by the Gabriella ship, Ro-Pax with a displacement of 16562t, and a service speed of 21.5 knots.

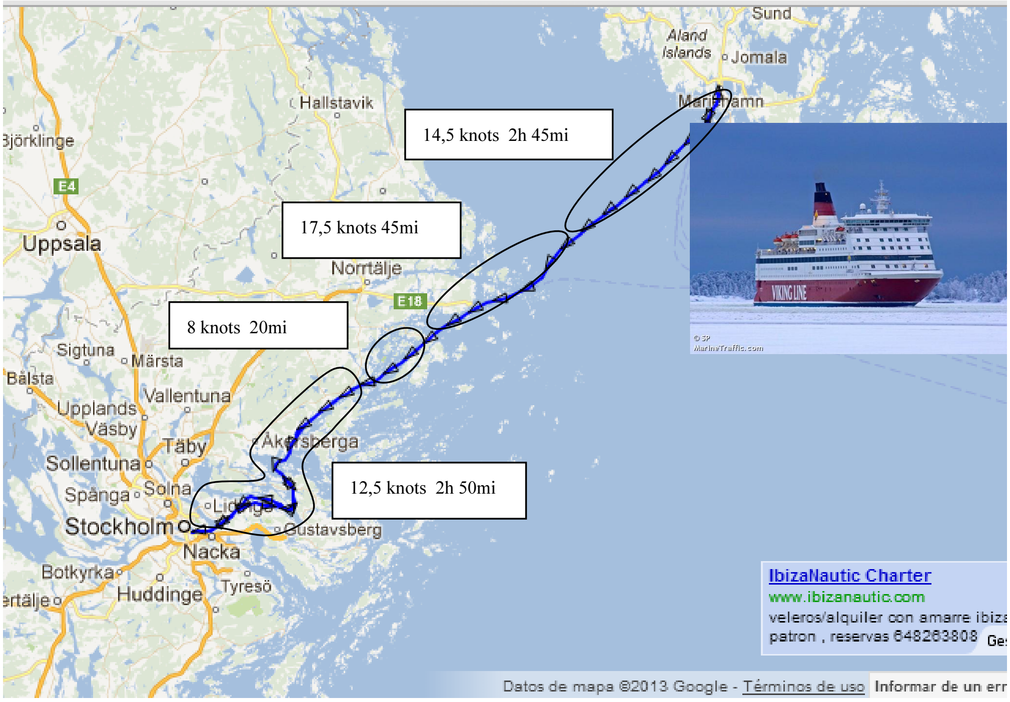


Fig. 42. Gabriella. Route Mariehamn -Stockholm

As in the previous example, we compute the charge, fuel consumption and emissions of the vessel's propulsive system to different speeds.

SPEED	knots	13	14	15	16	17	18	19	20	21	21,5	23
MMEE LOAD	%	18%	23%	28%	34%	40%	48%	56%	66%	76%	82%	100%
CONSUMP	kg	858	1072	1318	1600	1919	2278	2679	3125	3617	3882	4752
NOx	kg	50,6	63,2	77,8	94,4	113,2	134,4	158,1	184,4	213,4	229,0	280,4
CO_2	kg	2694,6	3365,5	4139,4	5023,7	6025,8	7152,9	8412,6	9812,0	11358,6	12189,4	14922,8

Fig. 43. Gabriella - Consumption and emissions at different speeds

From this we get again the total emissions from the system path propulsion.

time h	speed knots	F NOx/knots kg/h-knot	NOx kg
2,75	14,5	70,3	193,325
0,75	17	113,2	84,9
0,33	8	11,8	3,894
2,83	12,5	45	127,35
			278,2
time h	speed knots	F CO_2/knots kg/h-knot	CO_2 kg
2,75	14,5	3739,13729	10282,6275
0,75	17	6025,79245	4519,34434
0,33	8	627,967786	207,229369
2,83	12,5	2395,507	6779,2848
			21788,5

Fig. 44. Gabriella - Calculation of the emissions of the route Mariehamn - Stockholm

While the last two stages of the journey are conditioned by the sailing conditions, we have tried to adjust only the first two stages and look at a reduced ship sailing time of 45 minutes at 17 knots.

time h	speed knots	F NOx/knots kg/h-knot	NOx kg
3,5	15	77,8	272,227246
0,33	8	11,8	3,894
2,83	12,5	45	127,35
			272,2

time h	speed knots	F CO_2/knots kg/h-knot	CO_2 kg
3,5	15	4139,4	14488,0
0,33	8	745,0	245,8
2,83	12,5	2841,8	8042,3
			22776,2

Fig. 45. Gabriella - Calculation of the emissions at average speed

The table shows emissions have dropped slightly.

^

CONCLUSION 5: That for cases where the routes are conditioned by traffic, narrow passages, etc.

The programming can be done by omitting those phases where constraints do not allow us to modify the navigation system.

5- HELSINKI- TALLIN

SHIP: VIKING XPRS
The XPRS Viking, a Ro-Pax 19795t displacement and designed to sail at an average speed of 26 knots

Fig. 46. Viking XPRS. Route Helsinki- Tallin

SPEED	knots	14	16	18	20	22	24	25	26
MMEE LOAD	%	16%	23%	33%	46%	61%	79%	89%	100%
CONSUMPTION	kg	1249,3	1864,9	2655,3	3642,4	4848,0	6294,0	7114,0	8002,3
NOx	kg	73,7	110,0	156,7	214,9	286,0	371,3	419,7	472,1
CO2	kg	4653,8	6946,7	9890,9	13567,8	18058,8	23445,2	26499,6	29808,5

Fig. 47. Viking XPRS. Calculation of Consumptions and emissions at different speeds

Once the load has been obtained along with the fuel consumption and emissions for the different speed regimes, we will calculate the emissions path.

time h	speed knots	F NOx/knots kg/h-knot	NOx kg
0,33	14,5	81,4	26,862
0,16	19,5	199,2	31,872
1,75	21	248,8	435,4
0,16	19	184,2	29,472
			523,6

time h	speed knots	F CO_2/knots kg/h-knot	CO_2 kg
0,33	14,5	4358,4	1438,3
0,16	19,5	10600,5	1696,1
1,75	21	13239,8	23169,6
0,16	19	9805,8	1568,9
2,4			27872,9

Fig. 48. Viking XPRS - Calculation of emissions route Helsinki-Tallin

To follow the programmed path at a constant rate of 19.9 knots (20 knots practically), allows us to observe the time and reduce emissions. This helps avoid higher speeds.

time h	speed knots	F NOx/knots kg/h-knot	NOx kg
2,4	19,9	211,7	508,08
			508,1

time h	speed knots	F CO_2/knots kg/h-knot	CO_2 kg
2,4	19,9	11266,3	27039,2
			27039,2

Fig. 49. Viking XPRS - Calculation of emissions at average speed.

Emissions from this same journey made at 19 knots would be even lower.

time	speed	F NOx/knots	NOx
h	knots	kg/h-knot	kg
2,5	19	185,2	463
			463,0

time	speed	F CO_2/knots	CO_2
h	knots	kg/h-knot	kg
2,5	19	9805,8	24514,6
			24514,6

Fig. 50. Vicking XPRS – Calculation of emissions at reduced speed

NOx emissions have been reduced for this journey by 60kg of NOx and 3358kg of CO_2. A 11% reduction in NOx emissions and a 12% reduction in CO_2 emissions compared to the actual path. The only cost is an additonal travel time of 6 minutes.

6 - NYNASHAMN(SWEDEN) - VENTSPILS (LATVIA)

SHIP: SCOTTISH VIKING

For this ship the values of emissions have not been calculated, but it is of interest to identify a couple of observations that appear to the naked eye, especially along these longer paths.

First note that there is no forecast or determining of a constant speed for the route. The ship sails for about 5h at 14 knots, to increase thereafter 2,5h at 21.5 knots speed and reduce back again 1.5 h to 18.5 knots, to match the arrival with the provided ETA.

The 20 minutes at 8 knots could well be due to a maneuver or to pass a boat. To emphasize, this ship is a new ship, built in 2009, designed to sail at an average speed of 23.5 knots while its speed is 25.5 knots.

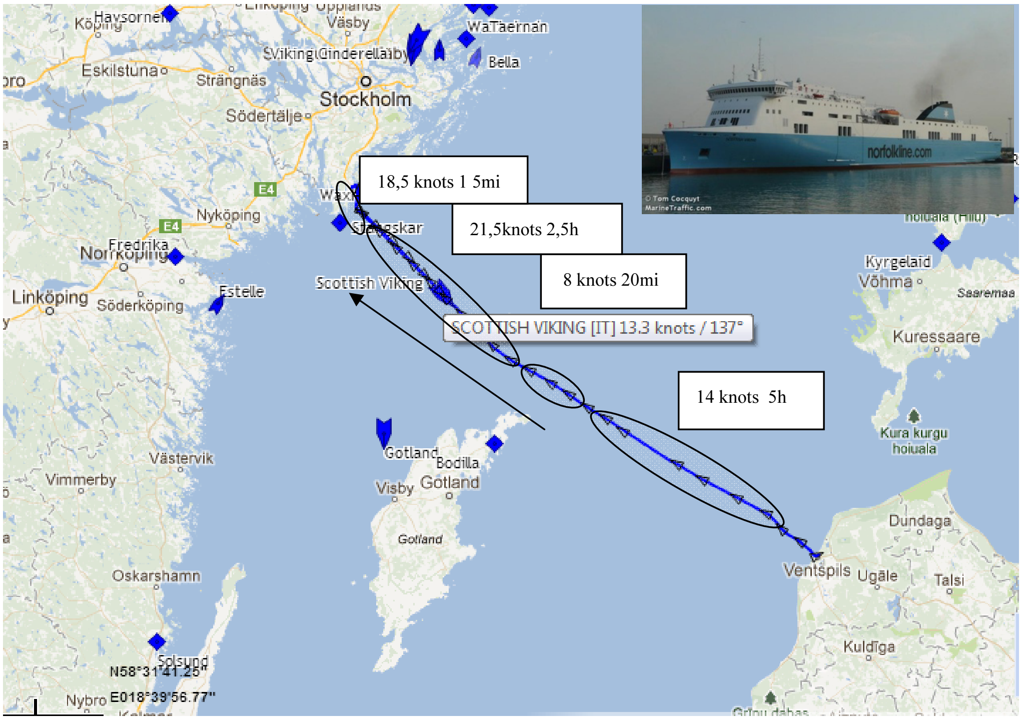


Fig. 51. Scottish Viking - Route Nynashamn – Ventspils

CONCLUSION 6: The maintenance of a constant speed is not planned in the day to day operations of ships.

CONCLUSION 7: New ships are being built are oversized to their routes

7- OSLO-KIEL

SHIP: COLOR MAGIC

This is one of the largest ships operating in the Baltic. We highlight its features as we did with the previous vessel:

- This is a new ship, built in 2007.
- Designed for a cruising speed 22.1knots.
- It is oversized in relation to the work done.
- A view of the changes in velocity in its trajectory, we see that it has a planned cruise speed.
- Apart from the 45 minutes at 12 knots for whatever reason. This route could be done at an average speed of 19 knots, keeping the schedules.

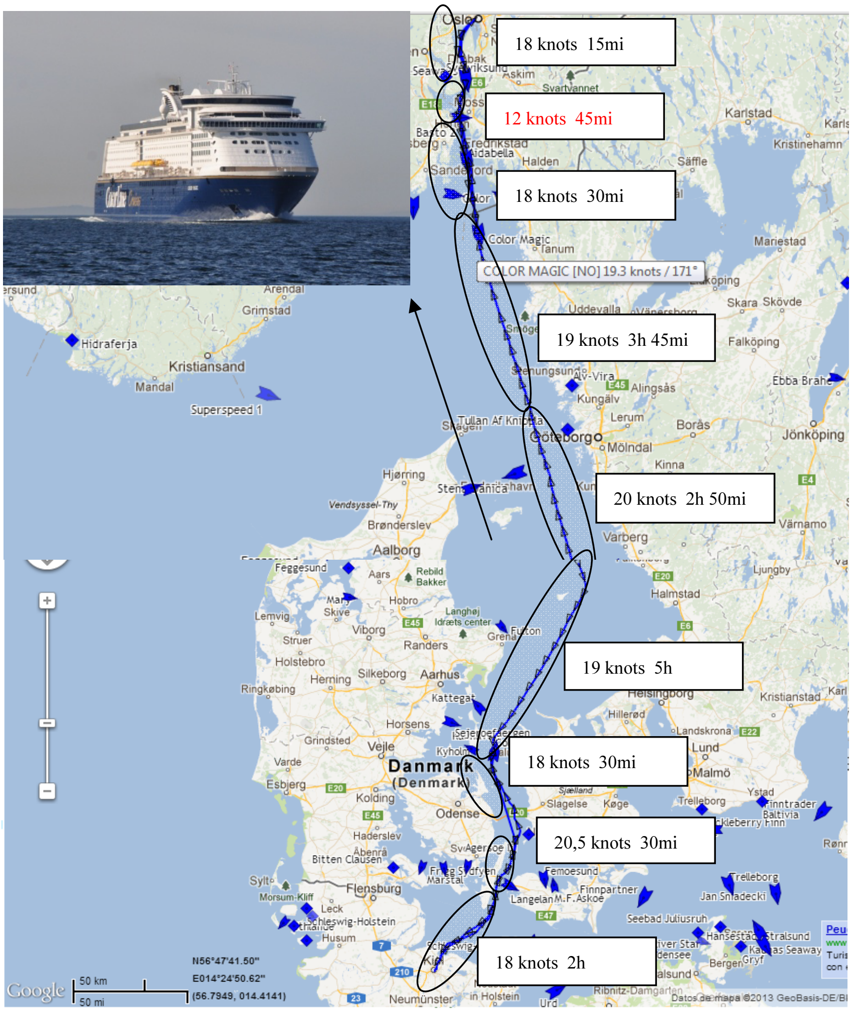


Fig. 52. Color Magic. Ruta Oslo-Kiel

2.3.2 Lost time at port - Programming scales

We saw in section 2.3.1, in the ship example - the variation/decrease in emissions we could get by lengthening the journey time by only 20 minutes. For some reason if the vessel is delayed in port then the ship is forced to increase its speed to respect and meet the timelines.

In the previous section, this route has been studied and we came to the conclusion that the same could be done at a constant speed of 19.2 knots.

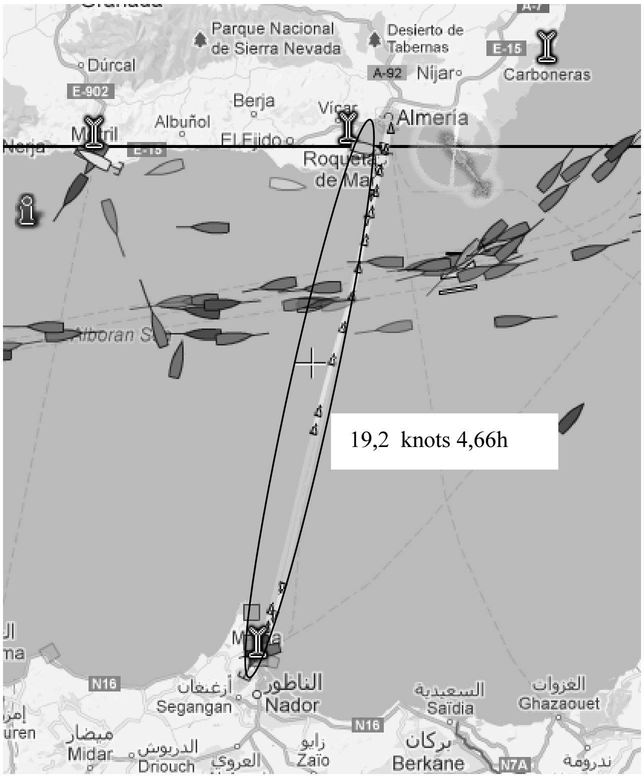


Fig. 53. Sorolla Ruta Almeria-Melilla

If due to some kind of delay or delay in loading, in management, in the maneuver, etc., the ship loses 20 minutes, then the time available for the journey will be at 4.33 h, so they had to increase the speed by more than one knot to 20.6 knots. This entails a considerable increase in emissions.

expected time journey				Fast journey, lost time			
time h	speed knots	F NOx/knots kg/h-knot	NOx kg	time h	speed knots	F NOx/knots kg/h-knot	NOx kg
4,66	19,2	142,1	662,186	4,33	20,6	182,6	790,658
			662,2				790,7
time h	speed knots	F CO_2/knots kg/h-knot	CO_2 kg	time h	speed knots	F CO_2/knots kg/h-knot	CO_2 kg
4,66	19,2	8336,5	38848,1	4,33	20,6	10296,3	44583,0
			38848,1				44583,0

Fig. 54. Sorolla - Delays in Port; Increase of speed and emissions during the travel

It recorded a significant increase in emissions of 128.5 kg NOx and 5734kg CO_2.

The increased emissions show:

- Measures are taken to minimize delays in loading and unloading operations in port.
- To relax or prioritize and improve the port arrivals.

Although this ultimately lies in raising awareness and showing the reality of these issues and factors.

CONCLUSION 8: The delays affect greatly increased emissions, and to respect the arrival time it becomes necessary to increase the speed.

Possible to define a new organizational model for greater flexibility to the inputs and outputs of these ships that are largely conditioned by their arrivals times.

CONCLUSION 9: Important to raise awareness, to eliminate or greatly reduce delays and think of the related environmental consequences.

2.3.3 Different settings – engine load stepped

Another aspect to consider is the propulsive power of vessels in relation to the working arrangements.
As summarized in paragraph 2.2.2.2. (studied in the project phase I), the 4 main engines of the ship during the underway manoeuvre, work at 10% of the maximum capacity. Also in navigation and given the speeds we have been discussing in section 2.3.3, the power developed in these is around 65% -70% of capacity.
One sees, that it would be interesting to have staggered engine configuration, which without subtracting system reliability allows us to have available or running only the necessary power with a small reserve margin.
The focus of this study is not to prove that the specific consumption decreases to about 80% for which the engines were designed. This is well known and we can easily appreciate the same by determining the turning points of the curve as presented by the manufacturer and explored in the previous sections.
The interest now is to see what happens with respect to the emissions to see if consumption appreciates in the same way at these points of inflection or not.
The following table shows how the specific consumption of the main engine, as expected, has its inflection point, i.e. its minimum, for powers of 70-80%, as well known.

$SFCO = 0,0093L^2 - 1,412L + 223,5$

LOAD	(%MCR)	10	13	20	40	60	65	70	80	85	90	100
Potencia neceasaria maniobra	kw	724										
Tiempo de maniobra t	h	1,5										
motores funcionando n	unid	4										
CONSUMO ESPECIFICO	kg	210,3	206,7	199,0	181,9	172,3	171,0	170,2	170,1	170,7	171,8	175,3

Fig. 55. Sorolla - consumption of the engines as a function of load

If we apply these same loads on the equation provided by the manufacturer of the engines installed on the ship we can determine NOx emissions.

$F_{g\text{-}NOx}=(-0,002L^2+0,5351L+39,714)$

Load Factor	%	10	13	20	40	60	65	70	80	85	90	100
Emmision Factor kg NOx	kg/t fuel	44,87	46,33	49,62	57,92	64,62	66,05	67,37	69,72	70,75	71,67	73,22

Fig. 56. Sorolla - Emissions of NOx as a function of the load of engines

We see that the behaviour is the same - as the load increases so does the level of NOx emissions.
By contrast, and assuming that for each ton of fuel consumed three tonnes CO_2 are obtained, it is obvious that the representing curve behaves in a manner similar to consumption.
The table below reflects the changes in emissions produced by the navigation of the Sorolla ship in port, for 1, 5h equivalent to its entry and exit manoeuvre. Instead of the burden taken by the 4 engines as the utilised capacity is very low of 10%, it could do with 3, 2 or even with a single engine.

For this type of calculation, the feasibility and the safety of work under these conditions is neglected, as the ship is not designed for this.

POWER PROPULSION IN MANEOUVER:			2896 kW	
Number of engines running:	**4**	**3**	**2**	**1**
DevelopmentPower for each one	724	965	1448	2896
Percentage of load	10%	13%	20%	40%
SFOC	223	207	199	182
Yotal power developed	2896	2896	2896	2896
Time of maneouver	1,5	1,5	1,5	1,5
Total fuel consumption during maneouver	968,712	899,2	864,5	790,608
CONSUMTION DECRESE →				
Calculation of NOx emissions				
Emission factor kg-NOX	39,77	46,33	49,62	57,92
Emission of NOx	38,5	41,7	42,9	45,8
NOx EMISSIONS ARISE →				
Calculation of CO_2 emissions				
Emissions of CO_2	2906,136	2698	2593	2371,82
CO_2 EMISSIONS DECRESE →				

Fig. 57. Sorolla - in manoeuver; Evolution of consumption and emissions based on whether the load is spread over 1, 2, 3 or 4 engines

The same represented in a graphic:

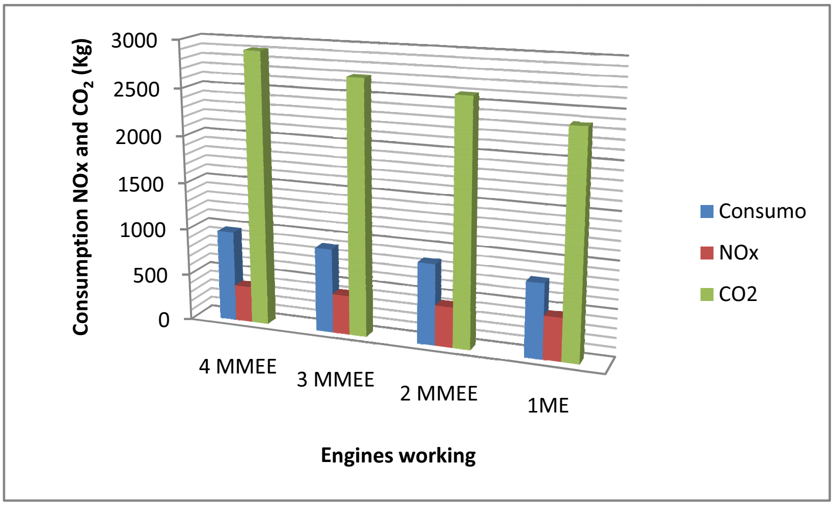


Fig. 58. Sorolla - Development of consumption and emissions according to distribution of load to 1, 2, 3, 4 engines

It can be seen therefore that the situation in terms of consumption and CO_2 emissions improves from 10% work load to 40% on the same engine.

The reductions in consumption and emissions would be higher by having smaller engines or staggered, one of them could do the work at 80% capacity.

> A better use of motors, i.e. working these on a 70 or 80% of their charge, implies a reduction in consumption and a reduction in CO_2 emissions.
>
> NOx emissions increase by contrast as the loaded engines work at high temperatures.
>
> New designs and auxiliary counting dimension in the usual regimes should facilitate work at 80% of the power propulsion.

2.3.4 New Fuels

Currently there are competitive alternatives to fuel oil and diesel oil such as the use of gas engines, dual motors or liquefied gas.

Maybe not for a 100% conversion but for switching regimes for port stay, auxiliary engines with these new forms of energy, would be a good option for the future.

Gas has no great advantages from an environmental point of view:
CO_2 emissions:
Natural gas and other fuels produces CO_2, however, due to high hydrogen to carbon ratio of the molecules, their emissions are 25-30% lower than those of fuel oil.

Nox emissions:
Nitrogen oxides are produced in the combustion when combined nitrogen radicals, from the fuel itself or, the air itself combust with the oxygen. This phenomenon occurs in high temperature reactions, especially industrial processes and reciprocating engines, handing proportions of 95-98% of NO and NO_2 2-5%. These oxides, due to their acidic nature, together with SO_2 contribute to acid rain and the formation of "smog".
The nature of the gas (the combustion takes place in the gas phase) allows to achieve a more perfect mixture with the combustion of air which leads to more efficient and complete combustion with less excess air.
The very composition of natural gas generates 2.5 times less NOx emissions than fuel oil.

SO_2 emissions
This is the main cause of acid rain, which in turn is responsible for the destruction of forests and lake acidification. Natural gas has a sulfur content lower than 10 ppm (parts per million) as odorant, so that emission of SO_2 in combustion is 150 times lower than that of gas-oil, and 2500 times less than that emitted by fuel oil.

Solid particles
The natural gas is characterized by the absence of any impurities and debris, which rules out any soot particles, soot, smoke, etc. and also permits, in many cases the use of the combustion gases directly

Given also that the relationship between theoretical usable heat in the exhaust gases and the cooling is very similar to the high performance gas engine and diesel engines operating on fuel oil or diesel. The absence of sulphur oxides in the flue natural gas defines a higher utilization of the heat in the production of heat, hot water or superheated water.

Having gas auxiliary engines also could allow heat recovery stew of these gases in port, thus preventing further operation of auxiliary boilers.

While the price of gas engines is somewhat higher, it is well amortizable:

- The life of the gas engine cogeneration tested so far and the auxiliary generators is double the hour lifetime of conventional engines.

- The cost of maintaining the gas engine is less than the cost of maintaining diesel engines or fuel oil.

2.3.5 Supply power from ground for stays in port

In paragraph 2.2.5 of this chapter, we study the consumption and emissions of our ship in port – even by the hour, so we can extend it to different types of stay.

Results obtained were:

FEATURES	CONSUMTION	EMISSIONS NOx	EMISSIONS CO_2
at berth AAEE 2 auxiliar working 50%, 1h	322kg	16,9kg	1117,8kg
at berth auxiliar boiler, 1h			269,7kg

Fig. 59. Sorolla -Emission of the auxiliary equipment

If we consider the data, we see that the vessel in question, in the worst loading conditions and occupation, needs in port, 2 motor-generators running at 50% 1620kW and 278kW for the operation of an auxiliary boiler for hot water.

In total for an hour of stay, the ship needs 1898kW.
And emits 22.6 kg / h of NOx and 1387.4 kg / h of CO_2.

An alternative would be to put in place ground supply of power for these generators, which:

- Is on the one hand more efficient and causes lower emissions and on the other helps in
- Off shoring the point of emission concentration in major ports and adjacent cities.

If we use the parameters described in the previous section, and assuming that this power could well be given from a gas-fired generation plant located on the outskirts of Barcelona, we have:

The 22, 6 kg / h of NOx produced by the ship is reduced to 9.04 kg / h.
The 1387kg / h of CO_2 produced by the ship is reduced to 971 kg / h
De-location of the point of issue. While it is important to reduce emissions another key aspect is to avoid the concentration of all emissions in the same area as the port.

2.3.6 Overview of other RO-PAX who frequent our ports – design considerations for new construction

For our study, we have developed two databases, one of which comes from the previous information collected and also relates to these ships and their stay in the port of Barcelona for which we also have the actual emissions for during manoeuvring and the port stays for these ships.
A second data set with other ships of the same features and operating in the Baltic Sea which is an area currently being threatened by high pollution in Europe by new construction.
The first group has been divided into two, one group that would be the Ro-Pax and the second with Ro-Ro vessels intended to carry cargo over.

So we have:

- Group 1. Ro-Pax Barcelona (identified with A)
- Group 2. Ro-Ro Barcelona (identified with numbers)
- Group 3. Ro-Pax Baltic(identified with B)
- Ro-Pax New (identified with C)

At the end of the document, as an attachment, is a table from which all the data that have been used for the analysis come from.

A general way in the graphs was to use the colour code described below:

Displacement	BLUE
GT	BROWN
MMEE Power	GREEN
Aux. Power	RED
Service Speed	ORANGE
NOx emissions	BLACK
CO_2 emissions	GREY

Fig. 60. Table of colours

Relationship between the displacement, the GT and the main and auxiliary power installed for Ro-Pax

Ref. nº	Displacement (t)	GT	MMEE (kW)	P Aux (kW)
1c	2200	6554	36000	1890
2c	3400	4313	5292	1000
3c	5500	9844	16000	3000
4c	5827	8082	16000	2790
1a	7547	11032	5808	2800
2a	7780	12705	15300	
5c	8099	17729	9000	9088
6c	8227	14551	8640	3865
7c	8600	12670	13440	4530
8c	8742	7882	31680	5100
9c	8907	13906	8640	3865
3b	9589	13144	8826	5057
2b	10907	14221	12460	6230
3a	11087	17955	17608	4192
4a	11505	16537	13240	1600
4b	14739	22874	13200	3300
5b	15515	35492	23760	8192
5a	15797	23933	31680	5840
6a	16555	26916	28960	7850
7a	16800	25028	23760	6400
8a	16826	22152	23760	5840
10a	16826	22152	23760	5840
9a	16826	22152	23760	5840
10c	17754	27510	21600	9000
11c	18680	35966	21600	5450
12a	19067	39139	23040	6450
11a	19067	35186	25920	6900
6b	19750	35918	40000	3000
7b	19872	39191	20760	6470
13c	20223	33940	39100	13360
14c	20418	35923	38400	14440
15c	20418	35923	38400	14440
1b	20623	15187	17600	3520
17c	21455	33690	21600	7000
16c	21455	33690	21600	7000
18c	21464	28460	21600	6392
19c	21469	28460	21600	6392
20c	21540	40975	26240	9264
22c	26813	47592	30400	18332
21c	26813	47592	30400	18332
8b	27828	57958	25920	10000
24c	33295	75027	31200	17600
25c	33700	64039	33600	11000

Fig. 61. Ro-Pax ships

As shown in the table, for this first analysis all the Ro-Pax were grouped together.

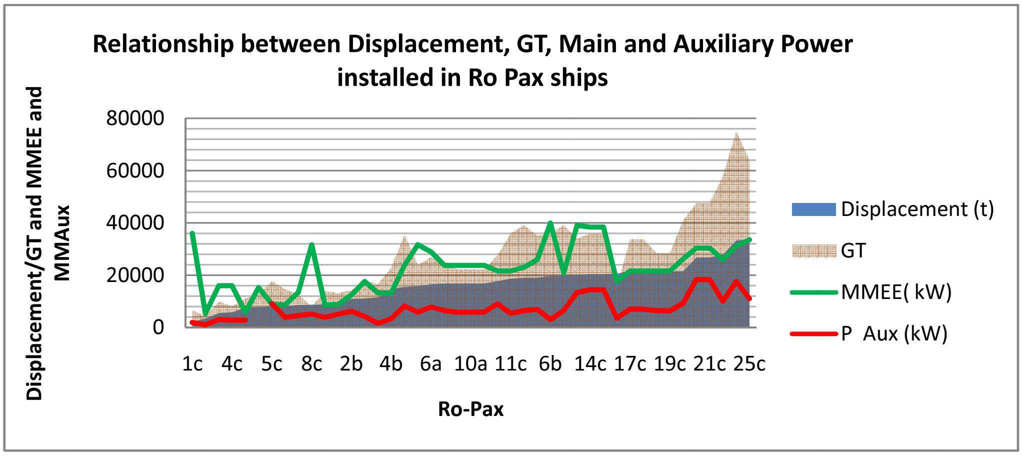


Fig. 62. Ro-Pax. Relationship between Displacement, GT, Main and Auxiliary Power installed in Ro Pax ships

Analysing the graph shows:

The available propulsive power on ships does not correlate with displacement or GT.

The propulsive power seems to be installed in stages, finding a large swath of vessels, between 5b and 8b, equipped with a very similar propulsive power, and its different movements of 15515t to 27828 t, respectively.

Below a lower displacement of 15000t, i.e. from ships 3c to 4b, we see what would be a previous step. 3c and 4b vessels are entitled to a displacement of 5500t and 14739t respectively and have 16000kW installed propulsion power and 13200kW. For the displacement of 5500t the ship has more power than it requires - 16500kW.

For these large oversized vessels, with these features, we mark the trend of the data. We noted on the graph, vessels 1c, 8c, 3a, 5a, 6b, 13c, 14c, y15c, in which the propulsion power is not only high for the stage but apparently increases exaggeratedly.

If we represent the propulsive power of these vessels with the average speed of the same design, we can clearly see how the high power we detected before corresponds to those vessels designed with a higher service speed.

All the vessels outlined above 1c, 8c, 3a, 5a, 6b, 13c, 14c, y15c, with blunt parallel design for speed, reaching values well above this average of 22 to 23 knots.

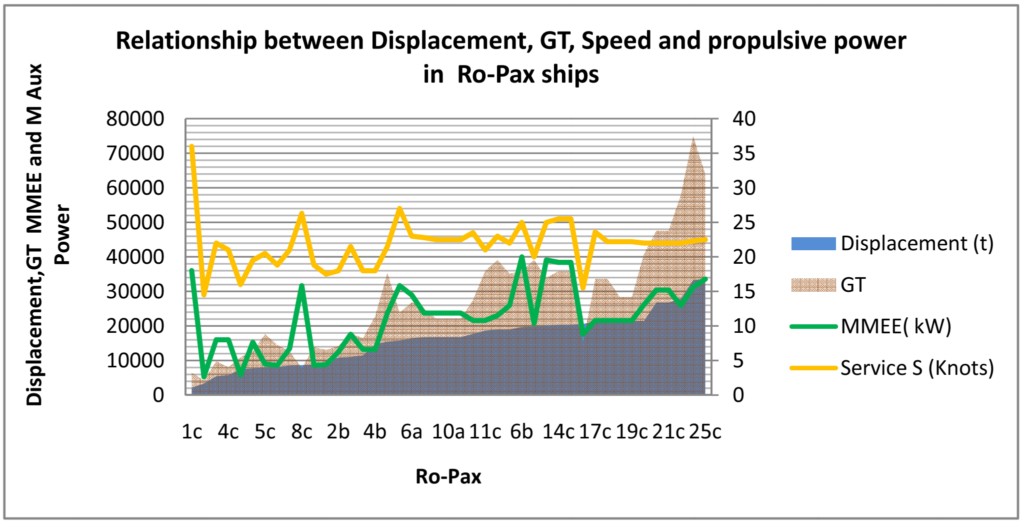


Fig. 63. Ro-Pax - Relationship between Displacement, GT, Speed and propulsive Power

CONCLUSION: Power available in propulsive stages in oversized ships is more

CONCLUSION: The large installed propulsive power peaks correspond to high vessel design speed.

The graph below shows the main and auxiliary power installed in these ships, now sorted by installed propulsive power.

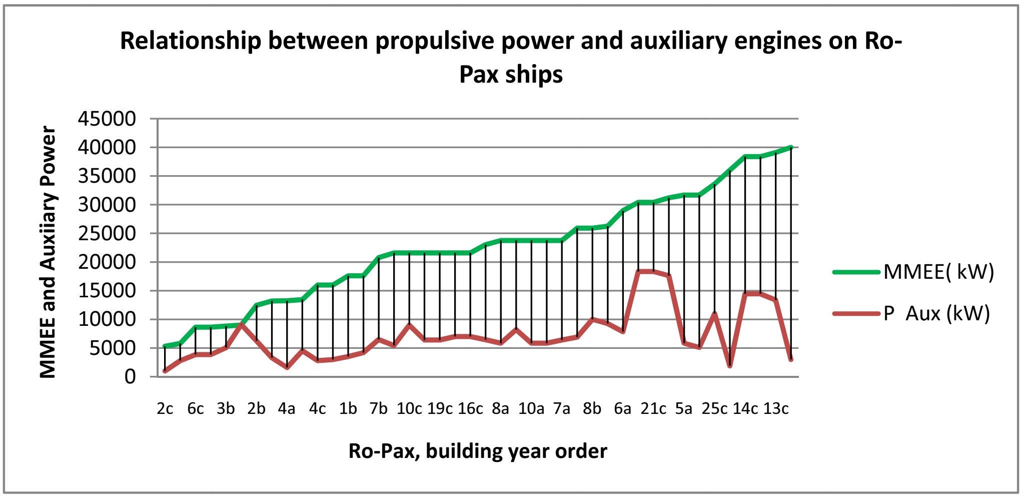


Fig. 64. Ro-Pax - Relationship between propulsive power and auxiliary engines on Ro-Pax ships

This shows the relationship between the two powers, with the installed power of approximately 25% to 35% of the principal, although it is true that there are ships have far superior power generation - to highlight the case of a 5c vessel, in which the auxiliary power exceeds the propulsive power.

Comparing the installed auxiliary power with the design speed:

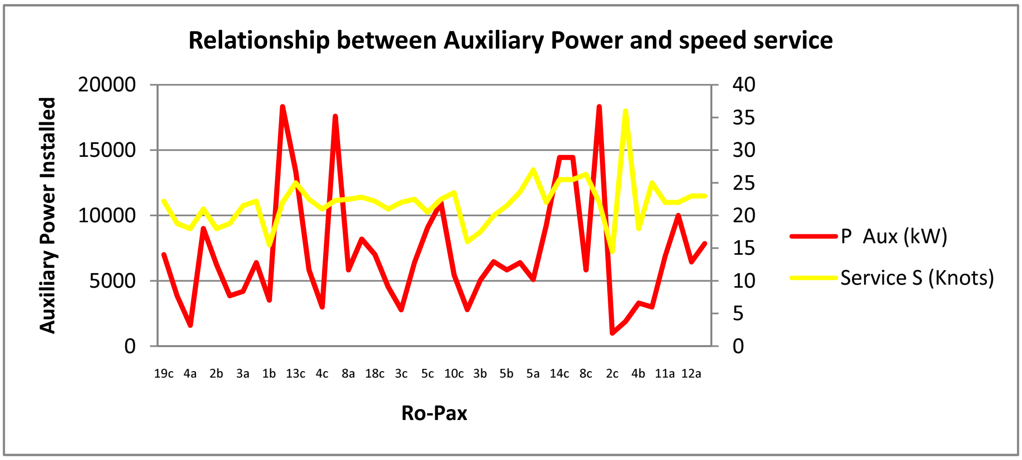


Fig. 65. Ro-Pax. Relationship between Auxiliary Power and speed

CONCLUSION: Auxiliary power is between 25% and 35% of the prime power installed.

CONCLUSION: There is no relationship between electrical output and the higher design speeds.

Relationship between displacement, GT and the main and auxiliary power installed on Ro-Ro

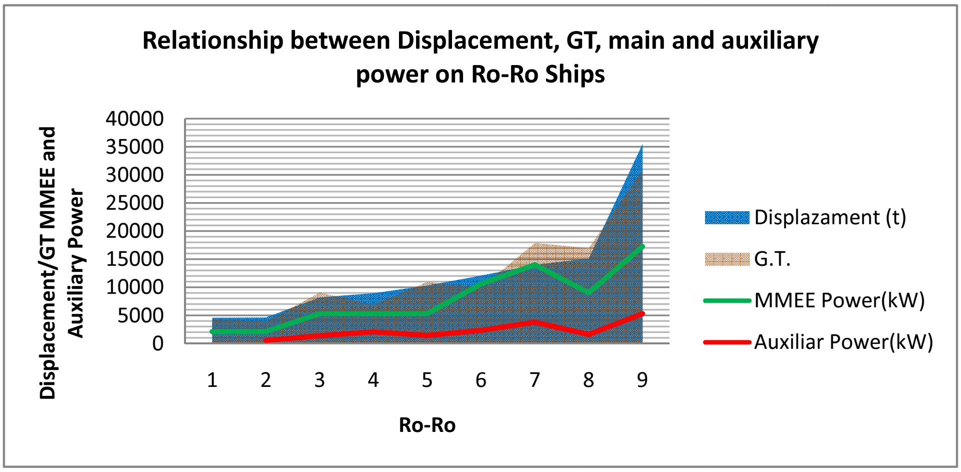


Fig. 66. Ro-Ro - Relationship between Displacement, GT, main and auxiliary power on Ro-Ro Ships

This graph represents the correlation between the displacement, GT, propulsive power and the installed electrical power on Ro-Ro vessels.

As in the former case, it can be seen that there is proportionality with the propulsive installed power. The installed power is between 25% and 30% in all cases, except for one vessel.
Comparing the propulsive power with speed, it can seen that there is a similarity between the curves, but the peaks are not so severe, as the operating speeds of this set of vessels in proportion.

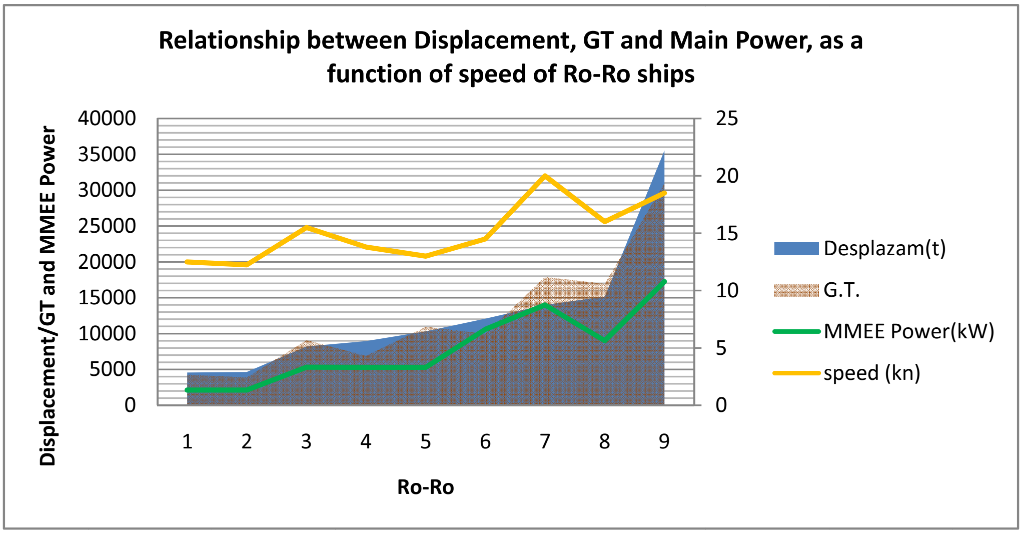


Fig. 67. Ro-Ro - Relationship between Displacement, GT and Main Power, as a function of speed

CONCLUSION: The installed propulsive power on ships is not adjusted directly with the displacement or the GT of the vessel concerned though you can see the upward trend.

CONCLUSION: The large installed propulsive power peaks correspond to high vessel design speed.

CONCLUSION: Auxiliary power is between 25% and 35% of the prime power installed.

Relationship between different parameters of the ship and registered emissions both manoeuvre and in port by Ro-Pax vessels Barcelona.

nº	NºIMO	Displacement	Ship Yard	Building year	SSC C	Kg NOx h maniov ring	Kg NOx h Port	G.T.	MMEE TOTAL(kW)	2s/ 4s MMPP	Auxiliary Power(kW)	normal speed
1a	9031997	7547	UNL VAL	1993	BV	45,8	8,7	10971	5808	4T	2800	16
2a	7813937	7780	HARLAN	1980	LR	53,04	10,1	12705	15300	4T		19,5
2a	7816874	11087	JOS L ME	1979	BV	75,69	14,4	17955	17608	4T	4192	16
4a	7356252	11505	NEW SO	1976	LR	69,04	13,1	16537	13240	4T	1600	18
5a	9086588	15797	SCHINCH	1995	LR	99,92	19,0	23933	31680	4T	5840	27
6a	9217125	16555	BARRER	2001	BV	112,4	21,3	26916	28960	4T	7850	23
7a	9237242	16800	IZAR CO	2002	LR	105,1	19,9	25028	23760	4T	6400	22,8
8a	9147291	16826	SRL SEVI	1958	LR	92,49	17,5	22152	23760	4T	5840	22,5
9a	9181091	16826	SRL SEVI	2000	LR	93,3	17,7	22152	23760	4T	5840	22,5
10a	9147306	16826	SRL SEVI	1999	LR	92,49	17,5	22152	23760	4T	5840	22,5
11a	9100267	19067	NUOVI C	1996	LR	146,9	27,9	35186	25920	2T	6900	22
12a	9015747	19067	NUOVI C	1994	RINA	163,3	31,0	39139	23040	4T	6450	23
13a	7818729		THE HAK	1979	NKK	114,2	21,7	7261	4413	4T	1200	15
14a	7501613		K ROGER	1976	GL	47,38	9,0	9079	8826	4T	2160	19,5
15a	7637149		VEROLM	1978	LR	56,38	10,7	13505	16184	4T	3200	21
16a	9265421		IZAR CO	2005	BV	83,6	15,9	20024	25154	4T		22
17a	9350680		NUOVI C	2007	RINA	104,2	19,8	25058	25200	4T		24,5
18a	9350692		NUOVI C	2007	RINA	98,17	18,6	25058	24600	4T		24,5
19a	7394759		NAIKAI S	1975	HELEN	106,3	20,2	25460	20596	4T	3520	21,5
20a	9287584		CANTIER	2004	RINA	109,8	20,8	26400	21600	4T		23,5
21a	9349760		CANTIER	2007	RINA	110,6	21,0	26500	21600	2T		23,5
22a	9208071		SAMSUN	2001	GL	132,5	25,1	30860	50424	4T	9200	28,5
23a	9015735		NUOVI C	1993	ABB	136,7	25,9	32777	23040	4T	6920	23
24a	9143441		NUOVI C	1998	RINA	164,9	31,3	39739	25952	4T		23
25a	9214276		NUOVI C	2002	RINA	205,7	39,0	49257	67200	4T	9440	28,5
26a	9214288		NUOVI C	2003	RINA	205,7	39,0	49270	67200	4T	9360	28
27a	9131527		FINCANT	1998	DNV	109,3	20,7		25020			22

Fig. 68. Ro-Pax Barcelona

Graphics for the relationship between displacement and NOx emissions:

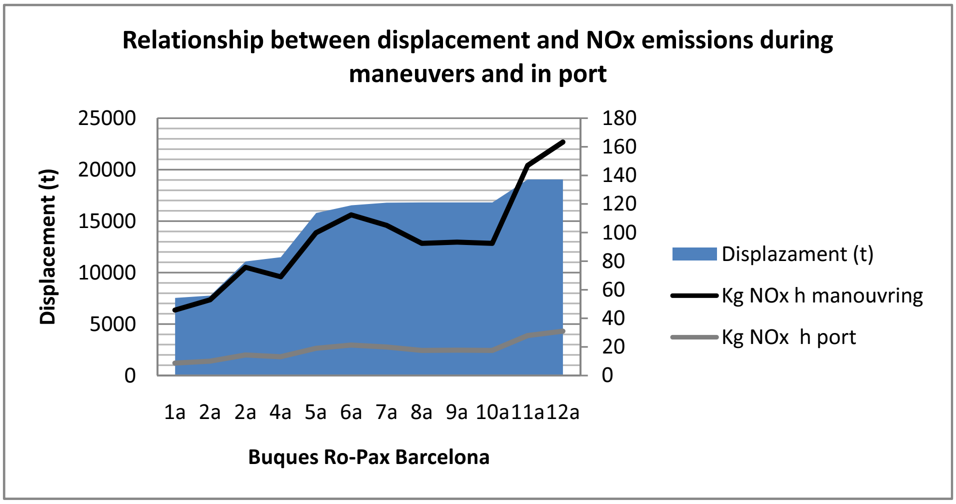


Fig. 69. Ro-Pax Barcelona - Relationship between displacement and NOx emissions during manoeuvers and in port

The graph shows the relationship between the displacement of vessels, and NOx emissions measured during manoeuvres in and out of the port of Barcelona, as well as the emissions during their stay in the port.

Registered emissions for manoeuvring therefore correspond to those issued by the propulsion equipment and auxiliary generators in service. Registered emissions correspond to the auxiliary port and a boiler or extra combustion equipment .

Viewing the graph shows the tendency for manoeuvre emissions to increase in the same direction as the displacement, meaning that the greater the displacement, the greater are the emissions, but this is not completely true, as we have an area in the graph for the vessels between 7th and 10th among which the displacement increases and so do emissions but not at a steep rate. The emissions in port also show the same upward trend, although this is more than having an operational reason. It seems to be due to the proportionality between the power generator and installed propulsive power.

Graph corresponding to the relationship between GT and NOx emissions:

The following graph compares the same measures of NOx emissions for both manoeuvring and in port, comparing with the GT of the ship.

The GT unit volume accounts for all closed volume; warehouses, depots, machine, lockers, accommodation, bridge etc. and there seems to be a direct relationship between this and NOx emissions during manoeuvring.

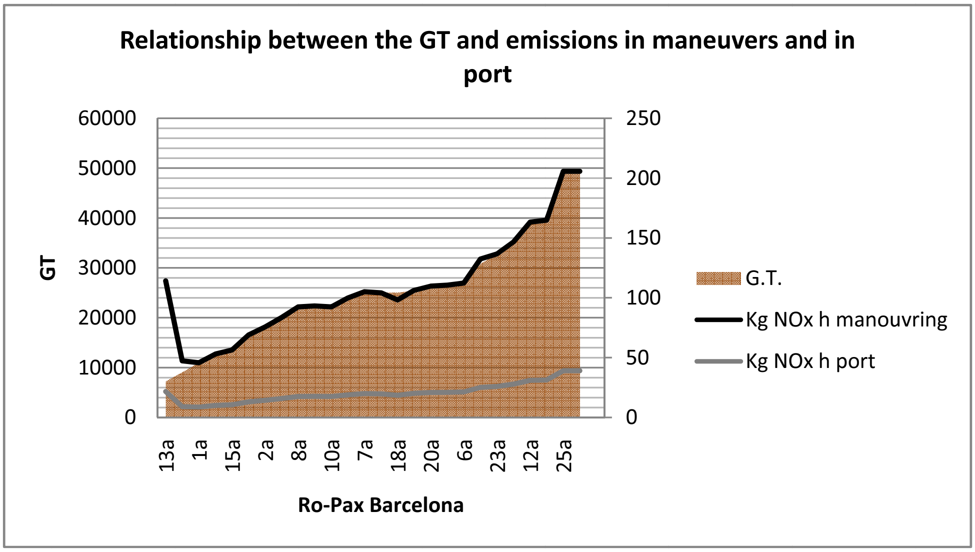


Fig. 70. Ro-Pax Barcelona - Relationship between the GT and emissions in maneuvers and in port

<u>Graph corresponding to the ratio between the propulsive power and speed of the vessel design and NOx emissions h manoeuvre:</u>

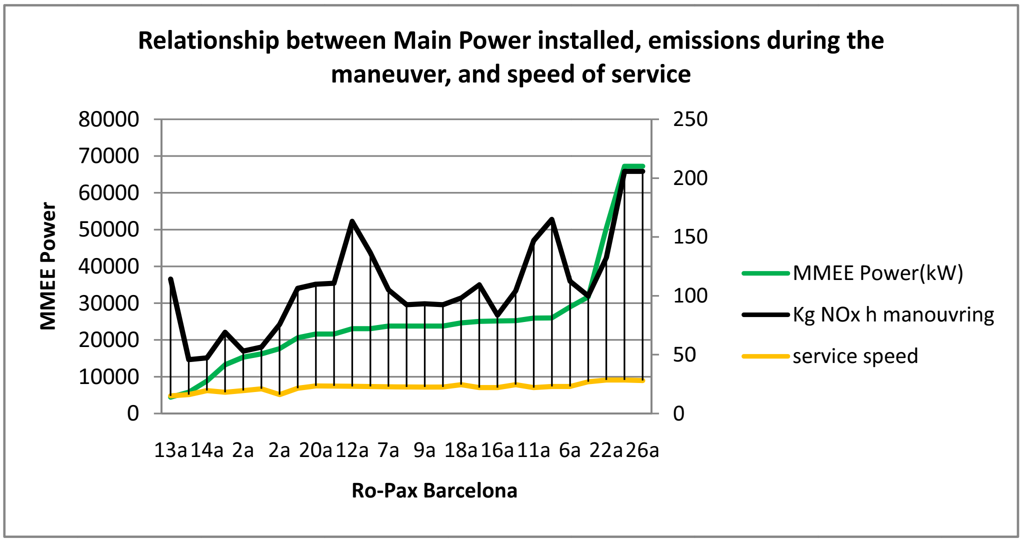


Fig. 71. Ro-Pax Barcelona - Relationship between Main Power installed, emissions during the maneuver and service speed

Unable to determine if there is a relationship between actual emissions and the installed power.
This large difference between the curves, further confirms that the oversized ships are trying to reach high speeds. From the emission level obtained, it is clear to say that the whole engine is working at different rates of charge to perform the same manoeuvre that usually can be carried out at a constant speed of 6 knots.

Graph corresponding to the ratio between the electric power installed on the ship and the NOx emissions per hour for stay in Port:

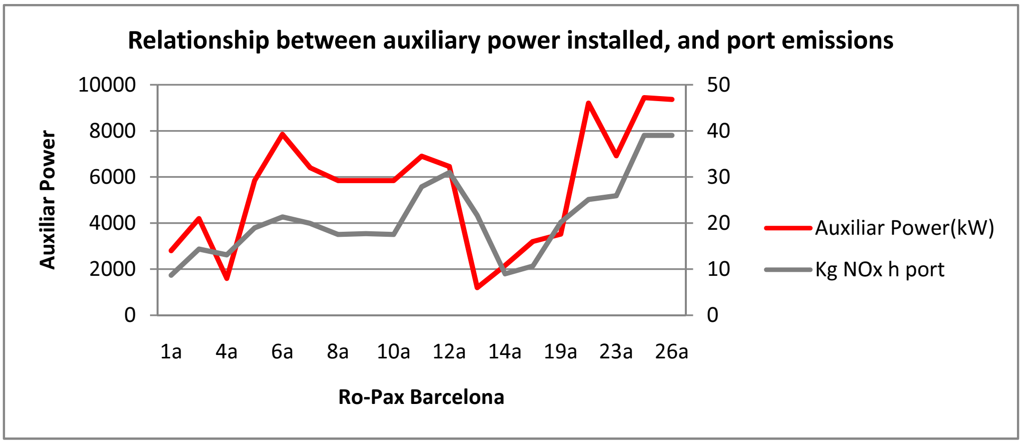


Fig. 72. Ro-Pax Barcelona - Relationship between auxiliary power installed and port emissions

Unable to say if there is a complete correlation from the graph. However there is a certain parallelism between the two curves.

Note that the emissions taken into account in this case are not only those produced by the generators but also the potential emissions from hot water boilers needed in port. As standard practice only the principal has recovery boilers coupled.

Relationship between different parameters of the ship and registered emissions for both manoeuvring and in port for Ro-Ro Barcelona.

nº	NºIMO	Displacement	Ship Yard	Building year	SSCC	Kg NOx h Port	G.T.	MMEE TOTAL(kW)	2s/ 4s MMPP	Auxiliary Power(kW)	normal speed
1	8203567	4583	ISKNG W	1983	GL	5,2521	4291	2120	4T		12,5
2	7812921	4653	DEUSCHE	1979	GL	47,42	3887	2118	4T	552	12,5
3	8009052	8210	GALATI	1984	DNV	11,109	9088	5300	4T	1375	15,5
4	8521945	8955	N SCHIFF	1985	RUSIAN	9,3135	6894	5296	4T	2080	13
5	8030283	10330	ASTANDE	1983	LR	14,579	10957	5296	4T	1440	13
6	8306589	12092	S THESEN	1984	ROMA BV	12,435	9983	10598	4T	2344	14,5
7	9142641	14004	HR & SPE	1997	BV	27,515	17907	14000	4T	3796	
8	7800746	15166	N ORESU	1978	DNV	24,355	16947	9000	4T	1615	16
9	7931765	35548	PUERTO	1982	LR	43,02	30969	17249	2T	5315	18,5
10	8996712	_	NS INDU	2000	DNV	26,777	236				
11	7531266	_	SHIMON	1977	BV	11,35	3629	8826	4T	1920	18,25
12	9119397	_	VA ASTILL	1997	LR	9,7198	7606	7400	4T	2424	17
13	7708297	_	SHIMON	1978	BV	11,491	8393	8826	4T	1920	21
14	8030295	_	ASTANDE	1984	LR	16,422	8762	52960	4T	1620	13
15	8502200	_	GALATI	1984	ROMA GL	13,942	9160	8826	4T	1840	17
16	7725130	_	ORP SHIZ	1979	LR	17,459	12076	5913	2T	2760	15,25
17	9129598	_	I CANTIE	1996	LR	33,192	18725	11120	2T	3140	19,7
18	9138783	_	ZIO VIAR	1998	DNV	28,667	21104	23040	4T	6400	22
19	8024284	_	SHIMA O	1981	NKK	40,536	27087	8826	4T	1320	18
20	7705960	_	IBISHI NA	1979	LR	54,076	38963	22185	2T	7100	20,5
21	7705958	_	IBISHI NA	1978	LR	52,614	38963	22185	2T	5950	20,5
22	9277802	_	IIA STOC	2003	DNV	78,586	57718	15540	2T	4410	20

Fig. 73. Ro-Ro in Barcelona

We perform the same analysis as above, but now with the data obtained from Ro-Ro ships.

Graphics for the relationship between displacement and NOx emissions:

Regarding the ratio between NOx Emissions registered and displacement manoeuvre of the ship in question. A greater parallelism can be seen than in the previous case of the Ro-Pax.

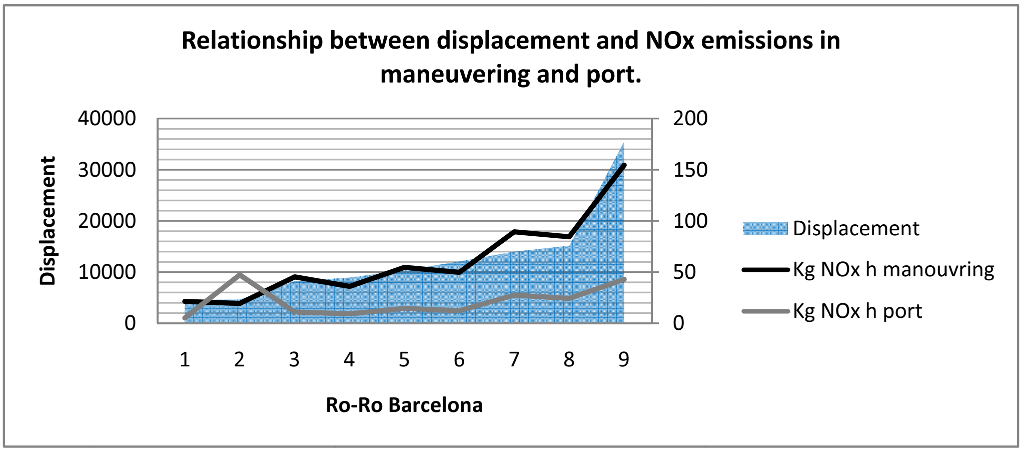


Fig. 74, Ro-Ro Barcelona - Relationship between displacement and NOx emissions in maneuvering and in port.

Graph corresponding to the ratio between GT and NOx emissions:

As in the previous section, there is a highly significant correlation between the curve defining the GT and the manoeuvring emissions curve.

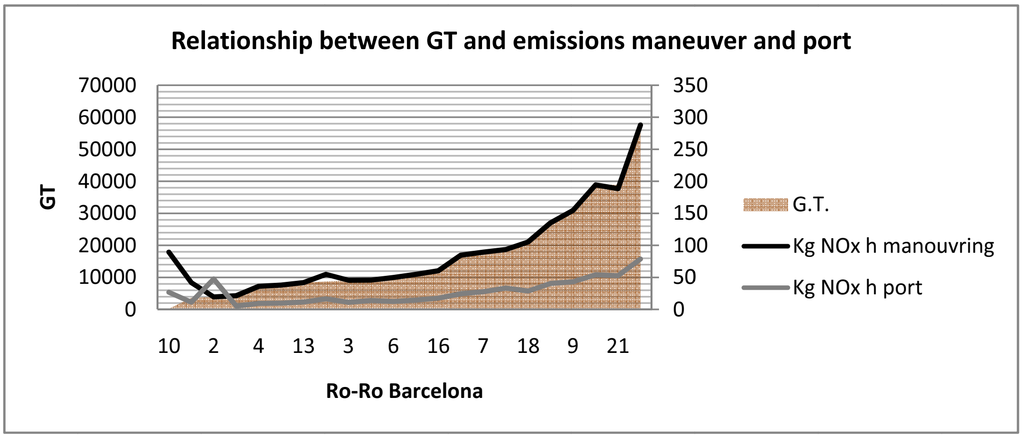


Fig. 75. Ro-Ro Barcelona - Relationship between GT and emissions for maneuver and port

Graph corresponding to the ratio between the propulsive power and speed of the vessel design and NOx emissions h manoeuvre:

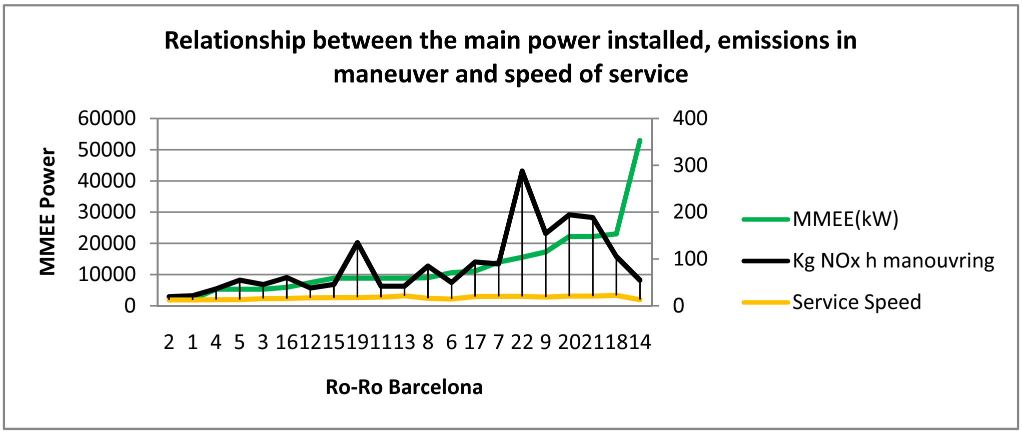


Fig. 76. Ro-Ro - Relationship between the main power installed, emissions in maneuver and speed of service

As in the previous section, we cannot determine the relationship between the measured emission and installed power.

Graph corresponding to the ratio between the electric power installed on the ship and NOx emissions per hour during stay in Port:

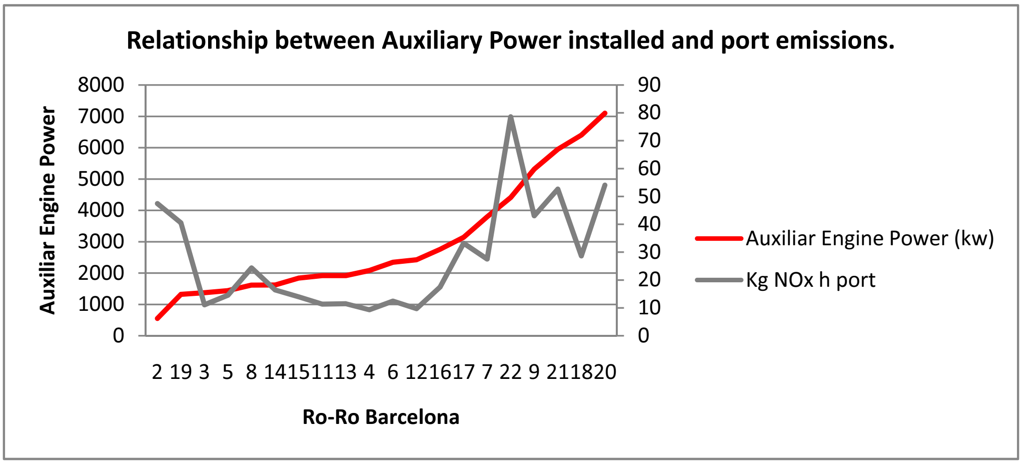


Fig. 77. Ro-Ro - Relationship between Auxiliary Power installed and port emissions.

Note that emissions taken in this case are not only those produced by the generators but also the potential emissions from hot water boilers needed in port.

NOx and CO_2 emissions calculated for Sorolla ship and the Baltic Ro-Pax.

The data collected of CO_2 and NOx emissions during the study have been calculated, the following table shows the emissions of these two gases with increasing speed.

Displacement/ Speed	6 kn	10 kn	14 kn	18 kn	22 kn	24 kn
NOx Kopernik D=9834	4,5	57,6	122,5	223,7		
NOx Wollin D=15572	4,5	21,0	57,7	122,5		
NOx Gabriella D=16562	5,0	23,0	63,2	134,4	245,4	
NOx Sorolla D=16567	3,6	17,4	50,4	114,5	228,3	
NOx Escanidinavia D=31409	5,1	23,6	64,7	137,5	251,0	
NOx Viking XPRS d=19795	5,8	26,9	73,7	156,7	286,0	472,1

Emisisons CO_2

Displacement/ Speed	6 kn	10 kn	14 kn	18 kn	22 kn	24 kn
CO_2 Kopernik D=9834	241,5	1118,1	3068,0	6520,6		
CO_2Wollin D=15572	270,9	1254,3	3441,9	7315,2		
CO_2 Gabriella D=16562	264,9	1226,5	3365,5	7152,9	13059,8	
CO_2 Sorolla D=16567	254,4	1177,8	3231,9	6869,1	12541,5	
CO_2 Escanidinavica D=31409	270,9	1254,3	3441,9	7315,2	13356,0	
CO_2 Viking XPRS d=19795	308,8	1429,6	3922,9	8337,6	15222,7	19763,2

Fig. 78. Emissions of NOx and CO2 calculated for the ship Sorolla and the Ro-Pax ships of Baltic Sea.

Based on the values, the graph shows that the emissions increase greatly by increasing the service speed of the ship.

The increase is quite appreciated in cases similar to the Sorolla in which NOx emissions are calculated from the emissions curve supplied by the manufacturer as in the other cases, emissions are calculated from consumption multiplied by the corresponding emission factor.

Ships are ordered by their displacement.

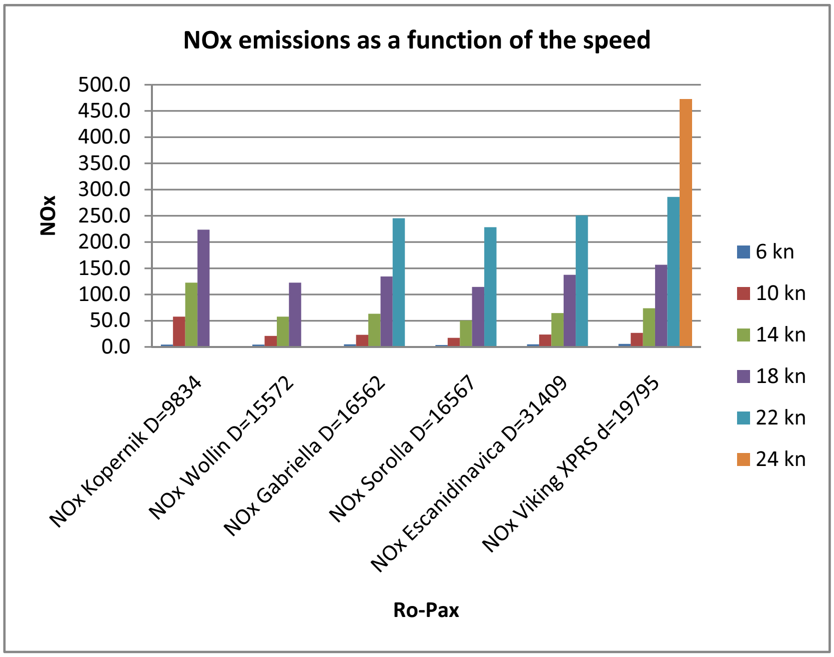


Fig. 79. Sorolla, Ro-Pax in Baltic Sea - NOx emissions as a function of speed

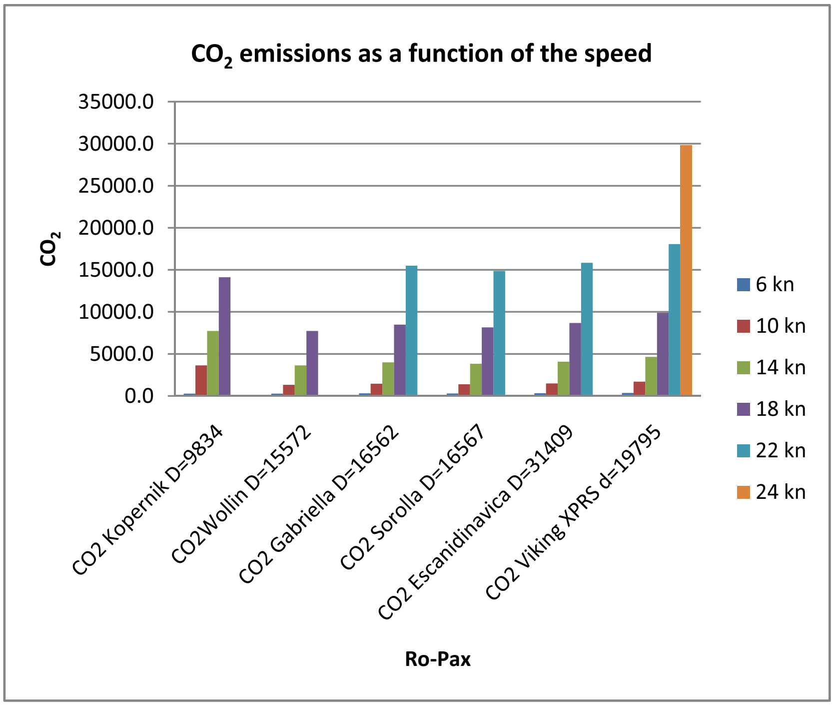


Fig. 80. Sorolla and Ro-Pax ships in Baltic Sea - CO_2 emissions as a function of speed

2.3.7 Calculation of Energy Efficiency Operational Indicator (EEOI)

Following the guidelines of the IMO, this is calculated in this section with an approximation for the various ships' EEOI - the ship Sorolla, the Kopernik, the Wollin, the Gabriella, the Escandinavika and Viking XPRS. All Ropax working vessels making regular journey daily.

EEOI calculation involves the summation of the different consumption readings recorded by different teams during the journeys - what is obtained here is an approximation in which on the one hand only the effect of the main and auxiliary is considered, boiler exhaust and on the other the combustion equipment installed. Consumption has been estimated from the ship load imposed by maintaining recorded speeds, such as described in previous sections.
Starting with a simplified expression of EEOI ;

$$EEOI = \sum FC_j . C_{Fj} \; / \; m^{cargo} . D$$

Where;

j is the fuel type;
FC j is the mass of consumed fuel at voyage ;
CFj is the fuel mass to CO_2 mass conversion factor for fuel j;

Type of fuel	Reference	Carbon content	C_F (t-CO_2/t-Fuel)
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil	(HFO) ISO 8217 Grades RME through RMK	0.85	3.114400
4. Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquified Natural Gas (LNG)		0.75	2.750000

Fig. 81 – Relation of CO2 emissions for tonnes of fuel

m_{cargo} is cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships; and D is the distance in nautical miles corresponding to the cargo carried or work done.

The correct result of this index would be obtained by adding the calculation of this expression for all the trips made annually.

We now proceed to calculate the index for the ships mentioned, for the difference between the indexes.

		Consumption (as function of speed)					
Ship	GT	6	10	14	18	22	24
Kopernik	14221	76,9	356,1	977,1	2076,6		
Wollin	22874	77	356	977	2077		
Gabriella	35492	84,4	390,6	1071,8	2278,0	4159,2	
Sorolla	26916	69,0	319,0	875,0	1859,0	3395,0	
Escanidinavica	57958	86	399	1096	2330	4254	
Viking XPRS	35978	98,3	455,3	1249,3	2655,3	4848,0	6294,0
	miles	Time in hours of the route					
GIVEN A ROUTE	100	16,7	10,0	7,1	5,6	4,5	4,2
FUEL COEF.	3,15104						
Kopernik	**EEIO**	**0,28%**	**1,31%**	**3,61%**	**7,67%**	**0,00%**	**0,00%**
Wollin	**EEIO**	**0,28%**	**1,32%**	**3,61%**	**7,67%**	**0,00%**	**0,00%**
Gabriella	**EEIO**	**0,31%**	**1,44%**	**3,96%**	**8,41%**	**15,36%**	**0,00%**
Sorolla	**EEIO**	**0,25%**	**1,18%**	**3,23%**	**6,87%**	**12,54%**	**0,00%**
Escanidinavica	**EEIO**	**0,32%**	**1,48%**	**4,05%**	**8,60%**	**15,71%**	**0,00%**
Viking XPRS	**EEIO**	**0,36%**	**1,68%**	**4,61%**	**9,81%**	**17,90%**	**23,24%**

Fig. 82. Sorolla - Ro-Pax from Baltic Sea - Approximation of EEOI.

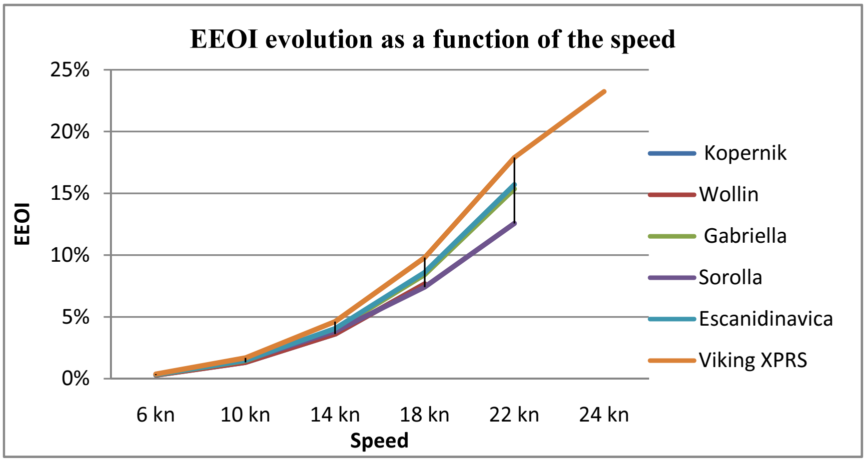


Fig. 83. Sorolla - Ro-Pax from Baltic Sea - EEOI evolution as a function of the speed

2.4 Summary and Conclusions

- Higher speeds are responsible for the increased emissions.
- These high emissions remain with varying speeds and it means additional time is needed at high speeds to make the same journey.
- Setting a constant speed for the journey, itself implies a reduction in emissions.
- Reducing the average speed by ½ or 1 knot for a path of a route for 4 and 8 hours, we can see reductions of between 11 and 19% for NOx and CO_2 emissions respectively, affecting the journey times by only 10 or 20 minutes respectively.
- The current approach routes can benefit from the planning of the passage. Good planning covers commercial expectations and does not penalize the environment.
- A possible flexibility in prioritizing the input ports of such vessels could also mean not having to adhere to strict timelines and avoid high speeds and therefore increased emissions.
- Important to raise awareness that not all of the delays must or may be absorbed by the ship by increasing its speed as a high environmental price is paid in this case.
- As provided in the propulsive power of Ro-Pax. We see that it is oversized. Vessel is disposed in staggered powers without following the slope which shows the displacement curve or of the whole GT.
- Large installed propulsive power peaks correspond to vessels whose design speed is high. There is some correlation between the powers on vessels and speeds of these, more independently to the displacement of the ship or the GT.
- This oversized notion is further reaffirmed when we observe that ships operate at speeds much lower than for what they are designed.
- The installed power generation equipment of auxiliary is between 25% and 35% of the propulsive power
- Both engines and auxiliary engines should be designed taking into account the loading conditions that usually correspond with the load of 80% and which area has the lowest specific consumption.
- NOx emissions recorded in manoeuvre, maintain a direct relationship with the GT of the ship.

After calculating the emissions produced during a complete manoeuvre in port (Barcelona taken as model for this section), by the main and auxiliary machinery of a representative Ro Ro Passenger ship, let us proceed to establish some conclusions for the reduction of the mentioned emissions.
There are a large number of papers and documents referring to this subject. This point has been focused on in the information contained in the document MAN B&W-2005 [31] for the NOx reduction methods.

It has to be borne in mind that due to the high dependence that the NOx formation has on the temperature, the way that results in the 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 NOx formation is reduced increasing the fuel consumption or to reduce the fuel consumption, the NOx formation greatly rises [4].

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 NOx 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 Nh3 or urea before passing through a layer of a special catalyst at a temperature between 300 and
400ºC, where the next reactions take place:

$$4NO + 4Nh_3 + O_2 \rightarrow 4N_2 + 6h_2O$$

$$6NO_2 + 8Nh_3 \rightarrow 7N_2 + 12h_2O$$

The efficiency of these reactions is related to the available surface of the catalyst. The geater is the contact area between the catalyst and the exhaust gases; the higher is the NOx 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 gas emissions (it will be specified in each explained method) 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 is as follows:

$$C_x h_y + n\ Air(O_2 + N_2) \rightarrow xCO_2 + (y\ 2)H_2O + 0{,}79nN_2 + heat$$

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

If the fuel type used in the main engine is changed during the manoeuvre 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 NOx and CO_2 can be 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 NOx 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 NOx emissions.

3 Advanced ship handling using Simulation Augmented Manoeuvring Design and Monitoring – a new method for increasing safety& efficiency

3.1 Introduction

This chapter describes the development and integration of enhanced a sophisticated approach to advanced ship handling using innovative fast time simulation technologies. The impact of this innovative approach for more energy-efficient ship operation and on reduction of greenhouse gas emission was demonstrated in the first phase of the project. In this section the integration into training courses is described by a systematic explanation of the principal concept for manoeuvre planning using enhanced tools for prediction and monitoring of complex manoeuvring sequences.

In the light of the ongoing development of the implementation of new sophisticated information and communication technologies in the frame of IMO's and IALA's e-Navigation initiative integrated navigation and integrated bridge systems are and will be installed on board ships. Availability of reliable and accurate sensor information allow for advanced support in ship operation in open sea but also in coastal sea areas and even in harbor basins with significant effects on greenhouse gas emissions and energy efficiency.

As one essential part of this development new concepts for on board displays and simulation tools were developed at Maritime Simulation Centre Warnemunde MSCW. A fast time simulation tool box is under development to simulate the ships motion with complex dynamic models and to display the ships track immediately for the intended or actual rudder or engine manoeuvre.

These “Simulation Augmented Manoeuvring Design and Monitoring” - SAMMON tool box will allow for a new type of design of a manoeuvring plan as enhancement exceeding the common pure way point planning and an unmatched monitoring of ship handling processes to follow the underlying manoeuvring plan. During the manoeuvring process the planned manoeuvres can be constantly displayed together with the actual ship motion and the predicted future track. This future track is based on actual input data from the ships sensors and manoeuvring handle positions. This SAMMON tool box is intended be used on board of real ships in future but it is in parallel an effective tool for training in ship handling simulators:

a) in the briefing for preparing a manoeuvring plan for the whole exercise in some minutes,
b) during the exercise run to see the consequences of the use of manoeuvring equipment even before the ship has changed her motion and
c) in debriefing sessions to discuss potential alternatives of the students decisions by simulating fast variations of their choices during the exercises. Examples will be given for results from test trials on board and in the full mission ship handling simulator of the Maritime Simulation Centre Warnemuende.

In the context of "green shipping" the toolbox has been applied for enhanced simulation based manoeuvre training and to support energy-efficient ship operation. Parts of this research has been presented at conferences and published in conference proceedings accordingly.

3.2 Basic idea and principal Concept of manoeuvre planning

Within this chapter investigations into the feasibility and user acceptance of a newly developed layout of a navigation display to support safe and energy-efficient manoeuvring will be introduced and selected results of simulation studies testing the influence on ma-noeuvre performance dependent on different kind of prediction functions will be discussed. Examples will be given for results from test trials in the full mission ship handling simulator of the Maritime Simulation Centre Warnemunde.

Normally ship officers have to steer the ships based on their mental model of the ships motion character-istics only. This mental model has been developed during the education, training in ship handling simulator in real time simulation and most important during their sea time practice. Up to now there was nearly no electronic tool to demonstrate manoeu-vring characteristics efficiently or moreover to de-sign a manoeuvring plan effectively - even in briefing procedures for ship handling training the potential manoeuvres will be explained and drafted on paper or described by sketches and short explanations. To overcome these shortcomings a fast time simulation tool box was developed to simulate the ships motion with complex dynamic models and to display the ships track immediately for the intended or actual rudder or engine manoeuvre. These "Simulation Augmented Manoeuvring Design and Monitoring" - SAMMON tool box will allow for a new type of design of a manoeuvring plan as enhancement exceeding the common pure way point plan-ning. The principles and advantages were described at MARSIM 2012 (Benedict et al. 2006) specifically for the potential on board application for manoeuvring real ships.

This chapter explains and describes the potential of the new method specifically for the teaching and learning process at maritime training institutions. Manoeuvring of ships is a human centred process. Most important elements of this process are the human itself and the technical equipment to support its task (see Figure 84).
However, most of the work is to be done manually because even today nearly no automation support is available for complex manoeuvres. Even worse, the conventional manoeuvring information for the ship officer is still available on paper only: the ship manoeuvring documents are mainly based on the initial ship yard trials or on some other selective manoeuvring trails for specific ship / environmental conditions - with only very little chance to be commonly used in the overall ship handling process situations effectively.
Ship Handling Simulation for simulator training has a proven high effect for the qualification, however, it is based on real time simulation, i.e. 1s calculation time by the computers represents 1s manoeuvring time as in real world. This means despite all other advantages of full mission ship handling simulation that collecting/gathering of manoeuvring experiences remains an utmost time consuming process.
For increasing the effectiveness of training and also the safety and efficiency for manoeuvring real ships the method of Fast Time Simulation will be used in future – Even with standard computers it can be achieved to simulate in 1 second computing time manoeuvres lasting about to 20 min using innovative simulation methods. This allows substantial support in both, the training process and the real manoeuvring process on board ships. In a comparison is given for some essential elements of the real manoeuvring process on ships and in training within the ship handling simulators as well. Additionally, in the right column some of the Fast Time Simulation (FTS) tools are mentioned and their roles to support each element of the manoeuvring process are indicated: These tools were initiated in research activities at the Maritime Simulation Centre Warnemuende which is a part of the Department of Maritime Studies of Hochschule Wismar, University of Applied Sciences - Technology, Business & Design in Germany. It has been further developed by the start-up company Innovative Ship Simulation and Maritime Systems (ISSIMS GmbH 2012).

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

- SAMMON is the brand name of the innovative system for "Simulation Augmented Manoeuvring – Design, Monitoring & Control", consisting of four software modules for Manoeuvring Design & Planning, Monitoring, Multiple Dynamic Prediction & Control and Simulation & Trial. It is made for both:
    - application in maritime education and training to support lecturing for ship handling to demonstrate and explain more easily manoeuvring technology details and to prepare more spe-cifically manoeuvring training in SHS environment, i.e. for developing manoeuvring plans in briefing sessions, to support manoeu-vring during the exercise run and to help in debriefing sessions the analysis of replays and discussions of quick demonstration of alterna-tive manoeuvres and
    - application on-board to assist manoeuvring of real ships e.g. to prepare manoeuvring plans for challenging harbour approaches with com-plex manoeuvres up to the final

berthing / un-berthing of ships, to assist the steering by multiple prediction during the manoeuvring process and even to give support for analysing the result and for on board training with the Simulation & Trial module.

- SIMOPT is a Simulation Optimiser software module based on FTS for optimising Standard Manoeuvres and modifying ship math model pa-rameters both for simulator ships and FTS Simu-lation Training Systems and for on board appli-cation of the SAMMON System.
- SIMDAT is a software module for analysing simulation results both from simulations in SHS or SIMOPT and from real ship trials: the data for manoeuvring characteristics can be automatically retrieved and comfortable graphic tools are available for displaying, comparing and assessing the results.

The SIMOPT and SIMDAT modules were described in earlier papers (Benedict et al. 2003 and 2006) for tuning of simulator ship model parameters and also the modules for Multiple Dynamic Prediction & Control (Benedict et al. 2009) for the on board use as steering assistance tool. In this section the focus will be laid on the potential of the SAMMON software for supporting the teaching and learning process.

3.3 Application of Fast Time Simulation Tools for Standard Ship Manoeuvring Elements

3.1.1 Ship dynamic model and SIMOPT / SIMDAT tools for fast time ship manoeuvring simulation and investigation

The role of computer based simulation is increasing on the ships bridge, especially for manoeuvre planning and for collision avoidance. Prediction tools are very helpful and already in use on ships for a long time. Well known is the so called Trial Manoeuvre mode in ARPA radars to be used in order to analyze future encounter situation for selected relevant course and speed alternatives to deck potential collision avoidance strategies.

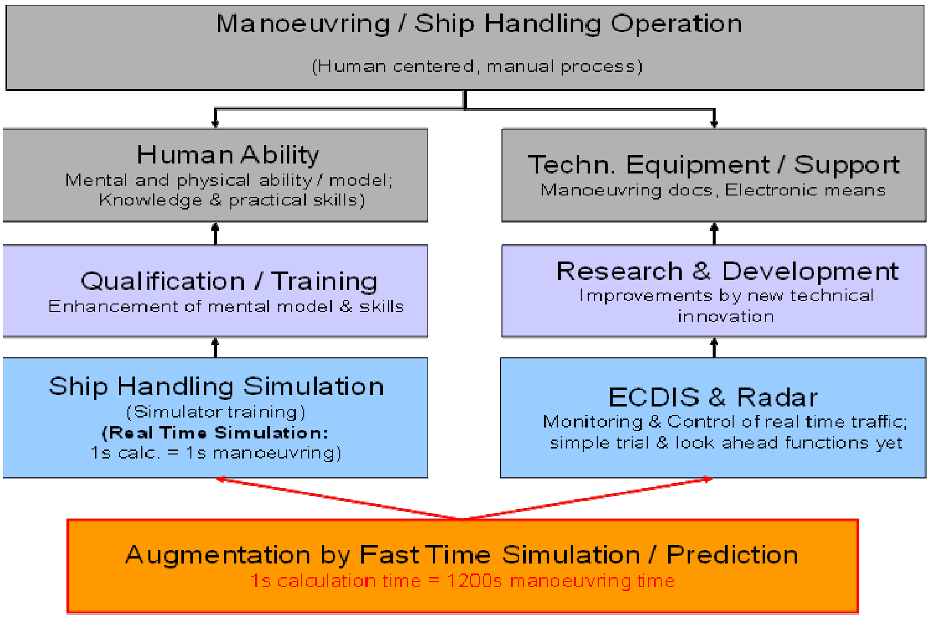


Fig. 84: Elements of the manoeuvring process and potential for enhancement by new Simulation / Augmentation methods

Elements of Manoeuvring Process on Ships & in Education/Training and support by Fast Time Simulation Modules / Tools		
Real World/ Ship Operation	**Ship Handling Simulator Training**	**Fast Time Simulation Tools**
Real ship / Familiarisation runs	Math model of the ship for simulation Familiarisation Exercises	**SIMOPT** & **SIMDAT** tool for developing & tuning of parameters of math models **MANOEUVRING TRIAL & TRAINING** tool for Demonstration / Lecturing / Familiarisation
Mission / Planning	Scenario / Briefing	**MANOEUVRING DESIGN & PLANNING** tool to generate and edit a manoeuvring plan
Manoeuvring Operation	Execution of exercise	**MANOEUVRING MONITORING & MULTIPLE DYNAMIC PREDICTION** tool to monitor and control the vessels motion
Recording (VDR, ECDIS)	Recording by simulator	**SIMDAT** tool to display and assess recordings
Evaluation of success	Debriefing	**MANOEUVRING TRIAL& TRAINING** tool for verification of results by simulation & prediction

Fig. 85 Elements of Manoeuvring Process on Ships & in Training and support by Fast Time Simulation Tools for Simulation / Augmentation

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

$$\begin{aligned} X &= m(\dot{u} - rv - x_G r^2) \\ Y &= m(\dot{v} + ru + x_G \dot{r}) \\ N &= I_z \dot{r} + m x_G (\dot{v} + ru) \\ Q &= I_{ME} \dot{n}_{ME} \end{aligned} \tag{1}$$

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

The ship's hull forces X and Y as well as the yawing moment N around the z-axis are on the left side. Their dimensionless coefficients are normally represented by polynomials based on dimensionless pa-rameters, for instance in the equation of transverse force Y and yaw moment N given as the sum of terms with linear components Nr, N_v, Y_r and Y_v and additional non-linear terms depending on speed components u, v, rate of turn r and revolution n. Other forces as for instance rudder forces and wind forces are expressed as look up tables. There are other models, e.g. for the engine or thruster opera-tion: for the sample in the fourth equation in (1) Q represents the sum of the torque components of en-gine, propellers and others; on the right side there is the inertia moment of the rotation parts around the propeller axis.

Additional differential equations represent the calculation of heading and position. The solution of this set of differential equations is calculated at least every second; some internal calculations are even done with higher frequency.

The quality of the math model for the simulation and the parameters in the equations are of high importance for the effectiveness of the simulation. There is a great need for fast and effective modelling / tuning processes both:

- for the general operation of Ship Handling Simulators SHS where clients from several shipping companies need to be trained on their specific ship types and
- for the SAMMON dynamic predictor and manoeuvre planning modules.

The parameters of these equations of motions can be found by parameter estimation technology – some methods were described at MARSIM 2009 und 2006 using the SIMOPT and SIMDAT Programs. The advantage of the module is to be seen in the performance: it is remarkably faster than real time and the steering of vessels is organized automatically by prepared files from a library for Manoeuvre-Control Settings / Commands for standard procedures and individual manoeuvres.

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

Simulations can be done in SIMOPT either as single run or as simulation series for selection of up to 3 Parameter series to be simulated in parallel or sequential for: Simulation parameters, e.g. Manoeuvre series; Ship Parameters (L, B, T, or others); Hull / force parameters coefficient and Environmental data, e.g. wind force and direction.

The SIMDAT software tool (see Figure 87.) was originally designed at the MSCW to supply the in-structor with semiautomatic assessment of the re-corded exercise data in ship handling simulator. For the purpose of ships model parameter tuning, the optimisation of manoeuvres and for lecturing this SIMDAT tool was extended: The Data for the manoeuvring characteristics can be automatically re-trieved for all manoeuvres; enhanced Graphic tools are available for displaying various types of results. Some results of particular evaluations are shown in the next figures.

3.3.2 Samples of Manoeuvre Demonstration and Optimisation with SIMOPT/SIMDAT

In order to explain ships dynamic simulations are very suitable to demonstrate the effect of specific manoeuvres. In the following figures86 and 87 the effect of so called "Combined Manoeuvres" will be shown where both rudder and engine will be changed at the same time to give some advantage in comparison with standard manoeuvres: the turning circles with constant speed rates for Full Ahead and Slow Ahead have nearly identical tracks; in case of using so called Kick Turns from Slow Ahead to Full Ahead or even more for Stop to Full Ahead the advance and transfer of the tracks are much smaller. The final steady state turning diameter is the same in all four cases.

Also for crash stop manoeuvres with Full Astern the rudder can help to significantly reduce the speed and therefore the stopping distance: in Figure 5.the standard crash stop manoeuvre is compared with a fish-tailing manoeuvre where the ruder is used periodically from full starboard to port and vice versa additionally to the reversed engine to save nearly one third of the stopping distance. The smallest advance can be seen for the turning circle with hard rudder where also the speed goes to zero after nearly half of the time compared to the standard stop manoeuvre.

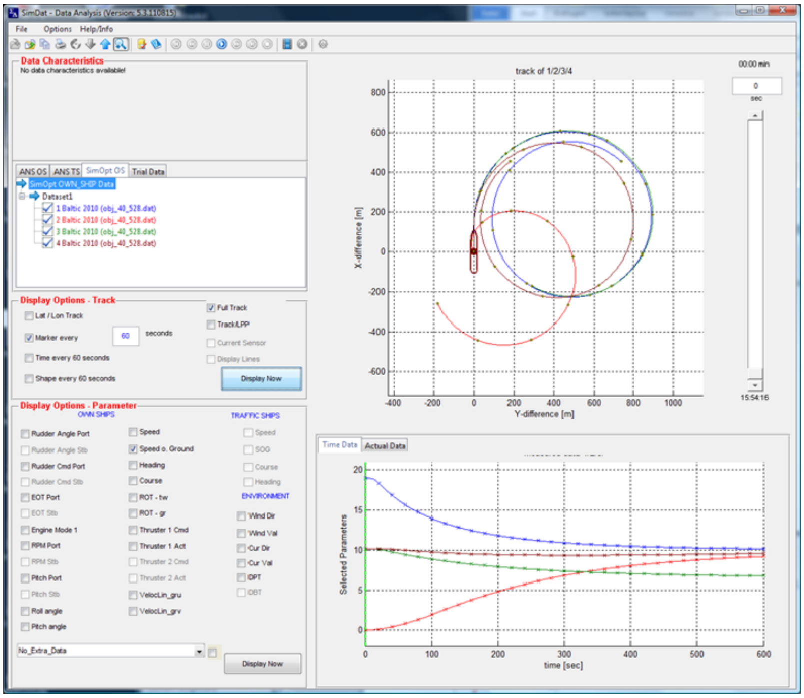


Fig. 86. Comparison of turning circles for Hard Rudder (35° STB) and constant speed rates with kick turns (CV 2500, left: ships' tracks, right: speed history):

Turning Circle with constant speed rate Full Sea Speed = 25.5 kn (blue)

Turning Circle with constant speed rate Slow Ahead = 11.3 kn, (green)

Kick-Turn from straight track with constant speed rate Slow Ahead = V_Start=11.3 kn) and change to Full Sea Speed (brown)

Kick-Turn from STOP at zero speed V = 0 kn and change to EOT = 100 % (red)

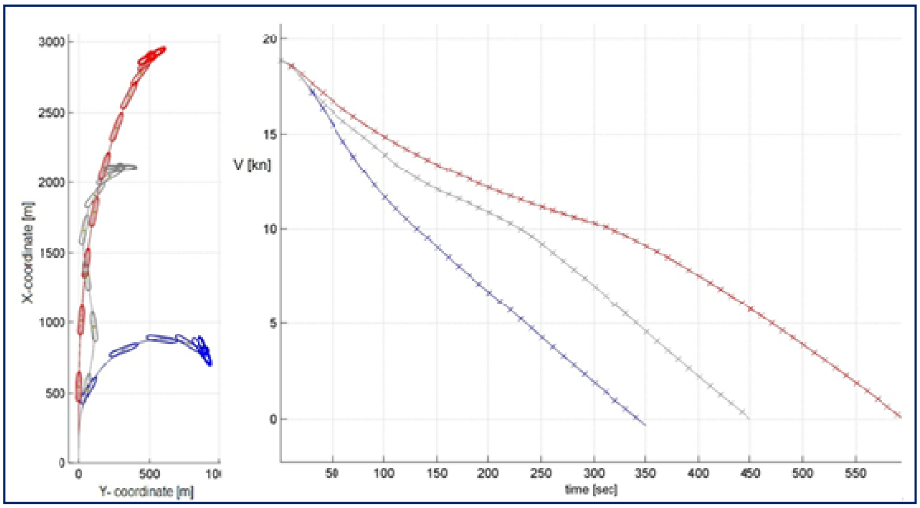
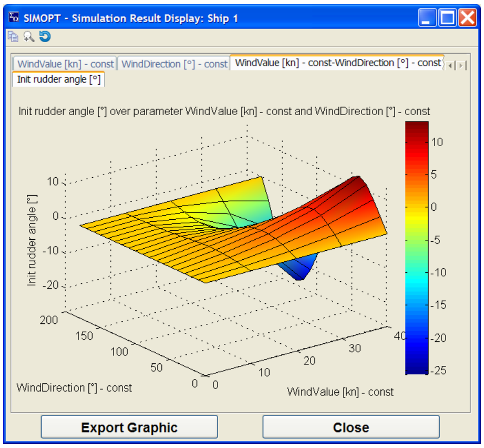
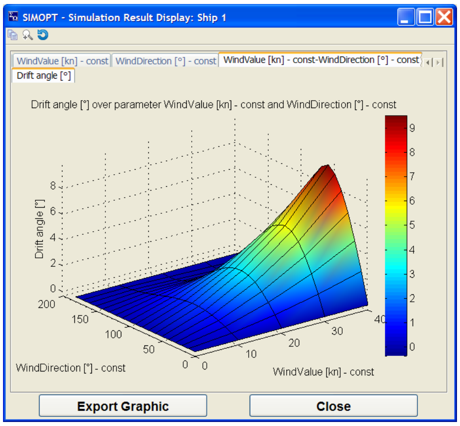


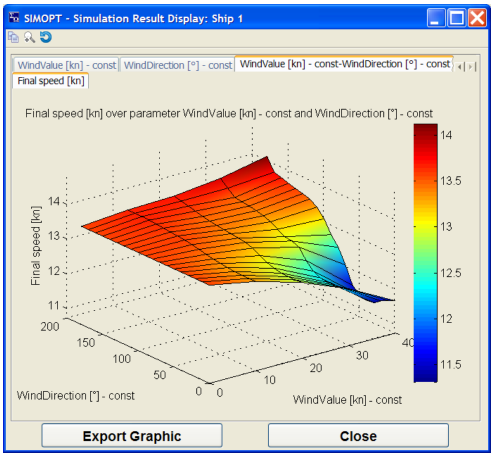
Fig. 87. Comparison of Crash Stop Manoeuvre (red) with Fishtailing (grey) and Hard Rudder Turning Circle from Full Ahead to Full Astern (blue) (CV 7500, left: ships' tracks - right: speed history)



a) rudder angle versus Wind direction and Wind speed



b) Drift angle versus Wind direction and Wind speed



c) Speed loss versus Wind direction and Wind speed

Fig. 88a-c. Balance of wind effects on straight track with constant speed in 2D & 3D presentation

Another important issue is the behaviour of the vessel under wind impact which can be easily explained and investigated by means of the SAMMON System. The basic understanding of this effect can be given to the students by explaining the equilibrium conditions under wind impact on a straight track with constant ship speed. For this purpose a series of calculations were made varying the wind speed from 0-40 kn and also the wind directions from bow wind 0° to stern wind conditions 180°.

In Figure 3 the table can be seen for the input control of the calculation series for simple Constant Speed Manoeuvres in SIMOPT. The results are shown in Figure 6. in 2D and - more comfortable – in 3D-representation respectively: it can clearly be seen that the rudder and drift angles to balance the wind moment and trans-verse forces are increasing with the wind speed, more precisely with the wind-tot-ship speed ratio. The effect of these equilibrium conditions will be demonstrated in the next chapter for the turning manoeuvres under wind.

3.4 Fast Time Simulation for Manoeuvring Demonstration in ECDIS Environment

The core modules of the same fast time simulation tools can be used for the demonstration of ma-noeuvres up to the design of complete manoeuvring plans. Some basic functions are shown in the next figures.

Figure 7 explains the operational interface in a sea chart environment which combines the electronic navigational chart ENC window (centre), the status of the current actual ship manoeuvring controls (left) and the interface window for the steering panel of the ship (right).

The ship was positioned in a certain place to demon-strate the ships motion for a very simple manoeuvre kick turn from zero speed. The ships motion can be controlled by the settings in the control panel window where any manoeuvre can be generated to be immediately displayed in the ENC in one second with full length. The length of the track corresponds to the settings in the prediction window (left top corner): the range value represents the duration of the manoeuvre; the interval value controls the number of displayed ship contours on that manoeuvre track. The sample represents a kick turn from zero speed to full ahead with full rudder to Port.

For the demonstration of wind effect the wind speed and direction can be set in the right bottom window. The effect can immediately be seen is in Figure 8 – The turning circle with full rudder to STB will be shifted in the direction with the wind from North (0°). This can be expected for low wind to ship speed because in the sample the engine order is set to 70%. If the EOT is set to only 30% the ship gains not enough speed and therefore she goes on a straight track with beam wind where the full rudder is just enough for the equilibrium to balance the forces and moment due to wind as discussed in Figure 6.

In extreme heavy weather it is recommended to re-duce the speed and to transfer into the “lying abeam” situation where the ship is only drifting with no engine power used. It is of great importance that this situation can be reached very quickly, i.e. that the transfer time from ahead motion into full drift motion requires a minimum of time to take advantage from the pure drifting motion as quick as possible. These effects can be demonstrated in ECDIS environment separately for every manoeuvring variant, but for an overview the different approaches are summarized in a SIMOPT / SIMDAT presentation in Figure 87.

It can be seen in Figure 87 that for a ship in stopping condition this procedure happens very fast: in about two minutes the ship reaches the full steady state transvers drift speed (green for a ship with super-structure in the middle, brown for superstructure at the stern); If the ship has a higher initial speed then it is recommended to use a full astern stopping manoeuvre because in this case she needs only 7-8 minutes the full drift compared to the coasting stop where more than 20 min will be needed for the same result.

3.5 *Fast Time Simulation for Designing Manoeuvring Plans*

3.5.1 Principle of Fast-Time Simulation of manoeuvres in ECDIS and sample data

The fast time simulation method is used to find out efficient manoeuvres and even more for the design of manoeuvring plans within the briefing for Ship Handling Simulator exercises and practically for route planning process on board (Benedict et al. 2012). The use of this tool will be explained by some sample scenarios:

The sample ship is the RO-PAX Ferry "Mecklenburg-Vorpommern" with Loa=200m, Boa=28.95m, Draft=6.2m, Displacement=22720t and Speed=22kn. She has two pitch propellers and two rudders located behind the propellers and additionally one bow thruster.

The test area is the Rostock Sea Port. The RO-PAX ferry is entering the fairway from north to be steered through the fairway and to be turned at the turning area followed by astern motion o the berth at west pier (as in in the sample given in Figure 96.

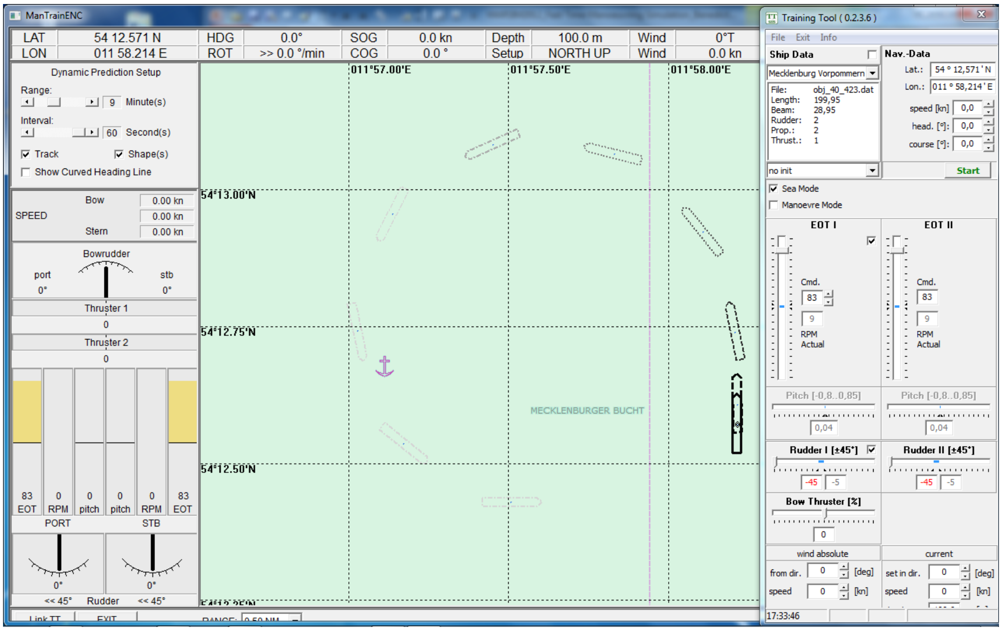


Fig. 89. SAMMON Trial & Training Tool Interface with sample for Kick turn from zero speed to port as sample for potential ships manoeuvring capabilities

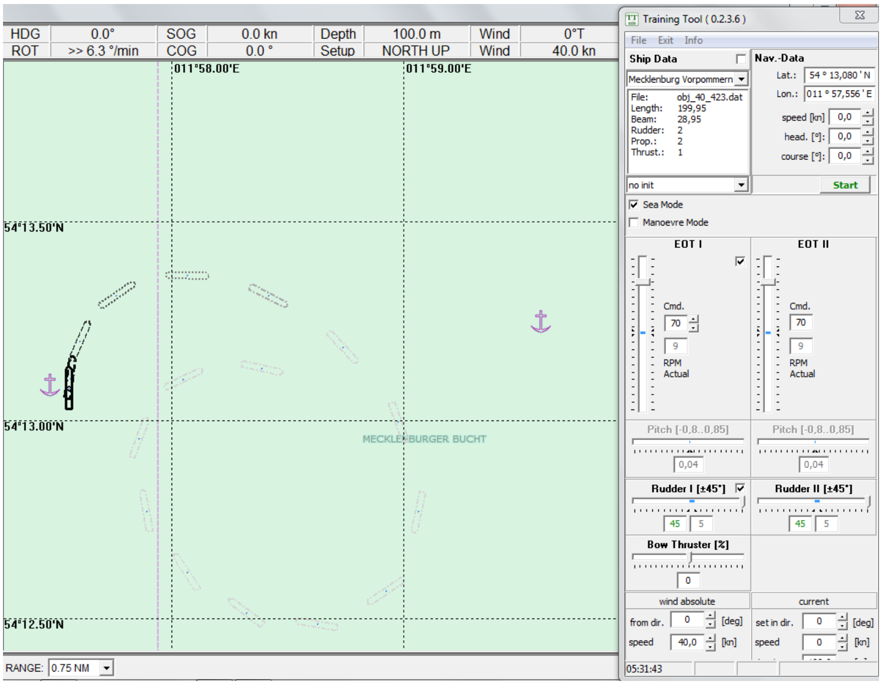


Fig. 90. SAMMON Trial & Training Tool -Interface with sample for wind impact for low ratio of wind-to-ships speed

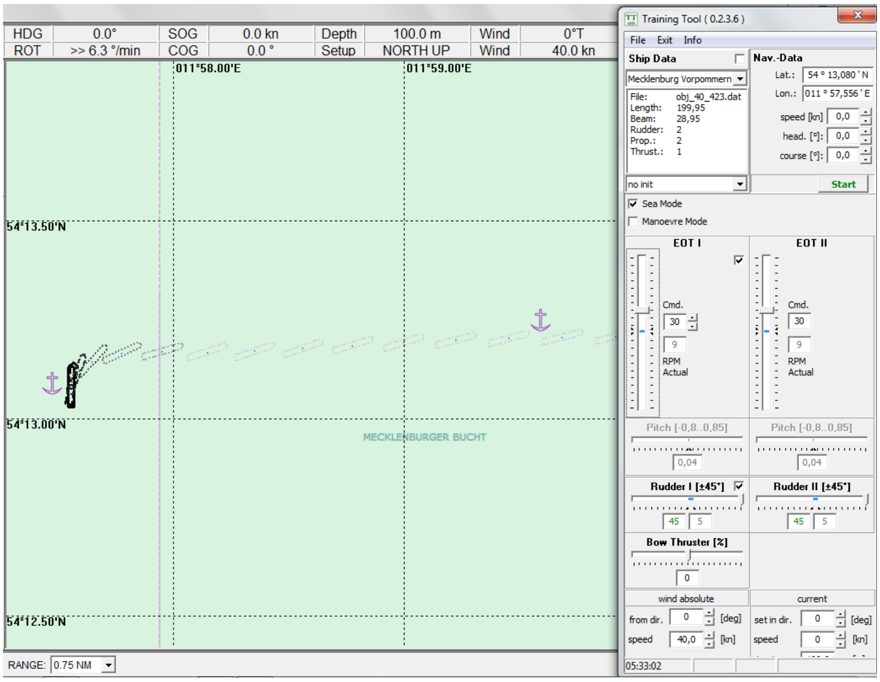


Fig. 91. SAMMON Trial & Training Tool -Interface with sample for wind impact high ratio of wind-to-ships speed

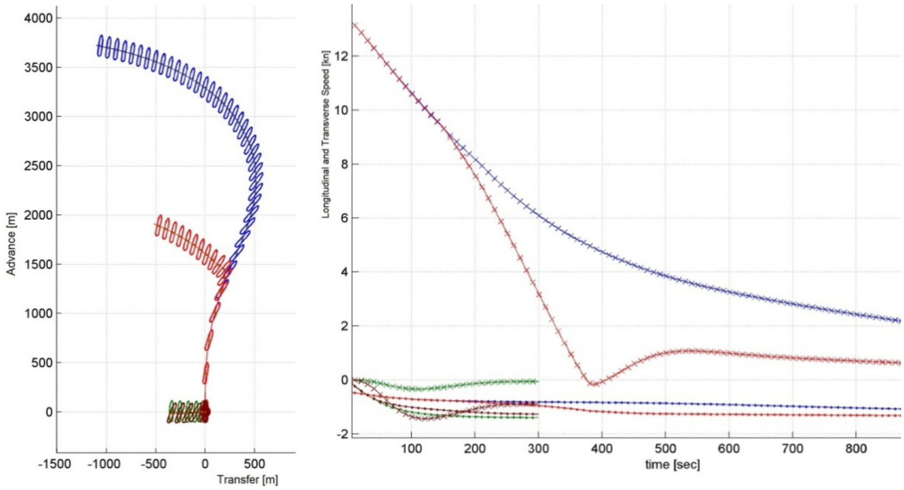


Fig. 92 SAMMON Simopt tool: Transfer into a "lying abeam" situation under strong wind from several initial situations for ships speed (Left: ships tracks, Right: time history of longitudinal and transverse speed components)

Some basic functions and interface displays are shown in the next figures: Figure 93 explains the method in a sea chart environment represented by an interface which combines the electronic navigational chart ENC window (centre), the interface window for the steering panel of the ship (right) for adjusting the controls for the selected manoeuvring point MP and the interface to display the status of the current actual ship manoeuvring controls (left) at the position of the next manoeuvring point which is indi-cated as ship shape in red colour in the ENC.

For purposes of demonstration of a complex manoeuvre procedure the ship is initially positioned in the fairway (black contour) and is going to enter the turning area as objective for the first manoeuvring segment. For the planning procedure the ship's mo-tion can be controlled by the settings in the control panel window on the right side. Any manoeuvre can be generated and will be immediately displayed in the ENC in less than one second with full length. In this case the rudders are set 10° to STB to achieve a small turning rate ROT=4.5°/min to port. The length of the simulated track corresponds to the settings in the prediction window (left top corner): the range value represents the duration of the simulated ma-noeuvre and that means the track length of that manoeuvring segment; the interval value controls the number of displayed ship contours on that predicted manoeuvre track. The selected end position of the manoeuvring segment is indicated by the red ship's contour. Its position can be shifted and adjusted us-ing the slider at the bottom line which is adjusted to 165 seconds after the beginning of the manoeuvre at initial Manoeuvring Point MP 0. If this position is accepted it will be acknowledged as the next ma-noeuvring point MP 1.

This planning process guarantees the full involvement of the student and navigating officer respectively: The best version of the manoeuvres can be found by trial and error but it is possible to bring in one's full knowledge and to take advantage of one's skills – it is possible to see and to verify immediately the results of the own ideas and to make sure that the intentions will work. This is import for safety and efficiency, but also for gaining experience for future manoeuvres.

3.5.2 Sample of designing a full manoeuvring sequence as training concept

The planning procedure for a complete manoeuvring plan follows the principles as described for a single segment in Figure 93 as follows: Figure 94 presents the situation after accepting the manoeuvre previously planned – now the next segment is to be planned from MP 1 to MP 2: the ship is going to en-ter the turning area and to slow down. Both engines are set to STOP (EOT 0). In Figure 13 the complex turning manoeuvre is to be seen: the ship is using in parallel engines, rudders and the bow thruster to turn as fast as possible. Afterwards the engines have to be reversed and the ship controls are adjusted to go astern to the berth. In Figure 96 the result for the full manoeuvring plan is to be seen with the whole set of Manoeuvring Points (MP) for the complete approach and the berthing manoeuvre.

The different settings of the controls and the track of the planned manoeuvre sequences are stored in a manoeuvre planning file to be displayed in the ENC.

For the execution of the manoeuvre this plan can be activated later to be superimposed in the ECDIS together with the actual position of the ship and, most important, with the prediction of manoeuvring capabilities for effective steering under the actual manoeuvring and environmental conditions.

3.6 Manoeuvring Monitoring and Multiple Dynamic Prediction Module - Overlaid prediction for On-line Manoeuvring Decision Support using Manoeuvring Plans

3.6.1 Presentation of dynamic predictions in ECDIS environment

For a compact presentation of information to the captain, pilot and responsible navigating officer respectively a new layout of a conning display was de-signed and implemented into the equipment installed on an integrated navigation system. For the purpose of testing the technical feasibility and user acceptance the new conning display with the integrated MULTIPLE MANOEUVRING PREDICTION MODULE was implemented in the INS equipment of the large full mission simulator bridge of the ship handling simulator of MSCW. The sample ship is again the RO-PAX Ferry "Mecklenburg-Vorpommern", the test area is the Rostock Sea Port. The RO-PAX ferry is leaving the berth to be steered through the fairway and to leave the port.

The layout of a dedicated prediction display integrated into an ECDIS is shown in Figure 96. It contains conning information together with the prediction and the planned manoeuvring track. The centre window shows the ENC in Head up Mode together with motion parameter for longitudinal speed and transverse speed as well as a circle segment with the rate of turn is shown. The ships position is displayed in the centre of the ENC as ship's contour where also the track prediction can be indicated as curved track or as chain of contours for the selected prediction time. The prediction parameters as range or interval of presentation can be set in the control win-dow at the right side.

Fig. 93. Display for Manoeuvring Design by Fast Time Simulation for immediate presentation of manoeuvring results: Sample for entering the turning area with slight turning to STB from initial conditions in a fairway at initial Manoeuvring Point MP 0

Fig. 94. Planning of the next segment from MP 1 to MP 2 – speed reduction

Fig. 95. Planning of the next segment from MP 2 to MP 3
– complex turning and stopping with engines, rudders and thruster

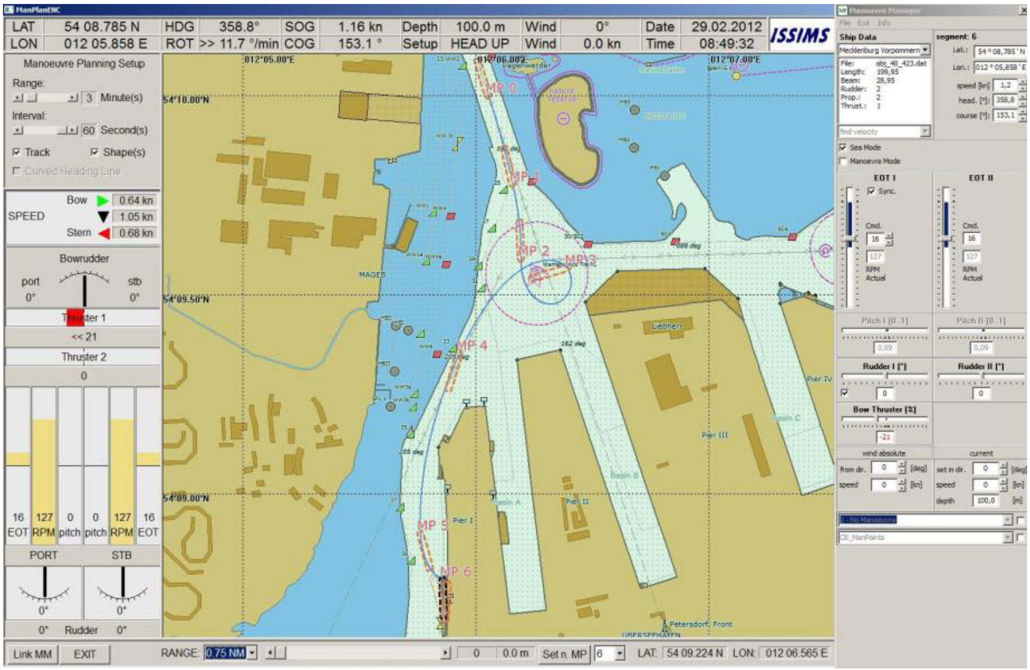


Fig. 96. Complete manoeuvring plan for the route segment for passing the turning area and approaching the berth in astern motion

The Dynamic Path Prediction with the sophisticated simulation model is shown as chain of ships contours based on full math model (ship contours every 60 sec for 5 min with turning to STB). This dynamic prediction reflects already the effect of the setting of rudder and propeller control parameters shown in the left bottom window: In this sample the two rudders of the ferry used are set to 12° Starboard and the Engine Order Telegraph for the two controllable pitch propellers are set to 50% representing 130 rpm of the propeller. The actual pitch status is 19. This interface allows a presentation of dynamic predictions of steering and stopping characteristics as an immediate response according to the current steering handle or engine order telegraph position. It can be perfectly compared with the planned manoeuvring track as a reference line or curve, shown as blue line in the ENC window along the chain of manoeuvring points MP.

The predicted track for the simplified static path prediction based on of current constant motion parameters (implemented as add-on in some ECDIS solutions) are shown as magenta curve: According to the actual/present small rate of turn to Port the predicted track is presented as a circle segment to the left side.

The use of path prediction with simplified models was already mentioned in previous papers, however, the use of this new multiple predictions based on the full dynamic model including the propulsion / engine process together with the result of preceding manoeuvring design is a great innovation and advantage. It was found that for the application of this dynamic prediction technology new strategies were found to save some minutes in this area which is very important in tight time schedules (Fischer & Benedict 2009).

3.6.2 SAMMON Manoeuvring Trial & Training Tool

This module combines a full simulation module for the ship manoeuvring process with all the modules above for planning and monitoring in order to test and try out manoeuvring plans and strategies, to be used both:

- as training tool in maritime education
  - in briefing / debriefing sessions for ship han-dling simulator training,
  - as well as in lectures on ships manoeuvring in classes and
- as training tool on board ships.

In order to control the virtual ship during the simulation process a manoeuvring panel on the screen allows steering the ship in real time along the planned route supported by the Multiple Predictor.

3.7 *Integration of SAMMON System into Education for Lecturing & Training Simulation*

For training & education the SAMMON System is available as a portable version based on Tablet PCs for Planning of Manoeuvres in Briefing, Instructor stations and use on Simulator bridges. The SAMMON system is interfaced to the Rheinmetall Defence Electronics ANS 5000 Ship Handling Simulator (SHS) at the Maritime Simulation Centre Warnemünde by WLAN connection.

Fig. 97. SAMMON System set up based on Tablet PCs within Ship Handling Simulator environment: as Bridge Version (top), Lecturer System (left) and Instructor Version (right)

All ship models which are available for the SHS are also ready for use in the SAMMON system for the following Concept of Application for Ship handling simulation:

Briefing

- Demonstrating ships manoeuvring characteristics by using SIMOPT for familiarisation
- Drafting Manoeuvring Concept as Manoeuvring Plan (using MANOEUVRING DESIGN & PLANNING tool) according to the training objectives
- Optimisation of the concept by several trials of the trainee (using MANOEUVRING TRIAL & TRAINING tool)

Execution of simulator Exercise:

- Training of conventional ship handling procedures and by using the by means of new FTS technology with underlying manoeuvring plan and dynamic prediction (MANOEUVRING MONITORING & MULTIPLE DYNAMIC PREDICTION tool)

Debriefing

- Assessment of the exercise results from full mission SHS by comparison of exercise recordings with trainees own concept or optimised manoeuvring plan by using SIMDAT tool for displaying and assessing the results of the exercise, e.g. comparing the result with the initial concept developed by the student in the briefing session and additionally to discuss alternative manoeuvring solutions by using the MANOEUVRING DESIGN & PLANNING tool).

A similar installation of the SAMMON system is also available at the MaRiSa-Simulation Laboratory at World Maritime University in Malmoe and can be used for demonstration and training of advanced manoeuvring planning and monitoring. As a pilot application the tool was integrated and used a train-the-trainer course and is described in chapter 5.

4 Human Factors and HMI design

4.1 *Introduction*

As noted in the first stage of this project, the promotion of a drive towards a greener, more environmentally friendly international shipping industry must also address a range of human performance related issues. 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. All these issues are fundamentally wrapped up into the concept of 'usability'. After considering this concept, the main aim of this chapter is to examine how we might assess possible human-machine interfaces that may be developed to support energy efficiency. We review two approaches to this issue – the assessment of situational awareness and the assessment of human error. This leads directly to a discussion of the training implications. These implications are currently theoretical, as the type of integrated energy efficiency interface envisioned by this project is currently not commercially available.

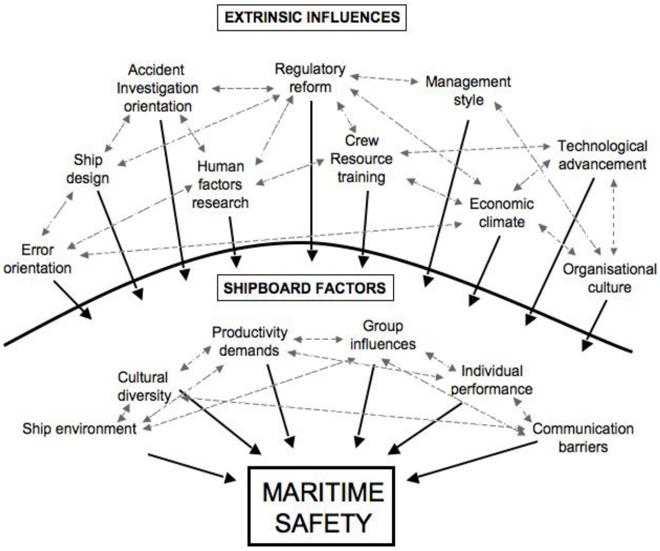


Fig. 98: Socio-technical relationships in the maritime domain [62]

4.2 *Background Issues – Usability and ISO*

A range of ISO standards are relevant to issues of usability, so it can be confusing when designers of bridge systems come to design 'usable' systems. At the broadest level, ISO 26800:2011(E) identifies a general approach and broad principles and concepts relevant to the design and evaluation of interactive systems.

One of the principles is that of ***Human-Centred Design*** (HCD). This means that all designable components of a system, product or service are fitted to the characteristics of the intended users, operators or workers, rather than selecting and/or adapting humans to fit the system, product or service (p.5).

Within this standard ***Usability is a concept*** to be applied in the specification, design and evaluation of systems, products and services. It encompasses the dimensions of effectiveness, efficiency and satisfaction and serves as a framework for specifying design goals and measuring their achievement.

The ISO 9241 series of standards are the central set of documents for user-centred design. A central concept within these documents is that of a 'dialogue'. A dialogue is defined as the interaction between a user and an interactive system as a sequence of user actions (inputs) and system responses (outputs) in order to achieve a goal. There are ***seven key dialogue principles*** identified in s.4 of ISO 9241-110:2006(E): Suitability for the task; Self-descriptiveness; Conformity with user expectations; Suitability for learning; Controllability; Error tolerance; Suitability for individualisation.

Whatever the design process and the allocation of responsibilities and the roles adopted, a human centred approach should follow the principles listed below:

- The design is based upon explicit understanding of users, tasks and environments.
- Users are involved throughout design and development.
- The design is driven and revised by user evaluation.
- The process is iterative.
- The design addresses the whole user experience.
- The design team includes multidisciplinary skills and perspectives.

The human-centred lifecycle process model has been developed in response to the need to improve the performance of the human-centred part of system development and support projects and is based upon seven developmental stages. These relate to the principles of HCD.

4.3 Map of Interactions between relevant standards

4.3.1 Introduction

The standards have been colour-coded to facilitate an understanding of their interaction. In the centre of the diagram (in purple) are the standards that focus particularly on human system interaction. To the side (in blue) are the standards, handbooks and technical reports that support the key standards. Further removed (in pink) are other standards that have some limited relationship to human-system interaction and the issue of usability but are not addressed in this document.

4.3.2 ISO 26800:2011(E) Ergonomics – General Approach, Principles and concepts

This standard has been developed in order to provide an integrated framework, bringing together the basic principles and concepts of ergonomics in one document, and thus providing a high level view of the way in which ergonomics is applied (p. v).

"Human, technological, economic, environmental and organizational factors all affect the behaviour, activities and well-being of people in work, domestic and leisure contexts. The underlying principles of ergonomics…are fundamental to the design process wherever human involvement is expected, in order to ensure the optimum integration of human requirements and characteristics into design. This International Standard considers systems, users, workers, tasks, activities, equipment and the environment as the basis for optimizing the match between them. These principles and concepts serve to improve the safety, performance and usability (effectiveness, efficiency and satisfaction) while safeguarding and enhancing human health and well-being, and improving accessibility (p.v)".

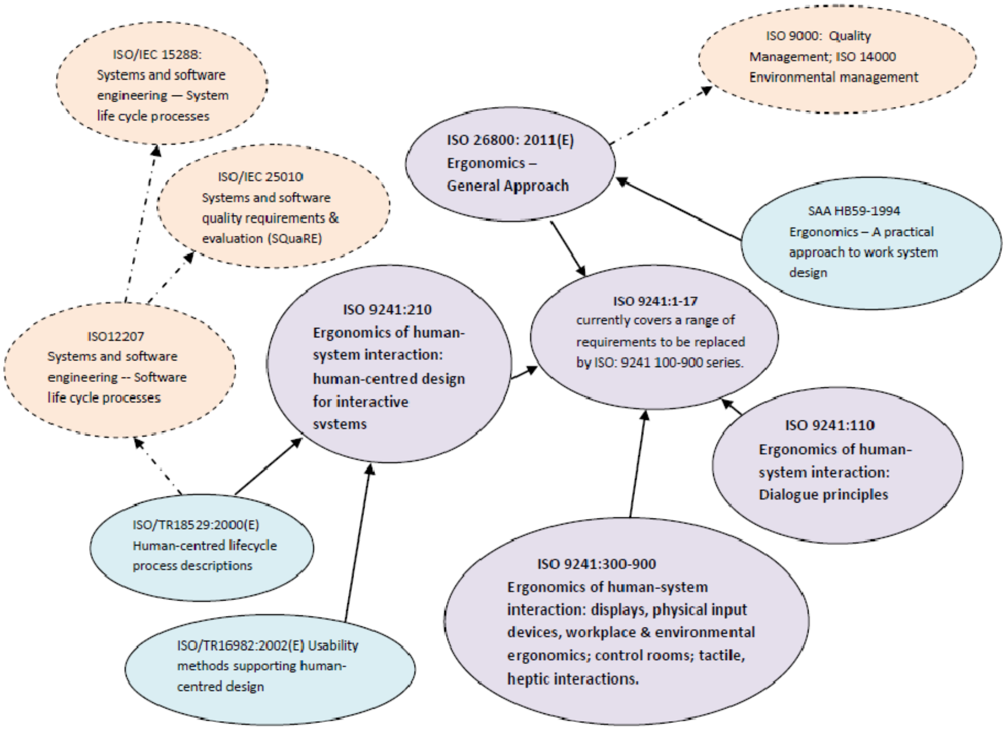


Fig. 99. Relationships between various international standards relevant to usability of bridge systems

In addressing the interaction between humans and other components of the system, ISO 26800:2011(E) identifies the following factors that need to be accounted for:

- The purpose of the system;
- The characteristics of the intended target population;
- Goals to be achieved and tasks to be performed;
- Existing constraints (e.g., legacy equipment or processes, economic and legal issues);
- Factors of the physical, organizational and social environment;
- Life cycle and any dynamic changes within it (p.3).

The Principles of Ergonomics are therefore:

1. **Human-Centred Design:** An ergonomic approach to design shall be human-centred. This means that all designable components of a system, product or service are fitted to the characteristics of the intended users, operators or workers, rather than selecting and/or adapting humans to fit the system, product or service (p.5).
2. **Target Population:** The target population shall be identified and described. Humans vary in their physical dimensions and in their biomechanical, sensory and cognitive capabilities" (p.5). The range of variation within the intended target population shall be specified (e.g., body size, visual abilities, literacy, skills, knowledge) (p.5).
3. **Task-Oriented:** Design shall take full account of the nature of the task and its implications for the human. Task-oriented design includes the appropriate allocation of functions and tasks between the human and technology and the possible consequences for the affected people and the system as a whole (p.6). Task-oriented design also takes account of differences between the designed task and the way the task is actually performed (p.6). Appropriately designed tasks (i) Can be performed safely and effectively by then target population, both in the short and the long term; (ii) Do not lead to short or long term impairment in members of this population; and (iii) Can be used to develop the operators'/users' capabilities and skills (p.6).
4. **Environmental Context**: The physical, organizational, social and legal environments in which a system product, service or facility is intended to be used shall be identified and described and their range defined. The physical attributes include issues such as thermal conditions, lighting, noise, spatial layout and furniture. The organizational and social aspects of the environment include factors such as work practices, organizational structure and attitudes (p.6). Sometimes the environmental contexts cannot be changed, in others they can be adjusted during the design process.
5. **Criteria-based Assessment:** Evaluation of the ergonomic design outcome of any system, product or service shall be based on established ergonomics criteria, regardless of whether or not it was designed following an ergonomics-based design process. Ergonomics criteria relate to human performance, health, safety and well-being and satisfaction. Iterative evaluation shall be an integral part of any ergonomic-based design process.

Usability is described within this standard as one of the key concepts in ergonomics.

Usability is a concept which is used in the specification, design and evaluation of systems, products and services. It encompasses the dimensions of effectiveness, efficiency and satisfaction and serves as a framework for specifying design goals and measuring their achievement.

Designing (or re-designing) for usability includes the consideration of usability at all stages of the life cycle, including the conception, detailed solution design, evaluation, implementation, long-term use, maintenance, disposal and recycling.

The specific design context (characteristics of the target population, goals, tasks, physical and technical environments, materials etc.) determines which operational aspects of effectiveness, efficiency and satisfaction are important. In the concept of usability there is no standard set of metrics that is universally applicable when assessing usability or its dimensions. The metric should be developed for the specific application (p.10).

For successful design, usability needs to be linked with another key concept – that of 'the human-machine environment system model or simply 'the system'. This addresses the interactions in the system between the human and other parts.

4.4 The ISO 9241 Series

4.4.1 Introduction

ISO 9241 is a multi-part standard addressing the ergonomics of human system interaction. The series moves from broad principles to more specific requirements for aspects of system design such as world-wide-web interfaces or physical input devices. The majority of the series have some relevance to the detailed design of e-navigation equipment, however most important are the usability concept (identified above) the dialogue principles, the characteristics of presented information and the human-centred process model. ***A dialogue*** is defined as ***the interaction between a user and an interactive system*** as a sequence of user actions (inputs) and system responses (outputs) in order to achieve a goal. Dialogue refers to both the form (syntax) and the meaning (semantics) of interaction. The seven design-dialogue principles identified in s.4 of ISO 9241-110:2006(E) are:

1. **Suitability for the task** an interactive system is suitable when it supports the user in the completion of the task. *(The dialogue should present the user with information related to the successful completion of the task).* For example: this requires an understanding of the task characteristics, presenting the user with only relevant information, managing input/output formats, appropriate default input settings; avoiding unnecessary steps in the task and achieving consistency between the user-interface and any source documents.
2. **Self-descriptiveness** *(a dialogue is self-descriptive to the extent that, at any time, it is obvious to the users which dialogue they are in, where they are within the dialogue, which actions can be taken and how they can be performed). For example:* this requires the information presented to the user to be accurate in guiding the user to complete the dialogue (including formats/units if necessary); the need to consult manuals during dialogues should be minimised; the user should be kept informed about the changing status of the interactive system.
3. **Conformity with user expectations** *(A dialogue conforms with user expectations if it corresponds to predictable contextual needs of the user and commonly accepted conventions).* For example, it uses a vocabulary familiar to the user, provides immediate and suitable feedback on actions and expectations; uses appropriate response times; reflects data structures the user perceives as being natural; follows appropriate linguistic and cultural conventions.
4. **Suitability for learning** *(the dialogue should support and guide the user in learning to use the system).* For example: Rules and underlying concepts useful for learning should be made available to the user; if dialogues are used infrequently the system should support re-learning; feedback should help build a conceptual understanding of the system.
5. **Controllability** *(A dialogue is controllable when the user is able to initiate and control the direction and pace of the interaction until the point at which the goal has been met).* For example the pace of user interaction should be under the control of the user; if a dialogue has been interrupted the user should be able to determine the point of re-start. If the volume of data relevant to the task is large, the user should be able to control the data presented.
6. **Error tolerance** *(A dialogue is error tolerant if, despite evident errors in input, the intended results may be achieved with either no, or minimal corrective action by the user. Error tolerance is achieved by means of error control (damage control), error correction or error management).*
7. **Suitability for individualisation** (*A dialogue is capable of individualization when the user can modify interaction and presentation of information to suit their individual capabilities and needs*). For example, the interactive system should allow the user to choose alternative forms of representation, the amount of explanation should be able to be modified to the users level of expertise; the user should be able to set the speed of dynamic inputs/outputs to match his/her needs where appropriate.

The principles are not strictly independent and can semantically overlap. It may be necessary to achieve a "trade-off" between principles in order to optimize usability.

4.4.2 The Principles of Human-Centred Design

Whatever the design process and the allocation of responsibilities and the roles adopted, a human centred approach should follow the principles listed below:

1. **The design is based upon explicit understanding of users, tasks and environments.** Products systems and services should be designed to take account of the people who will use them as well as other stakeholder groups, including those who will be affected (directly and indirectly) by their use.
2. **Users are involved throughout design and development.** This provides a valuable source of knowledge about the context of use, the tasks, and how users are likely to work with the future product, system or service.
3. **The design is driven and revised by user evaluation.** Evaluating designs with users and improving them based on their feedback provides an effective means of minimising the risk of a system not meeting user or organizational needs, including those requirements that are hidden or difficult to specify explicitly.
4. **The process is iterative.** In this context iteration means repeating a sequence of steps until a desired outcome is achieved, being used to progressively eliminate uncertainty and minimise the risk of the system under development failing to meet user requirements.
5. **The design addresses the whole user experience.** User experience is a consequence of the presentation, functionality, system performance, interactive behaviour, and assistive capabilities of an interactive system, both hardware and software. It is also a consequence of the user's prior experience, attitudes, skills, habits and personality. There is a common misconception that usability refers solely to making products easy to use. However the concept of usability in ISO9241 is broader and, when interpreted from the perspective of the user's personal goals, can include the kind of perceptual and emotional aspects typically associated with user experience, as well as issues such as job satisfaction and the elimination of monotony. *Note: In safety-critical and mission-critical systems, it might be more important to ensure the effectiveness or efficiency of the system than to satisfy user preferences.*
6. **The design team includes multidisciplinary skills and perspectives.** Human-centred design teams do not have to be large, but the team should be sufficiently diverse to collaborate over design and implementation trade-off decisions at appropriate times.

The figure below illustrates the interdependence of human-centred design activities. It does not imply a strict linear process, rather it illustrates that each human-centred design activity uses outputs from other activities.

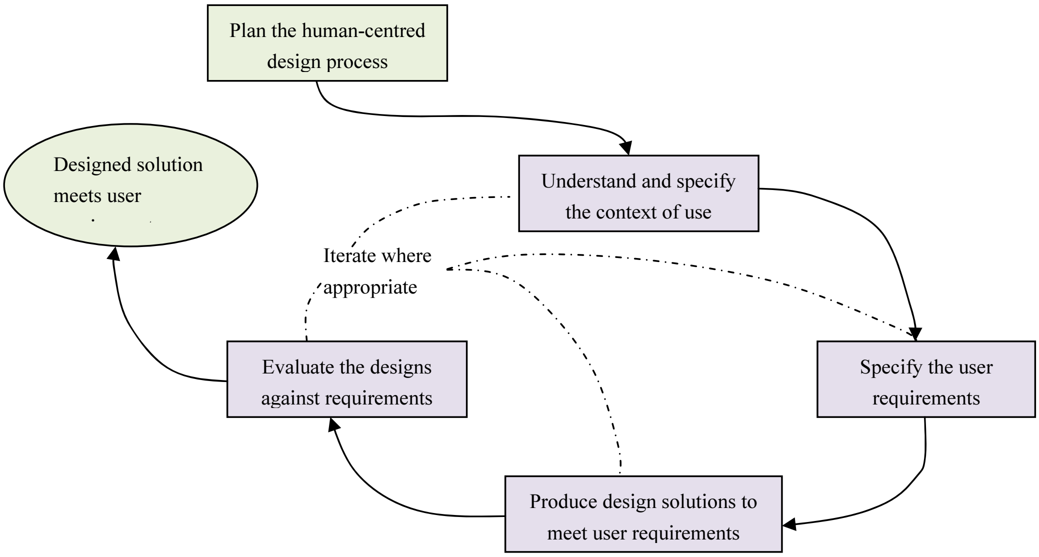


***Fig. 100. Interdependence of human centred design activities** (from ISO 9241-210:2010(E) p.11)*

4.5 ISO/TR18529 Human-Centred Lifecycle Process Descriptions and ISO/TR 16982

4.5.1 Background

The human-centred lifecycle process model has been developed in response to the need to improve the performance of the human-centred part of system development and support projects. The model is stand-alone, although is naturally linked to models such as ISO/IEC 12207 due to the interaction between hardware and software within the design of interactive systems. The model uses the format common to process assessment models, describing the processes that ought to occur in order to achieve defined technical goals. The human-centred process category therefore contains processes, and processes contain key practices. The processes generate and use work products. The elements of the model are described below:

Human-centred system development

↓

HCD1	HCD2	HCD3	HCD4	HCD5	HCD6	HCD7
Ensure HCD content in system strategy	**Plan and manage the HCD process**	**Specify stakeholder & organisational requirements**	**Understand and specify context of use**	**Produce design solutions**	**Evaluate designs against requirements**	**Introduce and operate the system**
Represent stakeholders Collect market intelligence Define & plan system strategy Collect market feedback Analyse user trends	Consult stakeholders Plan user involvement Select HC methods Ensure a HC approach Plan HCD activities Manage HCD activities Champion HC approach Support HCD	Clarify system goals Analyse stakeholders Assess H&S risks Define system Generate requirements Set quality in use objectives	Identify users tasks Identify user attributes Identify organisational environment Identify technical environment Identify physical environment	Allocate functions Produce task model Explore system design Develop design solutions Specify system and use Develop prototypes Develop user training Develop user support	Specify context of evaluation Evaluate for requirements Evaluate to improve design Evaluate against system requirements Evaluate against required practice. Evaluate in use.	Manage change. Determine impact Customisation and local design Deliver user training Support users Conformance to ergonomic legislation.

Linking the human-centred lifecycle in a process model requires the integration of Figure 1 with a broader system model. The relationship between the ISO/TR 18529 diagram of human-centred processes in the lifecycle and Figure 1: Interdependence of human centred design activities (ISO 9241-210:2010(E) p.11) is that the human-centred lifecycle in a process model embeds the design activities into a broader system strategy that includes a feedback loop to the operation of the system in the environment it is intended for. The inner circle of Figure 101 is therefore essentially the human centred design activities, albeit produced in a slightly different order.

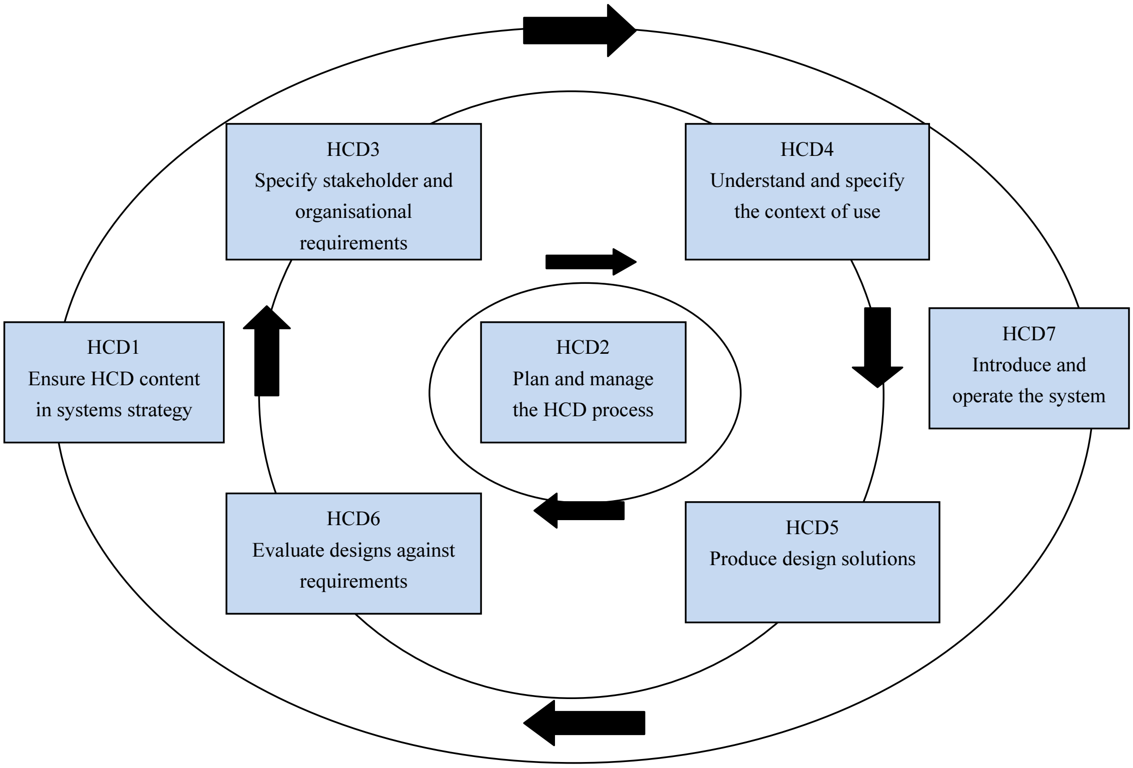


Fig. 101. ISO Standards Linking the human-centred lifecycle in a process model

4.5.2 Selecting Usability Methods

Once the process is managed, it remains to identify the methods to be used, and methods selection can be differentiated for design and evaluation.

For design: the focus is to determine users' knowledge, capabilities and limitations relative to the tasks for which the product or system is being designed. Of particular interest are the ways in which system and product designers can understand better users' tasks and task vocabulary, users' physical capabilities, etc. This information is used to guide the design of the system or product to maximize its usability

For evaluation: the focus is to assess a design on a particular dimension (e.g., interface features, recommendations, standards) or against a model (e.g., user model, expected task completion time, expected use pattern), with some kind of measurement and data gathering tools (e.g., questionnaires, errors-logging, time-stamp), according to users performance or preferences.

There are a series of factors to be considered when selecting the appropriate method:

- the lifecycle steps
- the characteristics of the users
- the characteristics of the tasks to be performed
- the product or system itself
- the constraints which affect the project, and
- the degree of expertise in ergonomics available in the development or evaluation team

A brief description of the referenced methods can be found below:

Name of the Method	Direct involvement of users	Short description of method
Observation of Users	Y	Collection in a precise and systematic way of information about the behaviour and the performance of users, in the context of specific tasks during user activity.
Performance-related measurements	Y	Collection of quantifiable performance measurements in order to understand the impacts of usability issues.
Critical incident analysis	Y	Systematic collection of specific events (positive or negative).
Questionnaires	Y	Indirect evaluation methods which gather users' opinions about the user interface in predefined questionnaires.
Interviews	Y	Similar to questionnaires with greater flexibility involving face-to-face interaction with the interviewee.
Thinking aloud	Y	Involves having users continuously verbalise their ideas, beliefs, expectations, doubts, discoveries etc. during their use of the system under test.
Collaborative design and evaluation	Y	Methods which allow different types of participants (users, product developers and human factors specialists, etc) to collaborate in the evaluation or design of systems.
Creativity methods	Y/N	Methods which involve the elicitation of new products and system features, usually extracted from group interactions. In the context of human-centred approaches, members of such groups are often users.
Document-based methods	N	Examination of existing documents by the usability specialist to form a professional judgement of the system.
Model-based approaches	N	Use of abstract representations of the evaluated product to allow the prediction of users' performance.
Expert evaluation	N	Evaluation based on the knowledge, expertise and practical experience in ergonomics of the usability specialist. **
Automated evaluation	N	Algorithms focused on usability criteria or using ergonomic knowledge-based systems which diagnose the deficiencies of a product compared to predefined rules.

** The standard does not include expert users in this category but this could reasonably be considered another form of expert evaluation.

Once the method is established, a further issue is how do we establish the boundary between a product with acceptable usability, and one without? This issue is fundamental to the development of energy-efficient human-machine interfaces, however the guidance with respect to this issue is not well established, particularly in the maritime-specific literature. Therefore the following sections not only consider the work being done within the International Maritime Organisation (IMO) to reconcile usability from the perspective of the e-navigation initiative, but also considers two research initiatives that have looked to design metrics for the assessment of usability within the bridge environment.

4.6 *Translation of these Standards into a maritime-specific output*

As a follow up to the first workshop conducted about Usability and E-Navigation in Malmo, Sweden in 2012, the Australian Maritime Safety Authority hosted a second e-navigation Usability Workshop in March, 2013. The aim was to assist the IMO's e-navigation strategy implementation plan by developing guidelines for the usability of navigation equipment and systems. There were 45 delegates, representing 10 countries participating in this workshop. Delegates represented four key stakeholder areas for e-navigation –

- maritime administrations,
- marine electronics industry,
- users (seafarers and shore organisations such as Vessel Traffic Services and pilots) and
- research/academia.

During this workshop participants were provided with an initial draft version of the Human Centred Design (HCD) guideline which was based on several pieces of research and relevant current international standards and the work of Peterson [68]. The initial HCD framework based on these guidelines is shown in Figure 101. The premise of this HCD guideline is that designable components of a system need to be fitted to the characteristics of the intended users (and maintainers), rather than selecting and/or adapting humans to fit the system, product or service.

Based on this information, and using working groups over three separate sessions, workshop delegates were requested to critically evaluate and assess the initial draft HCD guideline.

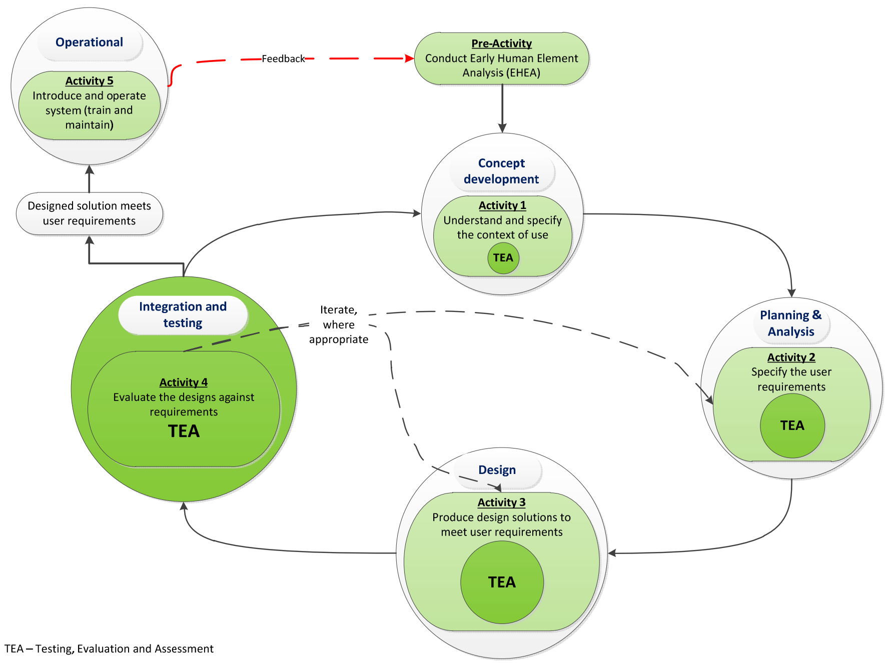


Fig. 102: Draft Human-Centred Design Framework

In e-Navigation the users play a crucial role and, hence the effectiveness of system usability evaluation is of particular importance. Therefore, the Testing, Evaluation and Assessment (TEA) is integrated within the HCD framework forming part of each phase of the system lifecycle and HCD activities. The TEA iterative process will ensure that human element issues are identified in the early stages of the design process and rectified accordingly. TEA covers a number of potential methods (i.e. heuristic evaluation, questionnaires, link analysis, walkthroughs and user tests) that could be used to evaluate system usability within each phase of the HCD process. As shown in Figure 102, the TEA circle becomes larger following each activity and each phase of the life-cycle process. This to some extent denotes the intensity of the TEA process following each HCD activity within the life-cycle process. There are a series of factors to be considered when selecting the appropriate TEA method within each activity. Often, in the early stages low-fidelity prototypes are utilised to obtain feedback at a reduced cost. The Table on pg.117 of this report previously identified some examples of TEA methods that can be applied within each activity of the HCD framework. The TEA following activity 4 is conducted prior to the system being deployed operationally, ultimately verifying and validating that all requirements from all user perspectives have been met – this includes operational users as well as system maintainers. An important component of TEA is to ensure that appropriate usability performance standards are used during the design and development of e-Navigation systems [69].

If we were to suppose that one of the ‘new’ e-navigation systems emphasised energy efficient shipping through integration of engine performance/GHG emissions and more effective decision support for route planning and manoeuvring, then such a system would need to be evaluated for usability performance. The two methods below identify possibilities in this respect.

4.7 Assessing Usability Study 1: Assessment of Errors as applied to ECDIS

This study demonstrates a method to assess human error as applied to an ECDIS and, if similar preparatory steps were followed, the basis of the method could be used to assess a human-machine interface for energy efficiency.

4.7.1 Materials, Methods and Participants

Eight Part Task Bridge (PTB) simulators were used, each including 3 components (*Multipilot, Conningpilot and Chartpilot*) with different modes and navigation functions. The *Multipilot* in *Chart Radar* mode possesses *ARPA (Automatic Radar Plotting Aid)* approval and an additional overlay of *Electronic Navigational Charts (ENC)* for route monitoring purposes. The *Chartpilot* is an approved *Electronic Chart Display Information System (ECDIS)* and it is operated with official ENCs. NACOS is also fitted with a *Track Control System (Trackpilot)* The simulator scenarios were designed and controlled by means of the *Operator Control Centre (OCC)* software.

50 deck officers agreed to participate to the study during 6 official training courses. Among them there were 16 master mariners, 21 deck officers qualified to be in charge of navigational watch, and 13 deck cadets. 1 simulator instructor conducted the observations. 5 users met the criteria to be considered expert users and their results were selected for further analysis.

Tasks and type specific procedures were defined by means of a *Hierarchical Task Analysis,* a core ergonomics approach extensively used for a range of applications, including interface design and evaluation [70]. The tasks have been grouped according to the main INS components, INS functions and their related tasks.

When user errors are caused by lack of understanding of the specific tasks, the failure is in the intention rather than in the execution, and the errors (also known as *mistakes*) are less likely to give insights in potential usability issues. This does not, however also lead to the conclusion that these errors are irrelevant or lack any value. Given the fact that a large proportion of seafarers are relatively inexperienced, errors made by inexperienced users (be they intentional failures or not), provide an indication of the degree of 'self descriptiveness' of the system. As identified earlier, *(a dialogue is self-descriptive to the extent that, at any time, it is obvious to the users which dialogue they are in, where they are within the dialogue, which actions can be taken and how they can be performed).*

The analysis of unintended (attentional or memory) failures of execution, also known as *slips of action* may yield more usability-related information. From their analysis it is also possible to develop principles of system design that minimize both their occurrence and their potential adverse effects [71]. Therefore *poor* performances (tasks not achieved due to observed mistakes) were not considered meaningful to obtain insights into usability issues. On the other hand, marginal and satisfactory performances (with observed slips of action) were considered to have such potential. Rather than counting the errors for each task, the type of prevailing slips for each task were recorded. The value of analysing slips of action resides in their link with design solutions. So, the overall objective of the analysis was to address design issues, rather than just identifying them.

4.7.2 Results

The selected users were in 5 different groups, thus allowing the observer to focus his attention on rating task performance and on identifying the type of slips. The first table below shows the percentages of task performances and type of slips averaged across the total amount of tasks carried out by the 5 selected users. Therefore, given that each user performs 37 tasks, for 5 users these results in both tables include observation of 185 tasks.

PERFORMANCE	PERCENTAGE	NO. OF TASKS
Task achieved – no error	62%	115
Task achieved – slip	33%	61
Task not achieved – slip	5%	9
Task not achieved - mistake	0%	0

Task performance of the selected users

By investigating the nature of slips of action (table below), it is possible to obtain insights into the possible design issues of the interactive system as a whole.

TYPE OF SLIP	PERCENTAGE	NO. OF TASKS
Description	71%	50
Activation	22%	15
Mode	7%	5

Slips of action carried out by the selected users

Among the various slips observed, particular attention should be posed to those associated to the tasks not achieved (5%) by at least one of the 5 users. These tasks involve:

- management of chart alarms (ECDIS)[1];
- control of the update status of ENCs installed (ECDIS);
- management of ENC layers (ECDIS).

These results are discussed in association with the results of Study 2 in section 4.9.

[1] The INS provides a functionality to set a warning zone ahead of the ship's bow and within the track limits, in order to generate a chart alarm. The Chartpilot (ECDIS) display does not visualize either the objects triggering the alarms, or the warning zones ahead of the ships' bow and across track. Such lack of visual description might make it difficult for the user to actively manage the alerts.

4.8 *Assessing Usability Study 2: Assessment of Situational Awareness*

This section provides a summary from the Masters thesis written by Peter Dann [76] and supervised by Dr Benjamin Brooks within the Masters of Human Factors, University of South Australia.

4.8.1 Method

Situational awareness is a concept that has grown in importance in recent years as both academics and those working in operational environments have recognised the value it has to both understanding human performance in the maritime domain and also maintaining levels of safety and reliability. Situational awareness includes the perception of information from the environment, its integration into a coherent 'mental model' of the situation and the projection of this model into the future in order to make decisions about how to act. The steps used to develop, then test the situation awareness behavioural markers (SABM) in this study consisted of:

a. The construction of a hierarchical task analysis (HTA) to allow the
b. Development of the SABM s which were then tested in
c. A simulated environment.

The student researcher, who has spent over 30 years in the maritime industry, 22 years at sea, six of which were as Captain and nine years as a ship s pilot, constructed the HTA. To help ensure the clarity of the HTA the pilotage is taken to be an inbound berthing using tugs.

Once the HTA had been completed it was taken to an expert group of six pilots who had a minimum of 10 years pilotage experience on top of their seagoing experience. The expert group reviewed the HTA to determine if:

1. If there were any errors or omissions in the goals, sub goals and tasks.
2. If the order is correct and if not then what should be the order.

After receiving feedback the HTA was revised and work was started on forming the behavioural markers. Behavioural markers are observable actions that can be assessed qualitatively to understand human performance within the work domain. From the HTA, Situation Awareness Behavioural Markers (SABM) were formed against tasks and SA measures that would endeavour to determine to what extent the pilot used the markers in the pilotage. The SABM s were reviewed by the research team before the start of the simulation exercises to ensure that the correct information would be captured.

The SABM form was developed following the Pilotage HTA.

4.8.2 Materials and Participants

The simulator used in the exercise was a full mission bridge simulator at the Australian Maritime College, classed to DNV Class A standard. It gives a 270 degree horizontal field of view and a vertical field of view of 18 degrees above the horizon and 17 degrees below the horizon.

The simulation exercises were completed over a period of three days and involved four pilots with varying degrees of pilotage experience ranging from three to 16 years, however all had spent a considerable time (+20 years) at sea serving as ship's Captains which involved varying forms of pilotage work and can thus be considered to be experts in their field.

The raters, who were all from an experienced sea going background (minimum 20 years) and had been shiphandling for a considerable period (minimum five years), used the SABM form to rate the competency of the observed performance on a four point Likert scale that was based on the ratings used in Line Operation Safety Audit (LOSA) methodology [72]. The LOSA method is derived from an aviation system, and predicated on the University of Texas Threat and Error Management (UTTEM) Model. The UTTEM Model suggests that there are 'errors' under the control of the bridge team, and 'threats' that exists externally to the bridge team. A deeper understanding of both within the normal operations of a workplace – be it the cockpit of a aeroplane or the bridge of a ship, leads to a more profound understanding of operational performance because it is not significantly altered by 'angel behaviour' (one's best behaviour) that is typically observed during audits.

The simulation exercises were varied and ranged from conning the vessel around a turn at the top of a channel and then swinging the vessel and backing down to the berth in varying wind and tidal configurations. Ship departures were also carried out. Ship sizes also varied considerably ranging from 125000 m3 Moss LNG ships to 177000 m3 Moss LNG ships and included a 217000 m3 Membrane ship. While tug numbers did not vary their power did ranging from 50t to 75t.

A familiarisation / training run was given before commencing the simulation runs to enable the other participants gain experience in using the sheets and also have any questions answered that they may have had and also to minimise learning effects before data collection.

In the simulation exercises the SABM s were used for two major tasks, those being:

1. SABM s for maintaining a safe passage to the berth by using appropriate methods including helm orders, main engine orders and tug orders.
2. SABM s for ensuring correct tug orders are given and carried out.

The SABM forms were completed at the end of the simulation exercises. This allowed the pilot to complete the exercises without any interruptions and also allow the observers to concentrate on their observer role. The simulation exercises ran for 20 to 40 minutes depending on the complexity of the task.

4.8.3 Results

A total of 13 runs were rated by two of the pilots independently. These raters observed via the control room, which gave them full view of the bridge team and access to screens that shared technical and positional performance of the ship, but also as unobtrusive observers on the bridge.

In determining the inter-rater reliability for the SABM s it was necessary to determine a value for Cohen s Kappa. Researchers have determined that for research purposes, there seems to be general agreement that the Kappa should be at least 0.6 and preferably 0.7 [73],[74]. In the current study a Kappa of 0.6 was achieved. The main area of disagreement lay between categories two and three in the Likert scale. This would indicate that the IRR is still within the valid range but was affected by the fact that one category received the majority of the ratings (92%).

1	**2**	**3**	**4**
Poor Observed performance had safety implications	**Marginal** Observed performance was barely adequate	**Good** Observed performance was effective	**Outstanding** Observed performance was truly noteworthy

Situational Awareness Behavioural Markers	
Attention, Detection and Perception	**Average Rating**
1. Does the pilot check and compare the vessels position using visual marks, radars, electronic chart systems (if available) and paper charts (or a combination of)	**2.91**
2. Does the pilot check the helm indicator when an order is given?	**2.77**
3. Does the pilot acknowledge the response of the helmsman?	**3**
4. Does pilot look at the Main Engine indicator when an order is given?	**2.84**
5. Does the pilot check speed indicators whilst maneouvring?	**2.91**
6. Does the pilot acknowledge the response of the Bridge Team member after giving Main Engine orders?	**2.8**
7. Does the pilot determine that a change is needed or that all is going according to plan by reference to visual marks or other means – e.g. radars and other position indicating equipment?	**2.91**
Interpretation	
1. Does the pilot interpret all of the above in a manner that helps him to make piloting decisions?	**2.95**
2. Does the pilot check that orders dealing with tugs, main engines and helm are having the appropriate effect by reference to visual marks or other position indicating equipment and if not take steps to rectify the situation?	**2.95**
Decision Making	
1. Does the pilot continue to check that his decisions are good ones and if needed, modify them accordingly?	**2.95**
Response Execution	
1. Does the pilot revert to a stereotype when things are not going according to plan? (Forgetfulness, higher pitched voice and etc).	**2.66**
Memory	
1. Does the pilot write down the tug's positions or use memory to recall their positions?	**2.83**
2. Does pilot refer to tug position note or use memory when giving tug orders.	**2.78**
Attention	
1. Does the pilot pay attention to the tugs position when an order is given?	**2.78**
2. Does the pilot acknowledge the response of the Tug Captain?	**2.9**
Detection / Perception	
1. Does the pilot determine that a change in tug power is needed by reference to visual marks or means such as reference to radars or electronic chart systems?	**2.95**
Interpretation / Decision Making	
1. Does the pilot check that his tug order is having the appropriate effect by reference to other aids such as visual marks or other position indicating equipment and if not take steps to rectify the situation?	**2.89**

4.9 Implications of Studies for Assessing Usability of Human Machine Interfaces for Energy Efficiency

In Part 1 of this research project we conceptualized a human-machine interface that combined the overall integration of ships systems found in an INS such as the NACOS INS with a fuel efficiency system such as Maersk Maritime Technology's Vessel Performance Management Service (VPMS). It was suggested there, and has been reiterated in Part 2 of this project, that effective passage and manoeuvre planning can make a significant contribution to energy efficient shipping and that such an interface might be the most appropriate solution, rather than creating a new, stand alone interface. If ships bridges need anything, it is de-cluttering rather than more interfaces – integration rather than disintegration.

However when we make changes to the way people perform their work tasks, including changing information we provide them, there is an obligation to understand the implications of those changes. In particular it is important to know if the changes will affect the cognition and attention of the bridge team (and therefore alter their situational awareness) or is likely to promote certain types of errors. In order to make these assessments the interface needs to be tested in a realistic scenario – best implemented in a simulated environment.

Both the studies reported in this chapter show promise for the development of metrics to assess the usability of an interface designed to improve energy efficiency. Situational awareness and human error are fundamental concepts for the safe operation of ships, and safety must not be compromised for energy efficiency, so there must be a determination of both these 'values' when considering a new Human Machine Interface (HMI).

The results of the study led by Di Lieto, and available in full in the publication Di Lieto and Brooks [75], indicate that it is important to not simply count errors made by people using systems. First, it is important to understand the competence of the user with the system itself. Secondly the type of error is important – be they slips, lapses or mistakes. Slips are particularly important, because they are unintended consequences of intended actions. Mistakes are typically caused by a lack of understanding and it is important to dig deeper into why that gap in knowledge exists.

The results of the study by Dann [76] have created a reliable set of behavioural markers for assessing situational awareness. These could be used to assess the implications for human performance of an integrated energy efficiency and ship maneuvering interface. Assessing a group of expert ship handlers led to an average performance that was very close to being rated 'good' for the majority of markers. A few markers did not rate as high (e.g., Does the pilot check the helm indicator when an order is given?; Does the pilot revert to a stereotype when things are not going according to plan? (Forgetfulness, higher pitched voice and etc) however there was no particular pattern to these.

4.10 Human Factors Implications for Maritime Education and Training associated with Energy Efficient Shipping

4.10.1 Introduction

Earlier sections of this report have demonstrated that small variations in speed (e.g., a reduction of ½ a knot) can lead to significant savings in GreenHouse Gas (GHG) emissions. This leads to the obvious question: 'If such a significant reduction is achievable, why isn't it implemented more readily'? Part of the answer is of course that the value of the reduction to the ship owner, the charter party (should there be one) and the Master is mostly not comparable to the value that they perceive is associated with on-time performance. The issue of building energy efficient operations is therefore associated with what we value and how individuals, organizations and even national cultures rank these values. Therefore it would seem implausible that any training that advocated methods for energy efficient shipping would exclude information on why we need to increase the relative value of being energy efficient. It is important to understand that seafarers will make decisions about vessel speed and engine performance with respect to a complex set of ship and organizational norms. While we can train seafarers to certain operational 'best practices' for energy efficient shipping, unless those cultural norms shift to adjust the relative value of energy efficiency, sub-optimal outcomes will be achieved. Having said this, environmental awareness is not the focus of this section of the report, so our attention turns to the issue of usability of human-machine interfaces

4.10.2 Initiatives to promote usability within the maritime sector.

One of the key challenges on ships' bridges is to provide a greater level of integration, and promoting usability through a human-centred design process is a way to achieve this. Whether we are talking about decision-support tools for passage planning and maneouvring, or tools to identify energy efficiency, the key is to make the task safer, more efficient, less risky than it previously was. The empirical studies identified in this chapter demonstrate opportunities to test prototypes before they come to market in order to resolve problems before they lead to accidents.

4.10.3 Elements to Add to a Training Program

From a training perspective, there are several implications of this work for the development of a simulation-based training module to promote energy efficient ship movements, however we focus on the addition of two key modules to support the operational focus identified in the current report.

1. Provide trainees with a detailed understanding of the software/hardware being used to either support decision making, or in the case of a NACOS INS in TrackPilot mode, the automation of the maneouvre. Discuss automation in more general terms and the challenges it creates for the human element.

This can only really be achieved by interaction between an expert user and the trainees. An expert user in this context might be defined as a Master Mariner with significant operational experience with the system and a significant knowledge of the theory and principles – (hydrodynamic, computational) that underpin the system. This understanding needs to include building the trainees' knowledge of how and why these systems fail and what to do when they do. Human Factors refers to these problems as 'Out-Of-The-Loop Control Problems' because the human has been an observer of the system, but when the system fails, must assume manual control. Many Bridge Resource Management courses now include a topic on Automation. These tend to be relatively simplistic and there could be an opportunity to provide more targeted material about the human element issues associated with automation in this context, but we recommend also extending this module to discuss issues of usability and in particular how these tools have been evaluated and the limitations of these evaluations.

2. Balancing Values – Safety, Reliability and Energy Efficiency

As discussed above, decisions to reduce speed or alter engine performance are influenced by a complex set of organizational and ship-based norms. This section of the training package would unpack those norms and look at how they interact to influence decision-making. Again, Bridge Resource Management courses discuss notions of organizational culture and the associated issues, however this module would be designed to be more specific to the issue of energy efficient shipping and the specific operational contexts where that becomes important (e.g., route planning).

5 Application of a simulation-based module

5.1 Preliminary remarks

For the application of a practical exercise, firstly, the framework for justification and integration will be given to introduce such a dedicated training module. It is globally very well recognized, that best results regarding maritime safety bases on well-trained crews. The same is valid for environmentally-friendly operation of ships. Only mariners and crews who have background knowledge and who know how they can contribute in the best way to energy efficient and emission reduced ship operation will be able to contribute to the ambitious aims.

Numerous technological developments in other transport modes has made shipping to become one of the main contributors to air pollution especially in coastal zones and harbour areas sensitive to inhabitants living there. Beside the efforts undertaken by IMO, it is assumed that e.g. optimized manoeuvring regimes have potential to contribute to a reduction of GHG emissions. Such procedures and supporting technologies can decrease the negative effects to the environment and also may reduce fuel consumption. However, related training has to be developed and to be integrated into existing course schemes accordingly.

The International Maritime Organization (IMO), through its Maritime Environmental Protection Committee (MEPC), has been carrying out substantial work to provide the fundamental conditions for the reduction and stepwise limitation of greenhouse gas emissions from international shipping since 1997, following the adoption of the Kyoto Protocol and the 1997 MARPOL Conference. While to date no mandatory GHG instrument for international shipping has been adopted, IMO has given significant consideration of the matter and has been working in accordance with an ambitious work plan with a view to adopting a package of technical provisions.

In continuation of those efforts IMO intended to develop a Model Course aiming at promoting the energy-efficient operation of ships. Such a training course intents to contributing to the IMO's environmental protection goals as set out in resolutions A.947(23) and A.998(25) by promulgating industry "best practices", which reduce greenhouse gas emissions and the negative impact of global shipping on climate change.

In this chapter the outline of the research work to develop training frameworks will be introduced and the fundamental ideas and concepts are described. The overall structure and the development of detailed content of a draft Model course will be exemplarily explained. Also, the developed draft modules for the model course and samples of the suggested integrated practical exercises will be introduced and discussed. One example and test results for an integrated simulation-based training module of the course are presented.

For the purpose of optimal distribution, the materials and data in thfollowing chapter have also been prepared for presenting and publishing at a conference and in conference proceedings.

5.2 Background and Present Situation

5.2.1 The work of IMO and the Protection of the Marine Environment

The IMO as the main international body is the driving force that has taken the responsibility for developing and adopting globally binding rules, regulations and guidance not only on safety and efficiency of ships but also on the protection of the marine and atmospheric environment from shipping operations. The work of the organisation's subjects related to the protection of the marine environment ranges from pollution prevention (including e.g. MARPOL) over pollution preparedness and response (e.g. OPRC 90), ballast water management and anti-fouling systems up to ship recycling and also covers special programmes and initiatives (like e.g. the 'GloBallast' initiative or the 'Marine Electronic Highway' demonstration project). All the initiatives and developed and adopted conventions and guidance are subject to training of the personnel involved in maritime transportation. Seafarers should be made aware of the conventions and their objectives. Without the participation of the frontline operators of the shipping industry, the implementation of the Conventions cannot be achieved properly. The integration of the environmental standards in the daily work practices onboard should ensure the implementation of the requirements.

The backbone of maritime training and education is IMO's International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (the STCW Convention), and its associated Code which were firstly adopted 7 July 1978 and set into force on 28 April 1986. There were numerous reviews and amendments. The latest and most important amendment of the convention and the code were adopted in June 2010 with substantial revisions and important changes of the training content and standards. These amendments were set into force by 1st January 2012. Among the significant number of changed subjects by the Manila amendments also new requirements for marine environment awareness training is mentioned (Bai, Jun, Zhang, Bin, Yu Jiajia, (2012).

New requirements about enhancing the protection of the marine environment are proposed and are addressed in "Chapter II Master and deck department" and "Chapter III Engine department". Consequently training and education for all mariners are concerned. Education and training courses should introduce knowledge of protection of the marine environment in order to enhance seafarers' consciousness. This requirement is accompanied by general requirements regarding the adjustment of existing MET management systems, teaching equipment and content as well as promoting teaching levels.

Beside the general requirements regarding the standards of training to be implemented into the course schemes for captains, engineers, deck and engine officers there are several model courses covering aspects of the protection of the marine environment. In the following chapters the Model course on energy efficient ship operation will be considered in more detail.

5.2.2 Development of a Draft Model course for Ship Energy Efficient Management Planning

With the specific focus on the reduction or limitation of greenhouse gas emissions from international shipping, IMO has given significant consideration of the matter and has been working in accordance with an ambitious work plan with a view to adopting a package of technical provisions to include among others:

- an energy efficiency design index (EEDI) for new ships;
- an energy efficiency operational indicator (EEOI), which will enable operators to measure the fuel efficiency of an existing ship and, therefore, gauge the effectiveness of any measure adopted to reduce energy consumption; and
- a Ship Energy Management Plan (SEMP) that incorporates guidance on best practices, to develop onboard their specific vessel, which include improved voyage planning, speed and power optimization, optimized ship handling, improved fleet management and cargo handling, as well as energy management.

It is in continuation of such efforts that it is intended to develop a Model Course aiming at promoting the energy-efficient operation of ships. The Course will contribute to the IMO's environmental protection goals as set out in resolutions A.947(23) and A.998(25) by promulgating industry "best practices", which reduce greenhouse gas emissions and the negative impact of global shipping on climate change.

Consequently the IMO Secretariat at its 60th session of the Marine Environment Protection Committee has commissioned World Maritime University to develop a draft model course for energy efficient operation of ships.

Based on literature and database reviews, questionnaires, interviews with stakeholders and further data collection a draft model course has been developed and submitted to IMO MEPC. This draft contains additionally and some kind unique a set of examples for practical activities by which both theoretical knowledge and practical skills can be easily obtained by participants to the course.

The initial course development was mainly be based on the introduced management tool of a Ship Energy Efficiency Management Plan (SEEMP) as agreed and circulated by MEPC 59/24 (Annex 19) as well as on the Guidance for the development of a SEEMP as agreed and distributed in MEPC.1/Circ.683.
Performed survey studies have shown that there have already been many courses or materials in terms of the energy-efficient operation of ships mainly developed by classification societies and shipping companies in the world. Though each of them is well developed and recognised as a good reference for the model course, the final draft model course submitted to IMO doesn't contain contents of those materials developed by them in order to avoid the issues on the copyright protection as well as confidentiality.

On the basis of the draft model course associated materials should be updated from time to time to introduce the latest development and situations in the shipping industry as well as the requirement of the related IMO instrument in terms of energy efficient operation of ships. Therefore, the final draft of the model course contains only the core part for the energy efficient operation of ships.

The developed draft outline of the model course suggested to MEPC for further discussion is given in the table in the following sub-chapter.

The draft course outline, submitted to MEPC, clearly states that its main purpose is to assist Maritime Education and Training institutions as well as their teaching staff in organising and introducing new training courses, or in enhancing, updating or supplementing existing training material, so that the quality and effectiveness of the training courses and materials may thereby be improved.

5.3 Development of a Train-the-trainer course

Beside the detailed development of a first draft outline for a training course on energy-efficient ship operation, which especially focuses on the onboard implementation of practical measures to ensure energy efficiency and reduced emissions of greenhouse gases.

The draft model course was developed mainly on the basis of the introduced management tool of a Ship Energy Efficiency Management Plan (SEEMP) as agreed and circulated by MEPC 59/24 (Annex 19) as well as on the Guidance for the development of a SEEMP as agreed and distributed in MEPC.1/Circ.683.

The draft serves as a starting point and should be further developed with experience gained by shipping companies and to support the distribution of good and innovative practices to implement sustainable energy efficient operation of ships and shipping companies.

As a continuation and accompanying measure the IMO also supported and drove forth the development of a train-the-trainer course on greenhouse gas emissions. Among others, this initiative was to accelerate the process of distribution of knowledge and good practices to all IMO member states.

The course development aimed at a training package to promote energy efficiency operations in shipping and is performed to provide a trainer's as well as a trainees manual, samples of presentations for use in lectures and seminars and a generic delivery guidelines. The course development also included a phase for testing the package in order to ensure a common understanding of the issue and moreover to develop basic capacity among the developing regions.

One of the main goals of the development work was to provide a ready-to-use training package and its accompanying presentations which focus on GHG issues in shipping.

The five modules of the package are designed to be adaptable and focus on the operational issues relevant on board as well as ashore. The course comprises the following five modules:

- Module 1: The climate change and the international response;
- Module 2: From Management to Operation;
- Module 3: Port stay and its Impacts
- Module 4: En Route
- Module 5: Energy Efficiency Management Systems

These modules contains lectures and workshop seminars, including presentations, discussions and group works and are embedded by discussions to explain IMO's intentions, provision of pedagogical guidance to experts as well as feedback sessions.

Outline of the draft IMO model course for "Energy Efficient Operation of Ships"

	Module & Task	Course hours	Lecture	Practical Activity
1	**Background**	**4 hours**		
1.1	Climate Change	4	2.0	-
1.2	IMO related work		2.0	-
2	**Guidance on best practices for fuel-efficient operation of ships Section I: Fuel efficient operations**	**18 hours**	**14 hours**	**4 hours**
2.1	Improved voyage planning		2.0	2.0
2.2	Weather routing			
2.3	Just in time			
2.4	Speed optimization			
2.5	Optimized shaft power			
	Section II: Optimized ship handling			
2.6	Optimum trim		2.0	2.0
2.7	Optimum ballast			
2.8	Optimum propeller and propeller inflow considerations			
2.9	Optimum use of rudder and heading control system (autopilots)			
	Section III: Hull and propulsion system			
2.10	Hull maintenance		2.0	2.0
2.11	Propulsion system			
2.12	Propulsion system maintenance			
2.13	Waste heat recovery			
	Section IV: Management			
2.14	Improved fleet management		2.0	2.0
2.15	Improved cargo handling			
2.16	Energy management			
2.17	Fuel type			
2.18	Other measures			
	Section V: Other Issues			
2.19	Compatibility of measures		1.0	1.0
2.20	Age and operational service life of a ship			
2.21	Trade and sailing area			
3	**Application**	**6 hours**		
3.1	Planning	6	4.0	2.0
3.2	Ship-specific measures			
3.3	Company-specific measures			
3.4	Human resource development			
3.5	Self-evaluation and improvement			
3.6	Voluntary reporting/review			
4	**Implementation and Monitoring**	**2 hours**		
4.1	Implementation	2	1.0	1.0
4.2	Monitoring			
	Total Course hours	**30 hours**	**18 hours**	**12 hours**

The submitted draft clearly states that its main purpose is to assist training providers and their teaching staff in organising and introducing new training courses, or in enhancing, updating or supplementing existing training material, so that the quality and effectiveness of the training courses may thereby be improved.

5.4 Practical Exercises – Enhanced Ship-handling Simulation Training for Energy-efficient Ship Operation

Five main subject areas for training have been defined in the draft model course on energy efficient ship operation and for each section practical activities are suggested. For instance "Fuel efficient operations" addresses the fields of voyage planning, weather routing as well as "Just-in-time" operations and can preferably be trained in ship handling simulation exercises.

The subject "Improved voyage planning" is foremost dedicated to the appropriate implementation of procedures according to IMO resolution A.893(21) (25 November 1999) – (and Chapter VIII of STCW Code) 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.

With respect to potential measures for green ship operation related to nautical departments, voyage planning and weather routing are seen as the "macro (planning) level" for rather strategic decisions whereas manoeuvring planning is seen as the micro (planning) level belonging to tactical decisions of the ship navigation process.

"Just-in-time" practices are described with emphasize 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, minimize delay, and produce reliable work schedule.

A sample should be given here for the section entitled "Optimized ship handling" where, among others, optimum trim and ballasting but also optimum propeller and propeller inflow considerations and optimal use of rudder and heading control systems are addressed. These items have impact on manoeuvring performance on both the macro (voyage planning in open sea areas) and the micro (manoeuvre planning in coastal areas and harbour basins) planning level and therefore are also relevant for the development of simulation-based training modules of such a training course.

Fig. 103: Recorded tracks of real harbour manoeuvres of a ferry

From research studies into the application of advanced tools for enhanced manoeuvre planning in coastal areas, approaches to ports and even in harbour basins specifically using Fast-Time-Simulation technologies for planning and monitoring purposes (Benedict, K.; Baldauf, M.; Fischer, S., Gluch, M. Kirchhoff, M.; 2009) it is known that detailed pre- planning of manoeuvres can significantly contribute to more energy-efficient ship operation in the harbour areas. Furthermore, as demonstrated in the simulations studies, there is clear potential for time as well as fuel savings and consequently also for the reduction of GHG emissions. The figure below depicts one section of a harbour area considered in a field study and additionally shows exemplarily the tracks of a ferry recorded onboard and ashore (synchronized VDR and AIS data) when manoeuvring in the harbour basin.
WINNES and FRIDELL (2010) have proven by direct measurements the emissions of both the main greenhouse gases NOx and CO2 of vessels are significantly higher especially when they are manoeuvring in coastal areas and harbour basins.

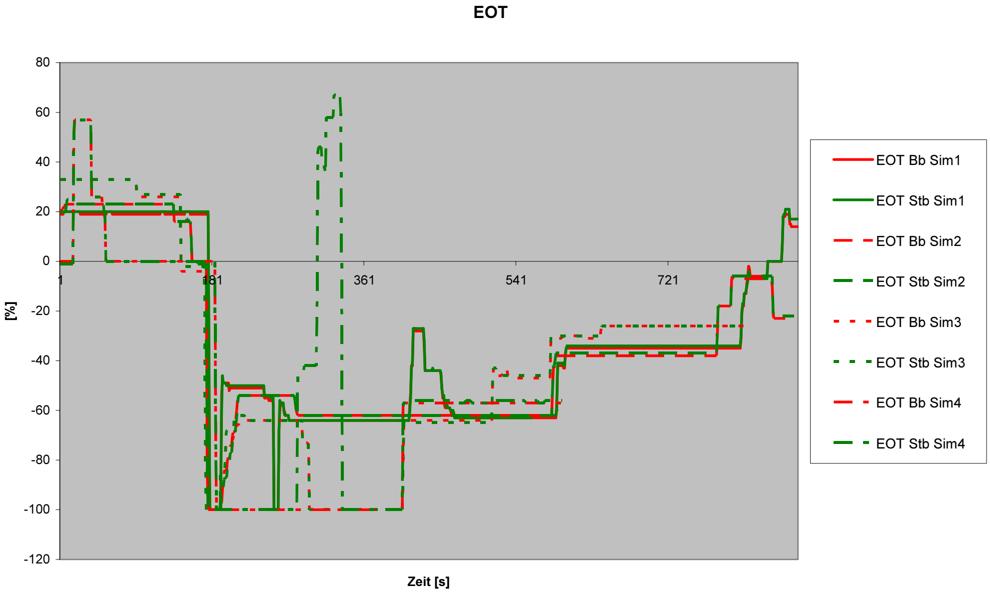


Fig. 104: Analysis of elementary manoeuvres of a ferry operating in a harbour basin (sample use of thrusters)

In the frame of the measurements of the combined field studies and simulation-based experiments of the IAMU project "ProGreenShip" (Baldauf et al (2012)) it was analysed that the number of elementary manoeuvres (defined as each given command for rudder, thrusters, engine etc. to manoeuvre the ship) is very high. Also the intensity (in terms of the used energy) of the used steering equipment is on a high level. An example is shown in Figure 2: different graphs are shown representing times and the intensity of thrusters' manoeuvres and illustrating that they were used relatively often and a high power rate.

5.5 Integration of IMO Competence-based training Objectives into Simulation Scenarios

As identified above, careful and thorough planning on macro (route optimisation including weather routeing) and micro level (optimisation of manoeuvring regimes in port approaches and harbour basins) are key elements for energy-efficient ship operation. Good planning needs experience and associated training.

Modern comprehensive improved voyage planning nowadays can be performed by using a dedicated software system providing processed information regarding e.g. currents, tidal streams, and impact of shallow water as well as weather 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 preferably connected to ship engine simulator.

In addition, there are also game-based simulators available enabling demonstrating relationships between power, speed, fuel consumption and CO2 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. However,

we have to consider that this practice is very often dictated by the ship's schedule and lack of reliable data concerning berth availability.
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 table. The framework allows for flexible integration of the suggested exercises into an applied IMO model course.

For a simulation-based exercise dedicated to the micro level planning 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 harbour is suggested. A potential frame for the sequence of events and tasks of such an exercise is given in table 2.

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

The learning objectives of the training unit including the practical activity should focus on the application of good practices for manoeuvre planning, the use of the available appropriate means, and consideration of different trim options and potential impact of wind on the manoeuvre performance. The paramount planning process must be completed with an updated manoeuvre plan available and appropriate for monitoring during the real conduction of the harbour manoeuvres.

The figure below gives an example for such a detailed manoeuvre plan developed with the sophisticated SAMMON tool (Benedict, K.; Baldauf, M.; Fischer, S.; Gluch, M.; Kirchhoff, M.; Schaub, M.; M.; Klaes, S. 2012) for planning, designing and monitoring ship manoeuvres. The picture shows the approach to the berthing place in the harbour basin of the port investigated in the above mentioned study for the manoeuvring regime of a RoRoPax ferry. The ship shapes in the chart represent the manoeuvring points (MP x) where a planned elementary manoeuvre is to be executed.

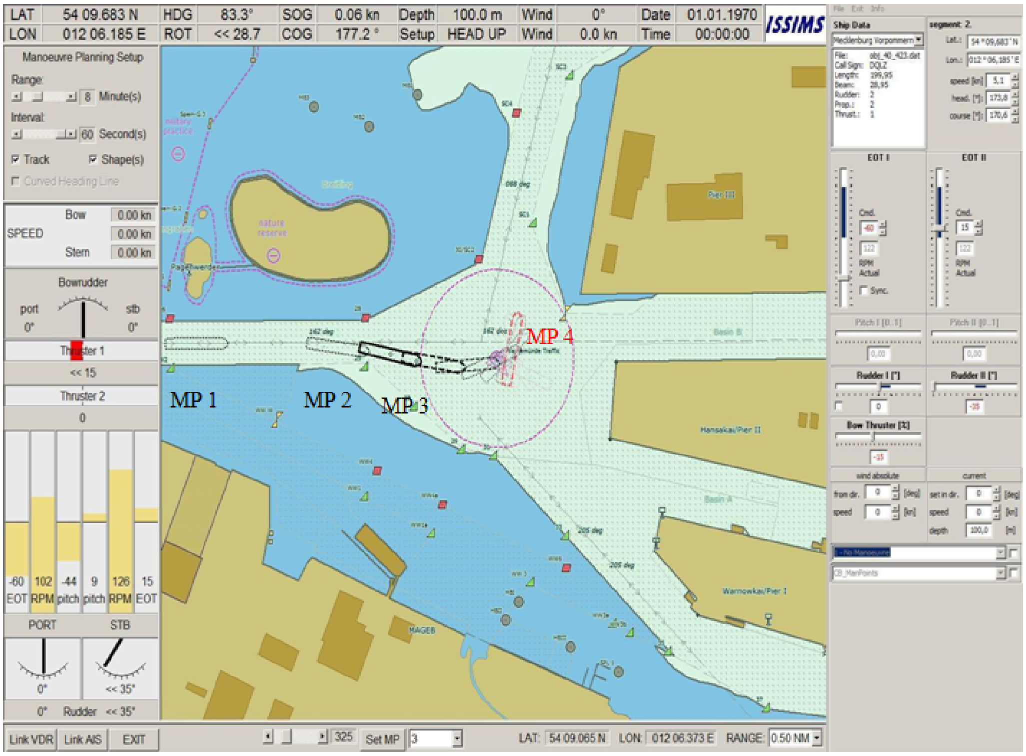


Fig. 105: Planning of elementary manoeuvres using an ECDIS based planning station with integrated Fast-Time Simulation functionality to approach the berthing place

One of the fundamental ideas of the SAMMON tool for the planning of complex manoeuvring regimes in a harbour basin is the dynamic prediction of the ship movement in response to any steering command and simultaneously taking into account the actual ship status as well as the environmental conditions (Källström, CG., Ottosson, P., Raggl, KJ., 1999).

During tests trainees planned manoeuvre steering sequences with just only less than ten elementary manoeuvres compared to more than 20 of the analysed real manoeuvring regimes. Moreover the conduction of the manoeuvres to approach the berthing were also faster and up to six minutes were saved in the simulation environment compared to the real manoeuvre regimes.

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

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 the IMO model course and were forwarded accordingly.

Integration of a simulation-based exercise into a module on overall voyage management and e-Navigation

From a pragmatic point of view the integration of a practical exercise using simulation seems to be voyage management in general. It allows for a general justification of the subject that can be integrated into the module. This has to be given to the students and trainees. Focus should be laid on different techniques and tools that are presently available and can be applied for energy-efficient and environmentally-friendly ship operation.

As suggested by the IMO GHG-Train-the-Trainer course such a module usually should comprises subjects of:

- Just-in-time,
- Virtual arrival,

- Weather Routeing,
- Tools to support energy efficient ship operation as well as
- Future developments and theier potential impact.

Manoeuvring planning and monitoring as investigated in this project can be integrated into the unit on "Supporting Tools". They again can be divided into tools for use in different sea areas. As contribution to the draft course the following elements have been developed:

1. Samples for supporting tools for green ship operation in open sea areas:
   - Voyage performance analyser: There are systems that can routinely measure ship speed, shaft propulsion power and environmental conditions. These systems could be used for monitoring voyage performance. They could also help to identify reasons for poor performance, deviations in speed and so on.
   - ECDIS (Electronic Chart Display and Information System): The electronic chart and information system could be used by means of integrated information for voyage management purposes and especially may support energy efficient ship operations in several ways.
   - Autopilot: The new generation of Autopilots are under development or already available on the market and are provided by several manufacturers. Sophisticated autopilot systems provide technical facilities to also adapt the steering actions to prevailing weather conditions and especially the sea states, even automatically. Those systems are providing dedicated functions such as 'precision' and 'economy' modes. An Autopilot operating in Economy mode reduces rudder movements and consequently contributes to fuel savings. On the other hand, using Autopilot in the Precision mode allows for the best accuracy and ensures safe navigation.

2. Samples for supporting tools in coastal areas and harbours

Generally, ship manoeuvres can be divided into routine manoeuvring and manoeuvring in safety-critical and emergency situations. This division can be developed further by considering different sea areas where manoeuvres have to be performed: e.g. in open seas, in coastal waters and fairways as well as in harbour approaches and basins. Routine manoeuvring in open seas covers ship-handling under normal conditions, e.g. in order to follow a planned route from the port of departure to the port of destination; this includes simple course change manoeuvres, speed adaptations etc. according to the voyage plan. Manoeuvring in coastal areas, at entrances to ports and in harbour basins include manoeuvres, e.g. to embark and disembark a pilot, to pass fairways and channels and even berthing manoeuvres with or without tug assistance. However, manoeuvring is always connected to fuel saving and emission reductions and therefore is crucial for energy-efficient and environmentally friendly ship operations.

Ships, during their normal operation, generate different kinds of pollutants emitted into the atmosphere. For example, the refrigeration plants of ships can contain ozone depleting substances; these are hydro- and chlorofluorocarbons. 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 CO_2 and that therefore the emission factor is dependent on the carbon content of the fuel.

It is known that shipping is a main contributor to air pollution, especially in coastal zones and harbour areas where many people are concerned. Measurements in the south Sweden region have shown that almost 70% of SO_2, approximately half of NO_x and 20% of particles in the air are caused by shipping activities. The manoeuvring activities in coastal zones, port approaches and harbour areas are usually higher than when sailing in open seas. Optimized manoeuvring regimes have great potential to decrease the negative effects and also may reduce fuel consumption. This can be realized by using manoeuvring assistance tools.

- Manoeuvring assistance tools: With the introduction of modern information and communication technologies, more and more assistance tools have been introduced additionally to standard mandatory navigational bridge equipment. Among those integrated systems there are tools for planning and monitoring purposes on the macro and micro level. **Macro planning** deals with waypoint planning for the sea trail of any voyage from point A to B. **Micro planning** is dedicated to the planning of detailed steering sequences for complex manoeuvres in harbour areas, even including berthing operations.

- Sophisticated manoeuvring assistance tools take into account not only the prevailing environmental conditions (especially wind, current and so on), but also the actual ship status conditions and the impact of their parameters (beside course, speed and heading also i.a. currents, draught and water depth). The purpose of using such systems is to foresightedly adapt the manoeuvring strategies and regimes into an energy-efficient range with the efficient use of energy and resources and consequently minimize the emissions of GHG. One of the main aims of pre-planning manoeuvres regarding energy-efficient ship operations is the adaptation of the number of elementary manoeuvres. Elementary manoeuvres are defined as each single manoeuvre or command of rudder, engine and thrusters and any further steering equipment.

  Once the planning process is completed and approved the bridge team can follow the steering sequence using any dedicated display to check the plan is being kept.

  The use of sophisticated planning and monitoring tools optimizes the number of elementary manoeuvres in order to meet the requirements for the safety of navigation while also meeting the requirements for the minimum use of the steering equipment and saving fuel and time and simultaneously reduce GHG emissions when operating in coastal and harbour areas.

While the above mentioned aspects can be presented in a lecture or workshop session, a practical exercise using simulation facilities is to demonstrate the potential and to deepen the knowledge about methods and techniques and on how bridge teams and ship crews practically can contribute to save time, and fuel and efficiently use the resource of energy and consequently ensure economic success and benefits.

Fig. 106: Simulation exercise on energy-efficient ship operation during the IMO GHG-T-t-T course at WMU - MaRiSa Simulation Laboratory

The figure above shows one scene on the test of the simulation-based exercise during the IMO-GHG-Train-the-Trainer course. An overall generic draft framework for such an practical exercise as basis for adaptation to own available facilities is given in the next chapter.

5.7 Draft Simulation Training Scenario Script

This sub-chapter provides the draft scenario script for the simulation-based exercise dedicated to green ship operation in sense of energy-efficient and reducing the ship emissions for integration into a maritime training and eduction course. This module was used in the IMO GHG train-the-trainer course held at WMU in May 2013.

Maritime Training Institution

Department of Energy Efficiency

Maritime Simulation Centre

Shiphandlingsimulator

SIMULATOR TRAINING - INSTRUCTOR INFORMATION

SCENARIO

Identifying number	**Energy-efficient Ship Operatioon**
Title	Manoeuvring in harbour basin
Created	**ID Firstname.Lastname**
Last update	**17. May 2013**
Training objective	Familiarisation with Manoeuvring methods
Simulator tool	Desktop / Full mission simulator (SHS) Bridge
Standard of competence	Master / Staff Captain / OOW
Own ship (ships)	STENA VORPOMMERANIA
Event description	

Remarks

Instructor description

Exercise description

- Student to become familiar with the area, the ship
- Student to perform one harbour approach pass the harbour basins up to berthing place using the conventional (intuitive) manoeuvring planing
- Familiarization with the tool for designing and monitoring manoeuvres
- Student to plan manoeuvring using the planning function
- Student to perform the manoeuvre (using dynamic prediction function)
- Student to exercise harbour manoeuvring using the function fordisplay and monitoring the pre-planned track

Action/time	**Activities**
18. X + 60 min	Manoeuvring and communication according to the (conventional and simulation-based) manoeuvring plan with and without monitoring and prediction function
19. X + 64 min	as above
20. X + 75 min	as above
21. X + 80 min	as above
22. X + 85 min	…
23. X + 90 min	and so on – to be continued as useful and seems to be supportive

Assessment criteria

- Safe passage of the fairways and basins
- Keeping the time schedule
- Fuel consumption
- Manoeuvring times
- Number of elementary manoeuvres
- Level of usage of steering commands (especially engine, rudder, thrusters)

Remarks

The planned exercise may develop in a complete different way, worse or better than planned.

All parties involved have to react and help creating a scenario as real as possible in all contributing attributes.

Initial Steering data of own ship and the target vessels

Sea Area:

Approach a port area entering and passing of harbour basin for berthing at ferry terminal

Type	Name / Call Sign	POS LAT/ LON BRG/RNG	Course /°/	Speed /kts/ EOT	Vessel Buoy Others	Remark	Destination
Own Ship							
OS 1 BR 1	STENA VORPOMMERANIA		152	7,5 kn			LP 6
Target Ships – Same Way							
TG 1	None						
TG 2	None						
Target Ships – Opposite Way							
TG 9	None						
Target Ships – Crossing							
TG 13	None						
Target Ships – Anchorage							
TG 14	None						
Target Ships – Standby							
TG 20	None						
Target Objects – Other							
TG 24	VTS						

Instructions for the handling of the traffic-ships

The scenario does not contain any traffic ship.

Ships-Name	Instructions for the handling of the Traffic-Ships by Instr. / Co.-Instr.

WMU – Desktop Ship Handling Simulator

TITLE: Energy-efficient ship operation

		Trainee information			
Date	:	17 May 2013		**time**	10:00
Ship particular					
Name	:	STENA VORPOMMERANIA			
Call sign	:	S69J			
Loading conditions	:				
Draft	:	5,2m fore	5,2m aft		
Starting position	:	Centre of canal fairway			
Course	:	152			
Speed	:	7,5 knots	EOT: 50%		
Ship-operating:		Ro-Pax Germany-Sweden			
Engine condition	:	manoeuvre mode			
Disturbances	:	none			
Steering	:	manual/automatic			
No. of passengers	:	255			
No. of crew	:	66			

(For further details please use the wheel house poster)

Environment		
Wind	:	Bft 1-2
Current	:	0
Tide	:	none
Sea state	:	0
Visibility	:	good (8 10 nm)

VHF-communication

Station	**range**	**Channel**
Port Traffic	5	13

Further information

Charts : SHD 162 ()

Int. Communication : Walky-Talky and
Intercommunication system Bridge – Engine Control Room

Ext. Communication : Bridge – VTS (entrance clearing procedure)

Masters instructions

- Approach berthing place at ferry terminal safely take into account energy-efficient operation of the ferry
- Keep the time schedule!
- Use all available means

Navigational equipment

- (D)GPS
- Echo sounder
- Speed log (DOLOG)
- RADAR/ARPA
- ECDIS/Electronic Chart
- Bearing Device
- Nautical charts, Mariners Routeing Guide (see above)
- Sailing Direction NP
- ALRS Vol. 5 GMDSS, Vol. 6(4) Pilot Service and VTS
- Emergency Procedures
- **SAMMON (Simulation Augmented Manoeuvring design and MONitoring system)**

TABLE OF WAYPOINTS

The voyage and manoeuvre plan resp. have to be prepared berth-to-berth by the Navigational Officer in advance.

No.	From Waypoint POS LAT / LONG BRG / RNG	To Waypoint POS LAT / LONG BRG / RNG	COURSE /°/	DISTANCE /nm/	CHART – No.	REMARK

Manoeuvre- Mode (Ahead / Astern)			

Operation of the Main Engine	
1. **Control System of the Main Engine**	
Engine Room	Control System of Main Engine from Engine Room
Engine Control Room	Control System of Main Engine from Engine Control Room
Bridge	Control System of Main Engine from Bridge By pressing this button, light is flashing up to release the changing over from Engine Control Room After release the change over light is flashing constant.
2. **Control program of the Main Engine**	
Sea	Main Engine in normal control program (service speed cruising speed)
Manoeuvre	Main Engine in manoeuvre control program (Manoeuvre speed)
Crash	Main Engine in Crash speed up program
3. **Alarm displays**	
D1 Alarm	Display of the SES Alarm D1: The main engine will be stopped in about 1 min Emergency stop program (shut down mode)
D2 Alarm	Display of the SES Alarms D2: The power of the main engine will be reduced to 80% (slow down mode)
Emergency Disturbed	Disturbance in the safety system / Engine Control Room has to be manned immediately
4. **Emergency stop (Crash Stop)**	
D1 Emergency Suppress	By pressing this button the main engine doesn't slow down with Emergency Stop in case of D1 Alarm
Reset Emergency	Safety system is activated / it is impossible to start the main engine without activating this system
Emergency Stop	The main engine slow down immediately

Data sheet for a Shiphandling simulator Exercise
For Session preparation by Co-Instructor

Exercise: ProGreenShip_001_BR1_Bal

Titele of exercise	ProGreenShip – 1
Type of exercise	Demonstration
Simulator type and configuration	DT-SHS
Bridge	Bridge 1
Instructor work station	1 – 3
ILT-statione	Nil
Replay-System	Yes
Exercise duration (total)	appr. 60 min
Logfile-resording / Bridge(s)	Yes
Own Ship(s)	
Bridge 1: Shp type / mode	RoPax-Ferry
POS / Course / Speed / RPM / EOT	Centre of Sa canal fairway,
Bridge 2: Shp type / mode	Nil
POS / Course / Speed / RPM / EOT	
Bridge 3: Shp type / mode	NIL
POS / Course / Speed / RPM / EOT	
Bridge n: Ship type / mode	NIL
POS / Course / Speed / RPM / EOT	
Number of Traffic ships	NIL
Number of further Objects	NIL
Environmental conditions	
Date / time	17. May 13 / 10:00 LT
Fixed Light on / off	Off
Wind direction / force	N/1-2
Current direction / force	None
Tides: Low water timei	n.a.
Sea charts	SHD 152
Further Documentation	ALRS Vol.), SD NP
Remarks / Comments	

ADDITIONAL INFORMATION

- as deemed helpful and needed

Engine Control

5. **Control Main Engine**	
Engine Room	Control of Main Engine from ECR
Engine Control Room	Control of Main Engine from ECR
Bridge	Steuerung Hauptmaschine von Brücke / Taste wird gedrückt, blinkt bis im Engine Room / Engine Control Room Übergabe freigegeben / Bei Freigabe Dauerlicht
6. **Standard Program Main Engine**	
Sea	Engine in normal status and program
Manoeuvre	Engine with quick Acceleration Program
Crash	Engine with Crash- Acceleration Program
7. **Alarm, Alert and Warning Display**	
D1 Alarm	Display of SES Alarm D1: Main Enginge will be stopped after appr. 1 min if in Emergency Stop-Program
D2 Alarm	Display of SES Alarm D2: Main Engine reduces to 80% power
Emergency Disturbed	Failure / Disturbance in Protection System, Engine Control Room hast o be manned immediately
8. **EMRGENCY-Control**	
D1 Emergency Suppress	Button avoids deceleration of the Main Engine in case of D1 Alarm with Emergency stop
Reset Emergency	Activates protection system – without acknowledgement main engine can not be re-started
Emergency Stop	Immediate stop of Main Engine

5.8 Concluding Remarks

Within this chapter general IMO activities to reduce pollution of the marine and atmospheric environment have been re-called and some selected training requirements and needs resulting from latest STCW amendments and developments of model courses are described.

Focus was laid on the development of the model course on energy efficient ship operation.

Moreover, investigations into potential contributions of ships to reduce greenhouse gas emissions that were performed in the frame of the development of the model course and a train-the trainer training package, are described.

One of the main objectives of the course development is to distribute knowledge and good practices. That is why a good balance of theoretical and practical activities should be provided by the course framework and simulation exercises should be integrated to highlight some key principles.

The main objective of the exemplarily described investigations into the integration of practical activities was to develop the basics for a simulation based training module that supports optimized ship operation by means of enhanced integrated manoeuvring planning and monitoring to assist captains, pilots and navigating officers when entering port entrances and manoeuvring in harbour areas. For this purpose a prototyped manoeuvring assistance system was integrated into a full-mission simulation environment and tested with respect to potentials for energy and time savings. It was demonstrated that by means of enhanced simulation-based technologies time savings are possible and allow for a reduction of fuel consumption while simultaneously keeping the economic constraints of the voyage's time schedule and consequently reduce emission of greenhouse gases.

6 Summary and conclusion

Within the project "ProGreenShipOperation II" further investigations into transfer of the results from phase I of the project into a training module to support environmentally-friendly green ship operation in order to enable ship crews to actively contribute to the reduction of greenhouse gas emissions have been performed. As a continuation the focus of the investigations in the second phase of the project was again laid on operation of ferries and the applied use of methods and tools for advanced maneuvering assistance for designing, planning and monitoring of complex and combined manoeuvres.

The main objective of the project's second phase was to complete the investigations into the development of the basics for a simulation based training module and apply them so that "green ship operation" by means of enhanced integrated manoeuvre planning can be applied to assist captains, pilots and navigating officers when they are entering port entrances and manoeuvering in harbor areas.

For the purpose of demonstrating the potentials for time saving and reduction of greenhouse gas emissions the SAMMON software package for simulation based augmented maneuvering design, planning and monitoring was integrated into a full-mission simulation environment of Hochschule Wismar and World Maritime University and exemplarily tested within maritime training courses.

The detailed study into effects of time savings and reduction of GHG emissions performed in phase I has been continued and training material including simulation-based calculation for a number of case studies has been conducted and delivered.

Also detailed investigations into the human factor related aspects of environmentally-friendly green ship operation has been completed. Studies into the assessment of human centred design approaches were performed and valuable material relevant for maritime education and training has been delivered and comprehensive lists of findings and recommendations on implications for MET have been drafted.

Overall it can be stated that the work performed by the partners substantially contributes to improve energy-efficiency of shipping and moreover to maritime safety and efficiency.Further dedicated exercises should be drafted according to the specific needs of shipping companies and ports respectively. Further new training items as e.g. e-Navigation but also the use of new types of fuel needs to be integrated into course programs as well.

A process of continuous updating of training content and related practical exercises remains a task of the highest priority also for promoting energy-efficient green ship operation.

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ANNEX:

Input data for Simulation (belonging to Chapter 2)
Control of Main Engine from ECR

RO- PAX (with Displacament)

Nº Ref	Name	IMO No.	Year of build	Ship Builder	Clase	Displacement (t)	GT	MMEE (kW)	Max speed (Knots)	Service Speed (kn)	P Aux (kW)
10a	BLANCA DEL MAR/ ARV3	9147306	1999	SRL SEVILLA ASTILLEROS SL	LR	16826	22152	23760		22,5	5840
10c	STENA LAGAN	9329849	2005	VISENTINI CANTIERE NAVALE	LR	17754	27510	21600	24,5	23,5	9000
11a	FANTASTIC	9100267	1996	NUOVI CANTIERI APUANIA	LR	19067	35186	25920		22	6900
11c	NORRONA	9227390	2003	FLENDER	DNV	18680	35966	21600		21	5450
12a	SPLENDID	9015747	1994	NUOVI CANTIERI APUANIA	RINA	19067	39139	23040		23	6450
13c	BERLIOZ	9305843	2005	ATLANTIQUE CHS	BV	20223	33940	39100	28	25	13360
14c	DELFT SEAWAYS	9293088	2006	SAMSUNG HEAVY INDUSTRIES	LR	20418	35923	38400	28	25,5	14440
15c	DOVER SEAWAYS	9318345	2006	SAMSUNG HEAVY INDUSTRIES	LR	20418	35923	38400	28	25,5	14440
16c	STENA TRANSIT	9469388	2011	SAMSUNG HEAVY INDUSTRIES	LR	21455	33690	21600	23,6	22,2	7000
17c	STENA TRANSPORTER	9469376	2011	SAMSUNG HEAVY INDUSTRIES	LR	21455	33690	21600	-	23,6	7000
18c	BLUE PUTTEES	9331177	2006	BALTIYSKIY	DNV	21464	28460	21600		22,2	6392
19c	HIGHLANDERS	9331189	2007	BALTIYSKIY	DNV	21469	28460	21600	25	22,2	6392
1a	LAS PALMAS DE GRAN CANARIA	9031997	1993	UNL VALENCIA	BV	7547	11032	5808		16	2800
1b	SCHLEWIS	9151539	1997	GienssenNord	GL	20623	15187	17600	20	15,5	3520
1c	GOTLANDIA II	9328015	2006	FINCANTIERI R. TRIGOSO	LR	2200	6554	36000	40	36	1890
20c	VICTORIA	9281281	2004	AKER FINNYARDS OY RAUMA	BV	21540	40975	26240	23,4	22	9264
21c	SPIRIT OF FRANCE	9533816	2012	STX FINLAND OY-RAUMA	LR	26813	47592	30400	23,5	22	18332
22c	SÌRIT OF BRITAIN	9524231	2011	STX FINLAND OY-RAUMA	LR	26813	47592	30400	23,5	22	18332
24c	COLOR FANTASI	9278234	2004	KVAERNER MASA-YARDS	DNV	33295	75027	31200		22,3	17600
25c	STENA HOLLANDICA	9419163	2010	NORDIC YARDS WISMAR GMBH	LR	33700	64039	33600		22,5	11000
2a	ISLA DE BOTAFOC/BARI	7813937	1980	HARLAND &WOLFF BELFAST	LR	7780	12705	15300		19,5	
2b	KOPERNIK	7527887	1977	Berges	GL	10907	14221	12460		18	6230
2c	ISLAND SKY	9370458	2008	VANCOUVER SHIPYARD	LR	3400	4313	5292	16,6	14,5	1000
3a	MELOODIA/ ARV1	7816874	1979	JOS L MEYER PAPERBURG	BV	11087	17955	17608		21,5	4192
3b	URD	7826855	1981	Nuovi Canteria apuania	LR	9589	13144	8826		17,5	5057
3c	NORTHERN ADVENTURE	9257735	2004	ATSALAKIS-SIDIRONAFTIKI	LR	5500	9844	16000		22	3000
4a	MERCEDES DEL MAR/BRIDGE	7356252	1976	NEW SOUTH WALES	LR	11505	16537	13240		18	1600
4b	WOLIN	8420842	1986	Moss Fredistad Moss		14739	22874	13200		18	3300
4c	LOBO MARINHO	9267390	2003	BALTIYSKIY	GL	5827	8082	16000	22	21	2790
5a	EUROSTAR ROMA/ SKANIA	9086588	1995	SCHINCHAU-SEEBECKWERFT BREMENH	LR	15797	23933	31680		27	5840
5b	GABRIELLA	8917601	1992	brodosplit	DNV	15515	35492	23760		21,5	8192
5c	NORTHERN EXPEDITION	9408413	2009	FLENSBURGER KG	ABB	8099	17729	9000	21,1	20,5	9088
6a	SOROLLA	9217125	2001	BARRERAS	BV	16555	26916	28960		23	7850
6b	VIKING XPRS	9375654	2008	Aker Yard Oy -Turku	LR	19750	35918	40000		25	3000
6c	HAMMERODDE	9323699	2005	MERWEDE SHIPYARD BV	BV	8227	14551	8640		18,8	3865
7a	MURILLO	9237242	2002	IZAR CONSTRUCCIONES NAVALES SEVI	LR	16800	25028	23760		22,8	6400
7b	STENA VISION	7907659	1987	Komuny Paryskej	LR	19872	39191	20760		20	6470
7c	SMYRIL	9275218	2005	NAVANTIA SA	DNV	8600	12670	13440	23	21	4530
8a	PAU CASALS/NORMAN TRADER	9147291	1958	SRL SEVILLA ASTILLEROS SL	LR	16826	22152	23760		22,5	5840
8b	STENA SCANDINAVICA	9235517	2003	Hyundai	LR	27828	57958	25920		22	10000
8c	NISSOS MYKONOS	9208679	2005	HELLENIC SHIPYARD	RINA	8742	7882	31680	28,5	26,3	5100
9a	ZURBARAN	9181091	2000	SRL SEVILLA ASTILLEROS SL	LR	16826	22152	23760		22,5	5840
9c	STRAISTMAN	9323704	2005	VOLHARDING SHIPYARD	BV	8907	13906	8640		18,8	3865

RO-PAX BARCELONA

nº	NºIMO	Displacement	Ship Yard	Building year	SSC C	Kg NOx h maniov ring	Kg NOx h Port	G.T.	MMEE TOTAL(kW)	2s/ 4s MMPP	Auxiliary Power(kW)	normal speed
1a	9031997	7547	UNL VAL	1993	BV	45,8	8,7	10971	5808	4T	2800	16
2a	7813937	7780	HARLAN	1980	LR	53,04	10,1	12705	15300	4T		19,5
2a	7816874	11087	JOS L ME	1979	BV	75,69	14,4	17955	17608	4T	4192	16
4a	7356252	11505	NEW SO	1976	LR	69,04	13,1	16537	13240	4T	1600	18
5a	9086588	15797	SCHINCH	1995	LR	99,92	19,0	23933	31680	4T	5840	27
6a	9217125	16555	BARRER/	2001	BV	112,4	21,3	26916	28960	4T	7850	23
7a	9237242	16800	IZAR CO	2002	LR	105,1	19,9	25028	23760	4T	6400	22,8
8a	9147291	16826	SRL SEVI	1958	LR	92,49	17,5	22152	23760	4T	5840	22,5
9a	9181091	16826	SRL SEVI	2000	LR	93,3	17,7	22152	23760	4T	5840	22,5
10a	9147306	16826	SRL SEVI	1999	LR	92,49	17,5	22152	23760	4T	5840	22,5
11a	9100267	19067	NUOVI C	1996	LR	146,9	27,9	35186	25920	2T	6900	22
12a	9015747	19067	NUOVI C	1994	RINA	163,3	31,0	39139	23040	4T	6450	23
13a	7818729		THE HAK	1979	NKK	114,2	21,7	7261	4413	4T	1200	15
14a	7501613		K ROGER	1976	GL	47,38	9,0	9079	8826	4T	2160	19,5
15a	7637149		VEROLM	1978	LR	56,38	10,7	13505	16184	4T	3200	21
16a	9265421		IZAR CO	2005	BV	83,6	15,9	20024	25154	4T		22
17a	9350680		NUOVI C	2007	RINA	104,2	19,8	25058	25200	4T		24,5
18a	9350692		NUOVI C	2007	RINA	98,17	18,6	25058	24600	4T		24,5
19a	7394759		NAIKAI S	1975	HELEN	106,3	20,2	25460	20596	4T	3520	21,5
20a	9287584		CANTIER	2004	RINA	109,8	20,8	26400	21600	4T		23,5
21a	9349760		CANTIER	2007	RINA	110,6	21,0	26500	21600	2T		23,5
22a	9208071		SAMSUN	2001	GL	132,5	25,1	30860	50424	4T	9200	28,5
23a	9015735		NUOVI C	1993	ABB	136,7	25,9	32777	23040	4T	6920	23
24a	9143441		NUOVI C	1998	RINA	164,9	31,3	39739	25952	4T		23
25a	9214276		NUOVI C	2002	RINA	205,7	39,0	49257	67200	4T	9440	28,5
26a	9214288		NUOVI C	2003	RINA	205,7	39,0	49270	67200	4T	9360	28
27a	9131527		FINCANT	1998	DNV	109,3	20,7		25020			22

RO-RO BARCELONA

nº	NºIMO	Displacement	Ship Yard	Building year	SSCC	Kg NOx h Port	G.T.	MMEE TOTAL(kW)	2s/ 4s MMPP	Auxiliary Power(kW)	normal speed
1	8203567	4583	ISKNG W	1983	GL	5,2521	4291	2120	4T		12,5
2	7812921	4653	DEUSCHE	1979	GL	47,42	3887	2118	4T	552	12,5
3	8009052	8210	GALATI	1984	DNV	11,109	9088	5300	4T	1375	15,5
4	8521945	8955	N SCHIFF	1985	RUSIAN	9,3135	6894	5296	4T	2080	13
5	8030283	10330	ASTANDE	1983	LR	14,579	10957	5296	4T	1440	13
6	8306589	12092	S THESEN	1984	ROMA BV	12,435	9983	10598	4T	2344	14,5
7	9142641	14004	HR & SPE	1997	BV	27,515	17907	14000	4T	3796	
8	7800746	15166	N ORESU	1978	DNV	24,355	16947	9000	4T	1615	16
9	7931765	35548	PUERTO	1982	LR	43,02	30969	17249	2T	5315	18,5
10	8996712	_	NS INDU	2000	DNV	26,777	236				
11	7531266	_	SHIMON	1977	BV	11,35	3629	8826	4T	1920	18,25
12	9119397	_	VA ASTILL	1997	LR	9,7198	7606	7400	4T	2424	17
13	7708297	_	SHIMON	1978	BV	11,491	8393	8826	4T	1920	21
14	8030295	_	ASTANDE	1984	LR	16,422	8762	52960	4T	1620	13
15	8502200	_	GALATI	1984	ROMA GL	13,942	9160	8826	4T	1840	17
16	7725130	_	ORP SHIZ	1979	LR	17,459	12076	5913	2T	2760	15,25
17	9129598	_	I CANTIE	1996	LR	33,192	18725	11120	2T	3140	19,7
18	9138783	_	ZIO VIAR	1998	DNV	28,667	21104	23040	4T	6400	22
19	8024284	_	SHIMA O	1981	NKK	40,536	27087	8826	4T	1320	18
20	7705960	_	BISHI NA	1979	LR	54,076	38963	22185	2T	7100	20,5
21	7705958	_	BISHI NA	1978	LR	52,614	38963	22185	2T	5950	20,5
22	9277802	_	IIA STOC	2003	DNV	78,586	57718	15540	2T	4410	20

RO-PAX BALTIC SEA

nº	NºIMO	Ship	Building year	Displacement	Ship Yard	SSCC	G.T.	MMEE TOTAL(kW)	Auxiliary Power(kW)	normal speed
1b	9151539	SCHLEWIS	1997	9306	GienssenNord	GL	15187	17600	3520	15,5
2b	7527887	KOPERNIK	1977	9834	Berges	GL	14221	12460	6230	18
3b	7826855	URD	1981	11477	Nuovi Canteria apuania	LR	13144	8826	5057	17,5
4b	8420842	WOLIN	1986	15572	Moss Fredistad Moss		22874	13200	3300	18
5b	8917601	GABRIELLA	1992	16562	brodosplit	DNV	35492	23760	8192	21,5
6b	9375654	VIKING XPRS	2008	19795	Aker Yard Oy -Turku	LR	35918	40000	1420	25
7b	7907659	STENA VISION	1987	20660	Komuny Paryskej	LR	39191	20760	6470	20
8b	9235517	STENA SCANDII	2003	31409	Hyundai	LR	57958	25920	1900	22
9b	7803205	KRONPRINS	1981		Naskow skibsvaerf	BV	16071	21600	6960	19
10b	7925297	TRELLEBORG	1982		Suewnsocwr	LR	20028	17600	4400	17
11b	8604711	JANSNIADKI	1988		Gotaverken		14417	11840	2960	16
12b	7901265	ROSELLA	1980		Warsila AB Turku	DNV	16879	17652	4413	21,3
13b	9188427	OPTIMA SEAWA	1999		Visentini Cantera Naval	RINA	25206	18900	3785	21,5
14b	7907661	STENA SPIRIT	1988		Lenina Stoczia	LR	39193	20760	6915	18,5
15b	9010175	TRASNEUROPA	1995		Gdanska stoczia	DNV	35533	23068	5767	18
16b	9017769	FINTRADER	1995		Gdanska stoczia	DNV	33313	23068		18
17b	9458535	REGINA SEAWA	2010		Nuovi Canteria apuania	RINA	25518	25200	0	24
18b	8818300	GRYF	1990		Bruces Verkstad	DNV	18653	7920	3960	16
19b	8601915	AMORELA	1988		Brodosplit	DNV	34384	23760	0	21,5
20b	8320573	MARIELLA	1985		Warsila AB Turku	DNV	37860	23008	5752	22
21b	9435454	SCOTTISH VIKIN	2009		Visentini Cantera Naval	RINA	26904	21600	0	23,5
22b	9350721	VICTORIA SEAW	2009		Nuovi Canteria apuania	RINA	25518	24000	12000	23
23b	9237589	SITJA ROMANTI	2002		Aker Finnyard	BV	40803	26240	6560	22
24b	9281281	VICTORIA I	2004		Aker Finnyard	BV	40803	26240	6560	22
25b	9443255	BALTIC QUEEN	2009		SXT Finland	BV	49915	32000	8000	22
26b	9333694	GALAXY	2006		Akerfinyed	BV	48915	26240	0	22
27b	9349863	COLOR MAGIC	2007		Aker Yard Oy -Turku	DNV	75156	33600	17760	22,1

RO-PAX RESTO DEL MUNDO

nº	Ship	NºIMO	Building year	Ship Yard	Displac ement	GT	MMEE TOTAL(kW)	Max speed (Knots)	normal speed	Auxiliary Power(kW)
1c	GOTLANDIA II	9328015	2006	FINCANTIERI R. TRIGOSO	2200	6554	36000	40	36	1890
2c	ISLAND SKY	9370458	2008	VANCOUVER SHIPYARD	3400	4313	5292	16,6	14,5	1000
3c	NORTHERN ADVEI	9257735	2004	ATSALAKIS-SIDIRONAFTIK	5500	9844	16000		22	3000
4c	LOBO MARINHO	9267390	2003	BALTIYSKIY	5827	8082	16000	22	21	2790
5c	NORTHERN EXPED	9408413	2009	FLENSBURGER KG	8099	17729	9000	21,1	20,5	9088
6c	HAMMERODDE	9323699	2005	MERWEDE SHIPYARD BV	8227	14551	8640		18,8	3865
7c	SMYRIL	9275218	2005	NAVANTIA SA	8600	12670	13440	23	21	4530
8c	NISSOS MYKONOS	9208679	2005	HELLENIC SHIPYARD	8742	7882	31680	28,5	26,3	5100
9c	STRAISTMAN	9323704	2005	VOLHARDING SHIPYARD	8907	13906	8640		18,8	3865
10c	STENA LAGAN	9329849	2005	VISENTINI CANTIERE NAVA	17754	27510	21600	24,5	23,5	9000
11c	NORRONA	9227390	2003	FLENDER	18680	35966	21600		21	5450
13c	BERLIOZ	9305843	2005	ATLANTIQUE CHS	20223	33940	39100	28	25	13360
14c	DELFT SEAWAYS	9293088	2006	SAMSUNG HEAVY INDUSTI	20418	35923	38400	28	25,5	14440
15c	DOVER SEAWAYS	9318345	2006	SAMSUNG HEAVY INDUSTI	20418	35923	38400	28	25,5	14440
16c	STENA TRANSIT	9469388	2011	SAMSUNG HEAVY INDUSTI	21455	33690	21600	23,6	22,2	7000
17c	STENA TRANSPOR	9469376	2011	SAMSUNG HEAVY INDUSTI	21455	33690	21600	-	23,6	7000
18c	BLUE PUTTEES	9331177	2006	BALTIYSKIY	21464	28460	21600		22,2	6392
19c	HIGHLANDERS	9331189	2007	BALTIYSKIY	21469	28460	21600	25	22,2	6392
20c	VICTORIA	9281281	2004	AKER FINNYARDS OY RAUI	21540	40975	26240	23,4	22	9264
21c	SPIRIT OF FRANCE	9533816	2012	STX FINLAND OY-RAUMA	26813	47592	30400	23,5	22	18332
22c	SÌRIT OF BRITAIN	9524231	2011	STX FINLAND OY-RAUMA	26813	47592	30400	23,5	22	18332
24c	COLOR FANTASI	9278234	2004	KVAERNER MASA-YARDS	33295	75027	31200		22,3	17600
25c	STENA HOLLANDIC	9419163	2010	NORDIC YARDS WISMAR G	33700	64039	33600		22,5	11000

APPENDICES

PPT – Presentation I
PPT – Presentation II
PPT – Presentation III
Interim Project Presentation at IAMU Conference

PPT – Presentation I

Lecture Notes I

Lecture Notes:
EXPLANATORY SUMMARY OF CALCULATION METHOD USED

In the present work we have made a number of basic calculations, which have enabled us to obtain, from the basic information available from our vessels orientation get the range of emissions of these to their different work.
In this section, we will try to explain in a basic way as they have done the same, so that the same method can be used to study and simulate the level of emissions of other vessel.

1º Obtaining data:
Regarding the data obtained and the basis for this study, we have to distinguish two sources:

- Databases such as Sea-Web, Equasis, Lloyds Register, etc. of which we have obtained information on survey vessels; Displacement, GT, total installed propulsive power, total installed auxiliary power, maximum speed, speed of service.

  Database based on an earlier document, which reflects the NOx emissions data measured in maneuver, the time length of it, and NOx emissions in port and residence times. All in the port of Barcelona.
  (which supply data, will be grounds for explanation at the end of this section, but we will refer to them for introducing this method of calculation, this information not be available for every ship and if necessary to obtain a relative fieldwork).

2º Estimation of the required load on the set of motors are the main propulsion of a ship according to their working arrangements.

Defined vessels obtained from these studies and information on displacement, total installed propulsive power, speed limits and service, we proceed to determine the power required (or that teams should be producing) to maintain certain sailing conditions. That is the load for each scheme or speed.

We have assumed for this that the ship is fully loaded, since for our study we always match the total displacement of the boat, ie corresponding to the maximum summer draft.

From this displacement and one of the working situations from known data of the vessel:

- Maximum installed power corresponds to the maximum speed.

- Service speed will usually correspond to 80% of installed capacity.

Using Admiralty Formula,

$$P = \Delta^{2/3} . V^3 / C_A$$

Where:

P Indicated power – IhP

Ship's displacement – Long T (1 Long T= 1,016 t)

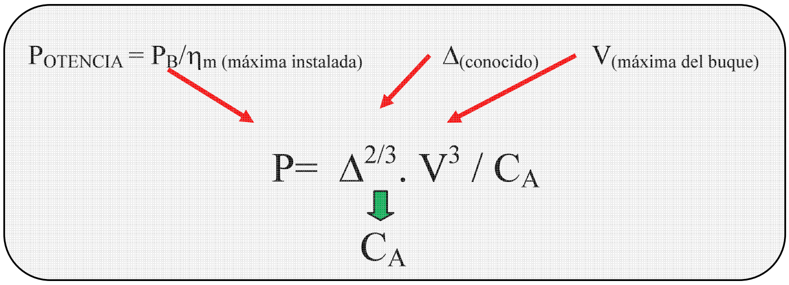
v Ship speed – kn

C_A Admiralty Coefficient.

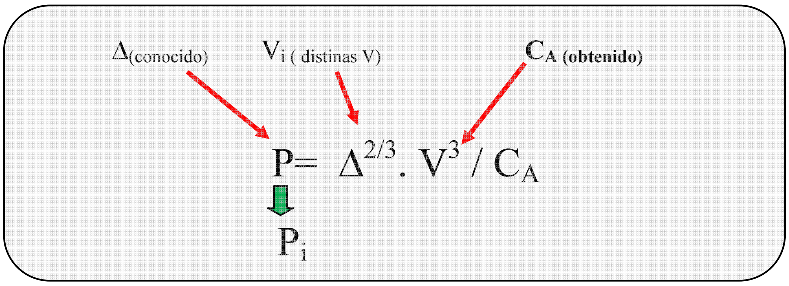
And we get the corresponding AC coefficient, taking into account that we know the other values of the equation.

Note that to obtain the indicated power, shall affect or planned installed capacity to 80% by mechanical efficiency and look at 0.8.

$$P_I = P_B / \eta_m$$



Once we get the Admiralty coefficient CA, and into the same equation known this, the displacement and the different speeds get the charging rate that applies to each engine based on the speed.



We obtain, therefore, from the formula, the power used to achieve the different speeds of navigation.

This ratio compared to the total installed power will give the % of loading.

3º Estimated fuel consumption as a function of each of the schemes or rates.
Obtained the necessary power or the load factor developed by all major engines to maintain a certain speed stop, there are two ways to obtain the corresponding consumption.

- We have a first system that is being used in the ship Sorolla, to know of this equation that gives us the manufacturer of the engines installed on it

  $C_{fuel\ V} = (0.0093L^2 - 1{,}42L + 223{,}5).P_V.t_V.n$

  Donde:

  $C_{fuel\ V}$:Total main engine fuel oil consumption at this speed(kg).

  L :Main engine load (% of MCR).

  P_v :Brake power of the main engine during navigation (kW).

  t: time (1 h).

  n:Number of main engines running.

  Being known all these values to a given speed, we just have to substitute in equation for consumption.

- Lacking in other vessels of the curve corresponding to the consumption, is used for this calculation the specific consumption ratio usual for this type of engines, average speed 4T

  Specific consumption = 170-200 fuel/ kWh

  Known in the previous section the power used to keep the different regimes, this power should be only for the specific consumption to obtain the consumption per hour to keep the vessel to a certain speed range.
  In this work we employed a specific consumption of fuel 200g / kW, to try to include here many losses that are not being considered.
  The calculation for the ship Sorolla, made using the above equation, show results more like working with a lower specific consumption.

4º Estimated NOx emissions for these regimes.
We must distinguish again two situations, the initial acquisition of this ship for Sorolla, and the estimate for the other ships.

- In the case of ship Sorolla and also having the curve provided by the manufacturer determines the NOx emission factor according to the load, we applied this to calculate these emissions maneuver schemes, speed of service and in port.

  $$E_{NO_x ME} = (0{,}002 \quad L\ 0{,}5351 \quad L\ 39{,}714) \quad C_{ME}$$

Being:

E_{NOxME}: NOxemissions from the main engine during the navigation (kg)

F_{ENOx} : NOxemission factor (kg/t fuel)

C_{ME}: Main engine total fuel oil consumption during 1 hour navigation.

- For other ships these emissions have been calculated considering the average emission factor for this type of engine, which is 59kg $_{NOx}$ / t $_{FUEL}$
  The level of emissions from navigation system is obtained by multiplying both consumption directly by this factor.

- In this section we should also note that, as explained at the beginning, there is a database on which we have worked and emissions have been obtained in field.

4º Estimated emissions of $C0_2$, for different navigation schemes.

This figure has been calculated for all cases using an emission factor obtained from Second IMO Greenhouse Gas Study 2007, average emission factor)
This emission factor C = 2 for marine engines we are concerned is issued kg CO_2 3.13 / t of fuel.

The result therefore for CO_2 emissions are calculated by multiplying the consumption obtained for each navigation scheme this emission factor.

Note that this factor is of 3,19 kg $_{CO2}$ / t $_{fuel}$ for diesel engines, being the factor which was used in calculating the auxiliary engine emissions.

5º Calculating emissions by different routes.

As it can be seen throughout the work, once obtained the values of consumption and NOx and CO2 emissions for the different speeds of the ship, these data have been used to calculate specific routes.

To obtain the same commercial devices have been used, which, thanks to the AIS equipment currently installed in almost all of our vessels, allow us to obtain the position of these, its direction and speed record more or less instantaneously.

We have therefore chosen several ships and their routes, and has followed up the same recording speeds and browsing time.
According to the recorded speed changes, have identified a number of stages along the way, and then calculated the time that the ship has been in each of the regimes or chosen speeds.
Certain these average speeds and the time when the ship is maintained in these, we calculated the consumption and emissions of the various paths by adding:

$C_{TOTAL} = \sum C_{v=i} \cdot t_1$

Being :

C_{TOTAL} : consumption during all journey.
$C_{V=i}$: consumption at different speeds registered during the journey.
t_i : time that's been maintained in this speed.

At the same stage we have calculated the emissions of CO_2 and NOx.

$E\ NOx_{TOTAL} = \sum ENOx_{v=i} \cdot t_1$

$E\ CO_{2TOTAL} = \sum ECO_{2\ v=i} \cdot t_1$

6º Graphics comparison between the design parameters and estimates for individual ships.

In section 3.6 of this paper, there's also a series of graphs which try to compare or relate in any way the design parameters of vessels available emission parameters, both possess these field data, as using emission values obtained in the previous sections.

It is presented for different databases, where boats are grouped by the information available.

A lineal representation of this information, sorted by the field that has seemed to have more relevance has allowed us to represent:

- Relationship between the displacement and the GT of vessels and propulsion and auxiliary power installed in them.
- Relationship between service speed and installed propulsive power.
- Relationship between propulsive power and auxiliary power installed
- Displacement ratio and the level of NOx emissions
- Relationship between the GT Ro-Pax vessels and emissions detected in maneuver.
- Change between the emission level and speed, etc...

7º EEOI estimation.
Finally and at the end of the document, 3.7 section has tried to bring or make a preliminary estimate of what would be the EEOI.
Not being able to make a comprehensive calculation of this factor because their calculation is due to perform the summation of individual consumption readings recorded by different paths polluting equipment for the ship developed in a considerable period of time, in the present work been we just only assess the extent of this factor based on emissions from the main engines and presented as varied this by increasing the speed.

Based on simplified expression of EEOI ;

$$EEOI = \sum FC_j . C_{Fj} \; / \; m^{cargo} . D$$

Where;

j is the fuel type;
FC j is the mass of consumed fuel at voyage ;
CFj is the fuel mass to CO_2 mass conversion factor for fuel j; Valor que obtenemos de la siguiente tabla

Type of fuel	Reference	Carbon content	C_F (t-CO_2/t-Fuel)
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil	(HFO) ISO 8217 Grades RME through RMK	0.85	3.114400
4. Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquified Natural Gas (LNG)		0.75	2.750000

m_{cargo} is cargo carried (tonnes) or work done (number of TEU or passengers) or goss tonnes for passanger ships; and
D is the distance in nautical miles corresponding to the cargo carried or work done.

PPT – Presentation II

Lecture Notes II

ENERGY EFFICIENCY OPERATION INDICATOR (EEOI) CALCULATION FOR SHIP SOROLLA. SIMULATION

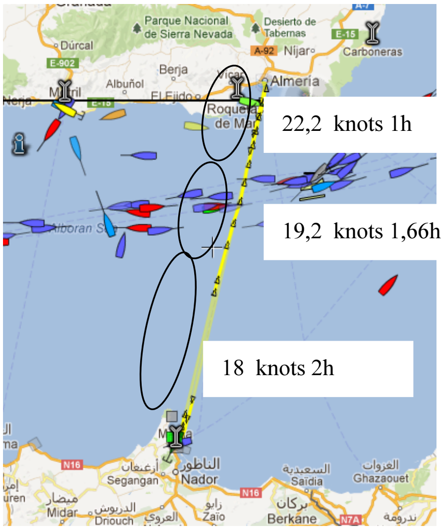
In the previous sections we have obtained data for the consumption of the ship Sorolla in different regimes.
Now, following some of the routes, we will try to calculate the index EEOI for this vessel.

As discussed in the previous section, the calculation of this index is designed so that it result proceed to mediate the outcome of this factor EEOI for a set of consecutive trips.

It will calculate the result of this factor for a number of routes. The same data were obtained using the same method described in the previous sections.

1th TRIP:

Melilla - AlmerÍa



Being EEOI factor ;

$$EEOI = \sum FC_j . C_{Fj} \ / \ \ m^{cargo} . D$$

$\sum FC_j . C_F$ is the sum of consumption of individual consumers teams (main engines, auxiliary engines, boilers…) each multiplied by the CO_2 emission factor that according to the table.

Type of fuel	Reference	Carbon content	C_F (t-CO_2/t-Fuel)
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil	(HFO) ISO 8217 Grades RME through RMK	0.85	3.114400
4. Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquified Natural Gas (LNG)		0.75	2.750000

Figure 1.- Relation tons CO_2 / tons Fuel

We have three adding, aboard Sorolla:

- The consumption of main engines, where we have that consumption is on the way:

time h	speed knots	consumption kg/h	T consumption kg
1	22,2	3491	3491
1,66	19,2	2367	3929,22
2	18	2006	4012
		Total	**11432,22**

We also have maneuver consumption. (Input 30mi, 30 mi exit, average speed 6 knots). Consumption of **914 kg** of fuel, will be somewhat higher than what would correspond to sail at 6 knots because tail generator that powers the bow thruster.

Being fuel type; IFO

$$FC_1.C_{F1} = (11432{,}22+914) \text{ x } 3{,}151040 = 38780$$

- The consumptions of auxiliary generators;

In Section 2.2.2 we calculated fuel consumption of auxiliary maneuver: 608.32 kg / h

In section 2.2.5 we determine that the navigation generation consumption was 277Kg / h.

Given that the maneuvers take place in 1 hour and the sailing time is 4.66 pm.

The total consumption of the auxiliaries will be:

$$(608{,}32\text{x } 1) + (277\text{x}4{,}66)=1899{,}14$$

Being fuel type; Diesel/Gas oil

$$FC_2 .C_{F2} = 1899{,}14 \text{ x } 3{,}206000 = 6088{,}64$$

- The consumption for the auxiliary boiler.

The boiler is stopped maneuver in navigation but consumes about 125kg of oil / hour.

$$FC_3 .C_{F3} = 125 \text{ x } 3{,}206000 = 400{,}75$$

The EEOI factor numerator is the sum of the three terms calculated.
The denominator we get:
mcargo is ,in this case, the GT of the ship because it is a passenger ship. Sorolla GT is 26916 t.
D is the distance in miles. Approximately 92 miles.

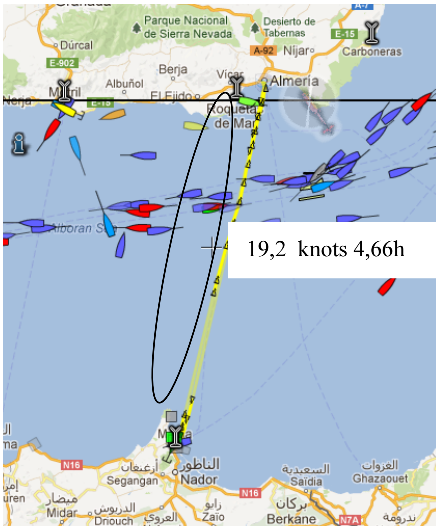
$$\textbf{EEOI} = \sum FC_j . C_{Fj} \; / \; m^{cargo} \; . \; D=$$

$$= (38780+6088{,}64+400{,}75)/(26916x92) =$$
$$= \mathbf{0{,}0183}$$

2ond TRIP:

Almeria – Melilla

We realize now the route back but maintaining an average speed of 19.2 knots. This speed allows the boat to keep the travel time.



For this second trip we have consider:

- The consumption of main engines during the trip,

time	speed	consumption	T consumption
h	knots	kg/h	kg
4,66	19,2	2367	11030,22
		Total	11030,22

It is 11030,22 kg, plus 914kg for maneuver main engines consumption.

$$FC_{11} . C_{F11} = (11032{,}22+914) \text{ x } 3{,}151040= 37636{,}7$$

- The consumptions of auxiliary generators;

We use the same calculations that trip before.

$$FC_{22}.C_{F22} = 1899{,}14 \text{ x } 3{,}206000 = 6088{,}64$$

- The consumption for the auxiliary boiler.

We do not have more information about it. We use the same calculations that we used the trip before, we have the same maneuver time.

$$FC_{33}.C_{F33} = 125 \text{ x } 3{,}206000 = 400{,}75$$

Route being also in this case 92 miles because it is the way back to the previous section.

$$\textbf{EEOI} = \sum FC_j.C_{Fj} \;/\; m^{\text{cargo}} . D=$$

$$= (37636{,}7+6088{,}64+400{,}75)/(26916 \text{x} 92) =$$

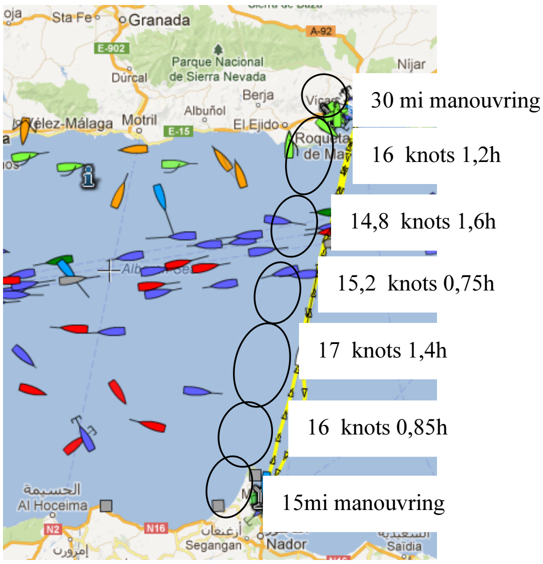
$$= \mathbf{0{,}0178}$$

3th TRIP:

Melilla – Almería

In this case the speeds we have taken are the ship's Plamas Gran Canaries, which replaces the Sorolla during its annual maintenance shutdown.

The consumption are form Sorolla . If it navigate whit this slower speed



For this third trip we have consider:

- The consumption of main engines during the trip,

time	speed	consumption	T consumption
h	knots	kg/h	kg
0,85	16	1479,48	1257,558
1,3	17	1732,2	2251,86
0,75	15,2	1292,24	969,18
1,6	14,8	1203,57	1925,712
1,2	16	1479,48	1775,376
		Total	8179,686

It is 8.179,68 kg, plus 685,5 kg for maneuver main engines consumption. In this travel one of the maneuvers takes only 15 mi.

$$FC_{111}.C_{F111} = (8179{,}68+685{,}5) \times 3{,}151040 = 27.934{,}5$$

- The consumptions of auxiliary generators;
  In this way the maneuvering time is 3/4 time and browsing time is 5.7 h.
  The auxiliary generators total fuel consumption be: (608,32x 0,75) + (277x5,77)=

$$FC_{222}.C_{F222} = 2054{,}53 \times 3{,}206000 = 6.586{,}82$$

- The consumption for the auxiliary boiler. We consider one hour working.

$$FC_{333}.C_{F333} = 125 \times 3{,}206000 = 400{,}75$$

Being the trip 92 miles again:.

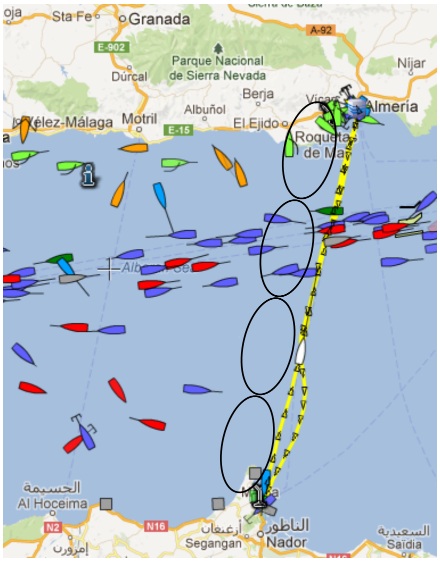
$$\textbf{EEOI} = \sum FC_j.C_{Fj} \; / \; m^{cargo}.D=$$

$$= (27.934{,}5+6.586{,}82+400{,}75)/(26916 \times 92) =$$
$$= \mathbf{0{,}0141}$$

4º TRIP:

Almería - Melilla

Also following the same rate of speed that is setting the boat substitution.



For this forth trip we have consider:

- The consumption of main engines during the trip,

time h	speed knots	consumption kg/h	T consumption kg
2,2	10,5	463	1018,6
1,8	15,5	1361	2449,8
2	13,5	938	1876
0,8	15	1247	997,6
		Total	6342

It is 6342 kg, plus 685,5 kg for maneuver main engines consumption. In this travel one of the maneuvers takes only 15 mi.

$$FC_{111}.C_{F111} = (6342+685,5) \text{ x } 3,151040= 22.143,93$$

- The consumptions of auxiliary generators;
  In this way the maneuvering time is 3/4 time and browsing time is 6,8 h.
  The auxiliary generators total fuel consumption be:
  (608,32x 0,75)+ (277x6,88)=2339,84

$$FC_{222}.C_{F222} = 2339,84 \text{ x } 3,206000 = 7.501,57$$

- The consumption for the auxiliary boiler. We consider one hour working.

$$FC_{333}.C_{F333} = 125 \text{ x } 3,206000 =400,75$$

Being the trip 92 miles again:.

EEOI = $\sum FC_j . C_{Fj}$ / m^{cargo} . D=

= (22.143,93 + 7.501,57+400,75)/ (26916x92) =
= **0,0120**
We can see clearly how the index EEOI is reduced due to reduce the speed.

At the same way that we have been doing with these four trips, we would follow with different travels, it does not matter if the others trips are to another harbors, we would do the same calculation with the corresponding distance.

The ENERGY EFFICIENCY OPERATION INDICATOR (EEOI) for the ship will be the average of the EEOI gotten at the different trips during a long period of time. One year per example.

1th Trip :	EEOI	0,0183
2ond Trip:	EEOI	0,0178
3th Trip:	EEOI	0,0141
4^{th} Trip:	EEOI	0,0120
...	…	…
Average:	**EEOI**	**0,0155**

Do not forget that all these calculations have been established with the specific consumption. To do it right you have to do the same by taking the actual consumption on board.

PPT – Presentation III

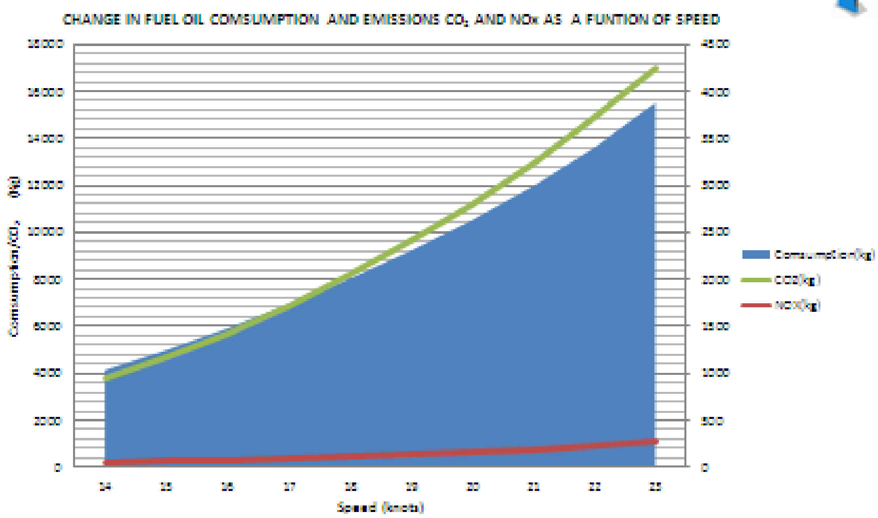
- For a few years, is of great concern in the maritime sector, the amount of emissions generated by our ships, and the concentration of these emissions in our ports.

- **What factors enhance these emissions?**

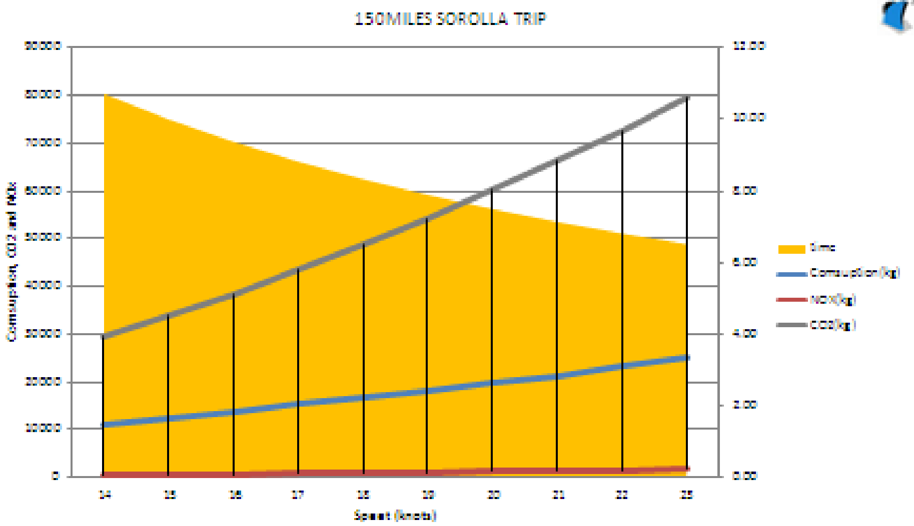
- **How can we act on these factors to reduce emissions?**

- **What factors enhance these emissions?**

1. THE SPEED



- Higher speeds are responsible for the increased emissions.



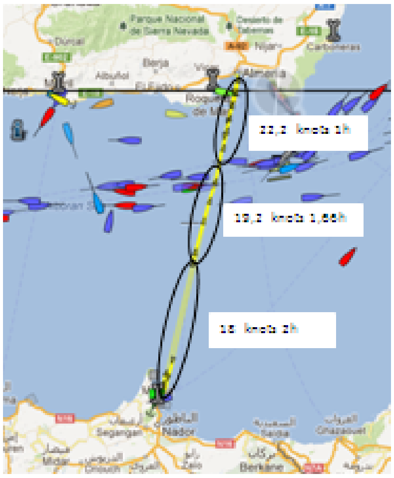
Reduce speed means increasing travel time.
Even considering this extra time, slow navigation reduces emissions.

- **How can we act on THE SPEED to reduce emissions?**

(WMU)

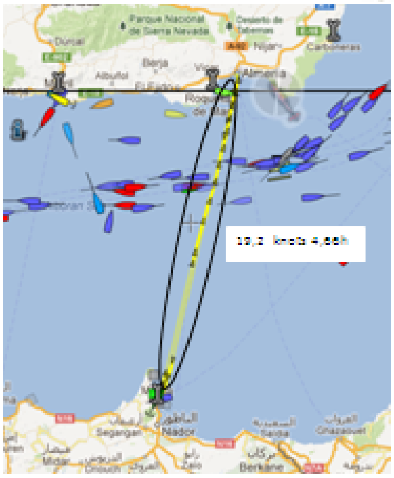
REGULAR TRAVEL

TRAVEL SPEED PROGRAM



= milles

= time



634 kg NOx
33737kg CO_2

620 kg NOx
33021kg CO_2

- Set the speed for a journey, itself implies a reduction in emissions.

Same MILLES
Time + 20mi

548,5 kg NOx
29193,5 kg CO_2

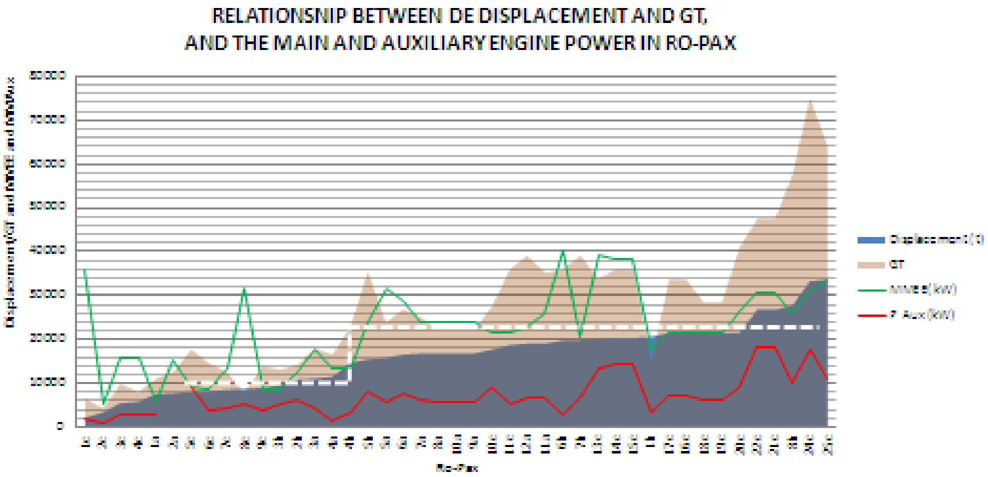
- Reduce ½ or 1 knot speed average, is on routes 4 and 8 hours, reductions of between 10 and 15% for NOx and CO2 emissions, affecting journey times only 10 or 30 minutes respectively.

(WMU)

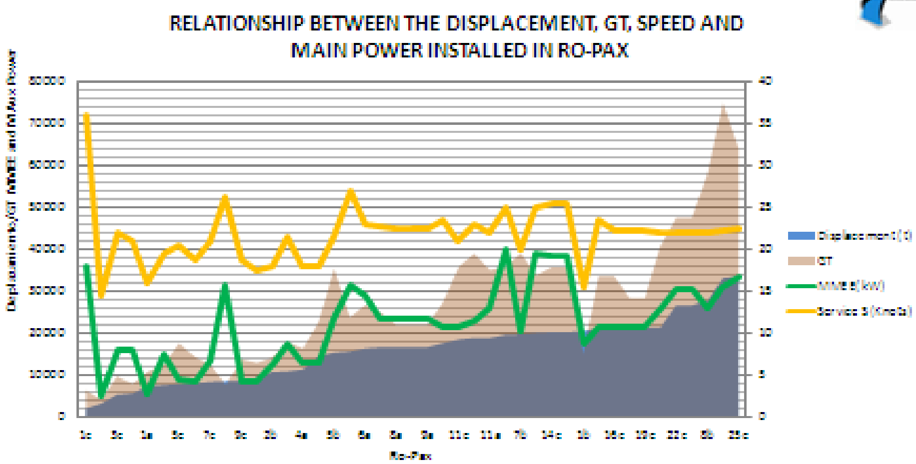
- **Important raising awareness;** not all delays must be absorbed by the ship increases its speed. We paid a high environmental price for it.
- The current routes are adjusted passenger service. **Good planning** can allow cover commercial expectations and not penalize the environment.
- The **port flexibility** in relation to the ETAs of Ro-Pax vessels. A vessel delay is not required to make up the time in navigation to arrive on time.

- **What factors enhance these emissions?**

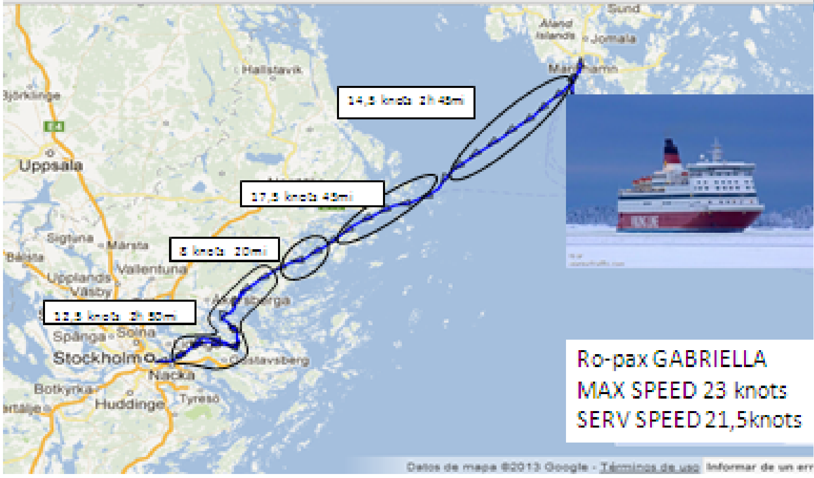
2. INTALLED POWER



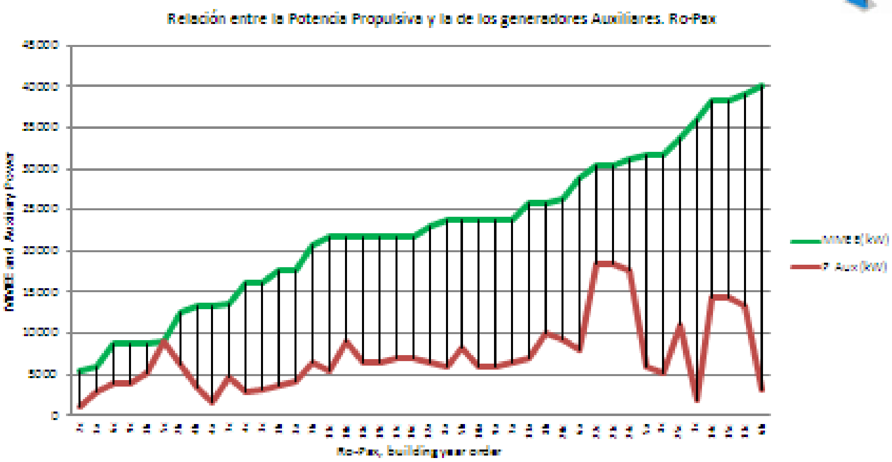
- The propulsive power arranged in Ro-Pax vessels are oversized.



- The propulsive power peaks correspond to higher speed vessels
- There is a higher power ratio on vessels and speeds of these, which is not seen with their dimensions.



- This power oversized marked by the need to achieve high speeds and which itself generates unnecessary loss, gets even more evident when we see that the ships never sail at these high speeds.



- The auxiliary power ranges between 25 and 35% of the propulsive power. The demand for high speeds do not affect the auxiliary power.

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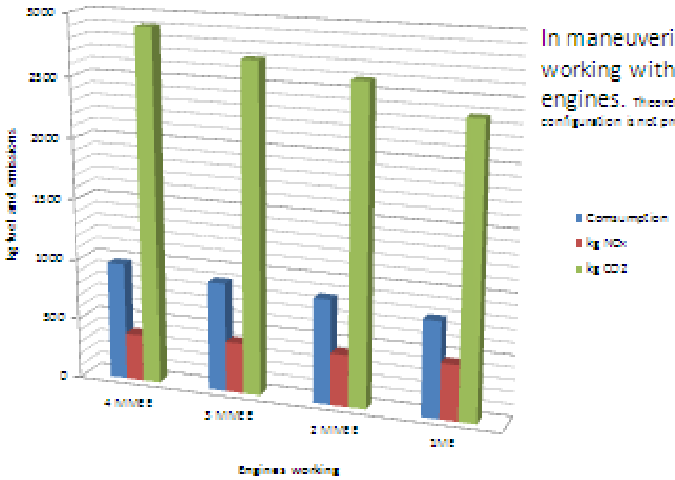


In maneuvering, ship Sorolla working with 1, 2, 3 or 4 main engines. Theoretical calculations, the current configuration is not prepared to work in this way)

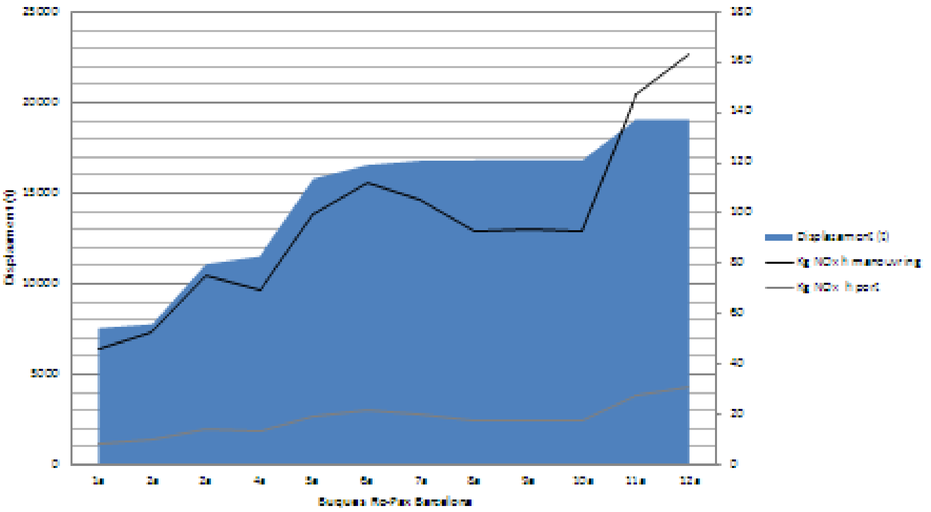
- Engines and auxiliary engines should be designed or arranged considering the workload conditions for those who are running be the 80%

- **How can we act on THE INSTALLED POWER to reduce emissions?**

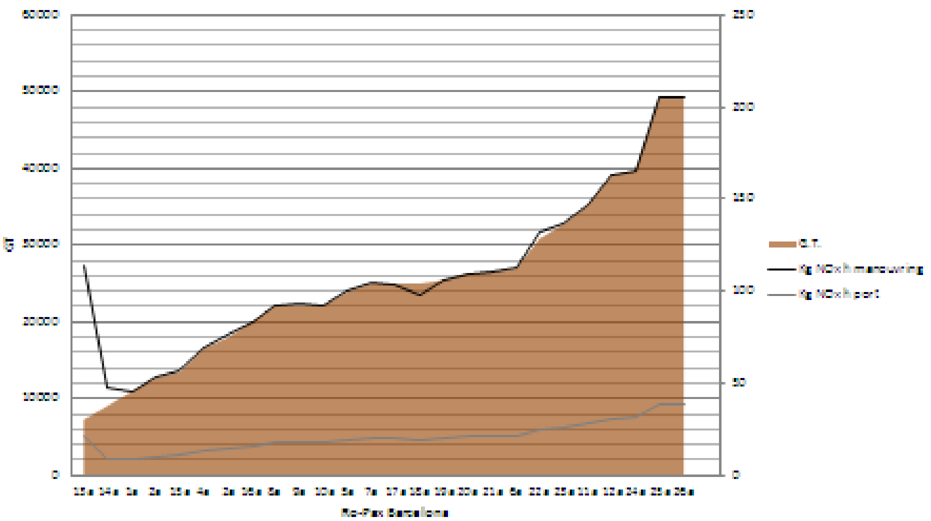
Not for existing vessels but for future design :

- Determine working routes and **reduced speeds** for these.
- **Calculate for each vessel main and auxiliary power** to be installed in accordance with their needs.
- Provide main and auxiliary power required to cover these routes and speeds.
- **Do not overestimate the installation for** the journey at **much higher speeds.**
- Keeping the duplication of equipment, to thereby guarantee the reliability and safety of navigation **equipment** available so that **they work about 80%** of its usual load regimes.
- Consider **new fuels**. If not for navigation, for operating periods or in port.
- Consider **docks electrification** model. This will completely stop electric generation on ships while in port.

- **Relationship between GT and emissions**
- **ENERGY EFFICIENCY OPERATION INDICATOR.**



- Relationship between Displacement and the level of NOx emissions maneuver.



- Relationship between GT and the level of NOx emissions maneuver.

ENERGY EFFICIENCY OPERATION INDICATOR

- **EEOI =** $\sum FC_j . C_{Fj} \ / \ m^{cargo} . D$

  Be;

  j is the fuel type;

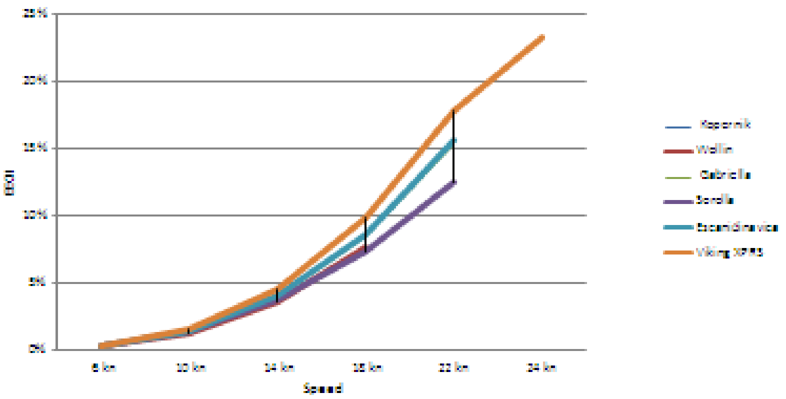
  FC j is the mass of consumed fuel at voyage ;

  CFj is the fuel mass to CO_2 mass conversion factor for fuel j;

Type of fuel	Reference	Carbon content	Cf (t-CO_2/t-Fuel)
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil	(HFO) ISO 8217 Grades RME through RMK	0.85	3.114400
4. Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquified Natural Gas (LNG)		0.75	2.750000

  m_{cargo} is cargo carried (t) or work done (number of TEU or passengers) or goss tonnes for passanger ships;

  D is the distance in nautical miles corresponding to the cargo carried or work done.



- EEOI ship main engine variation in funtion of the speed.

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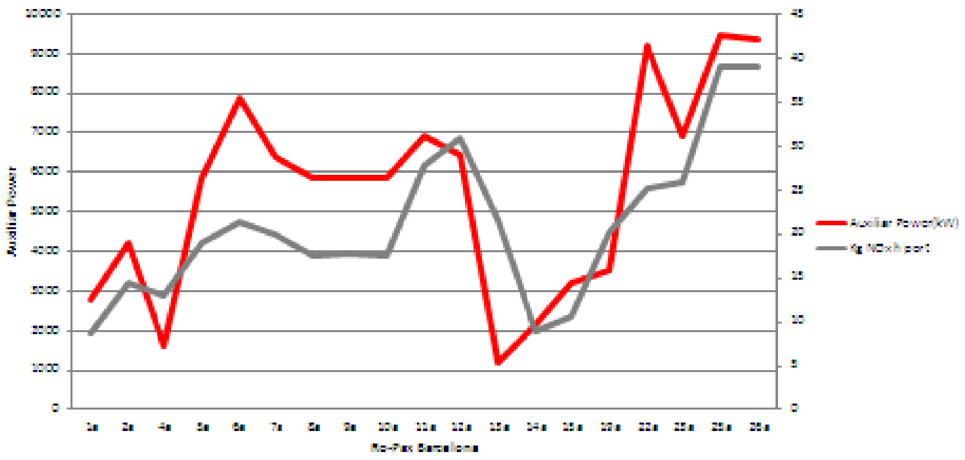

- Relationship between the installed auxiliary power and NOx emissions.

APPENDIX IV:

Interim Report:

Project Presentation at IAMU AGA 13

St. John's, 15 – 17 October

ProGreenShipOperation: Simulation-based training module to promote green energy-efficient ship operation

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iamu AGA 13

13th IAMU AGA 13
2012

St. John's, Newfoundland
15 - 17 October

Simulation-based training module to promote green energy-efficient ship operation

Michael Baldauf, Sebastian Klaes
(World Maritime University Malmö, Sweden)

Knud Benedict, Sandro Fischer, Michéle Schaub
(Hochschule Wismar, University of Applied Sciences, ISSIMS
Rostock - Warnemünde, Germany)

Ben Brooks, A. Di Lieto, P. Dann, D. Dingsdag
(Australian Maritime College
Institute of the University of Tasmania)

German de Melo, I.C. Delgado
(University of Catalonia – Faculty of Nautical Studies
Barcelona, Spain)

iamu AGA 13

13th Annual General Assembly
International Association of Maritime Universities
St. John's, Newfoundland and Labrador, Canada 15 – 17 October 2012

Outline

- Introduction
- IMO Approach
- Aims and objectives
- Project structure
- State of progress
- Preliminary results
- Summary
- Outlook

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ProGreenShipOperation - Basics

Work packages and structure:

- WP 1: an experimental field and simulation study into the potential of manoeuvring assistance for "green ship operation"
- WP 2: investigations into appropriate design of the Human-Machine-Interface of the Manoeuvring Assistance module
- 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

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ProGreenShipOperation - Application

Work packages and structure:

- WP 1: Transfer of the concept into a learning objective-oriented training module to be integrated in an IMO Model course
- WP 2: Design and implementation of a simulation exercise for training and demonstration
- WP 3: development of related training materials for simulation-based training modules
- WP 4: Investigation into the development of an approach for the assessment
- WP 5: Demonstration and test trials

5

Introduction

State of the art

"The compensation of just a five minutes delay needs seven tons of additional fuel to keep the given time schedule given."

Statement of captain of a RoRoPax-Ferry during the discussion at the e-Navigation underway conference 31. January/1. February onboard "Crown of Scandinavia"

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Introduction

- Motivation:
  - enhance training in order to promote "green ship operation" by integrating new methods into maritime education and training schemes
  - focus on planning of environmentally-friendly manoeuvring strategies and their practising

- Aim and objective:
  - Integrate prototyped manoeuvring assistance system into full mission simulation environment to reduce GHG emissions and saving time

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Background and IMO - approach

Among others:

- Kyoto protocol, MARPOL conference (1997)
- EEDI, EEOI, SEEMP
- A.947(23), A.998(25)
- 60. MEPC: decided to develop a IMO Model course
- 1st draft developed especially on basis of of MEPC 59/24 (Annex 19), MEPC.1/Circ.683

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Background

Defined terms of reference for the research work:

- "Green Ship Operation"
  - Operational measures and aspects of navigation that contribute to
    - time savings
    - fuel savings
    - efficient use of resources of energy/power onboard that
    - Consequently may lead to reduction of GHG emissions
- Voyage planning on "macro" (weather routeing) and "micro" level (manoeuvring planning)

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Research studies

Work content:

- **Field measurements** to gather comparable sets of data in order to perform analysis with respect to relevant characteristic data of energy efficiency (as e.g. fuel consumption, time and cost saving)
- **Simulation study** with enhanced manoeuvring support for harbour operation
- concept for a training module for demonstration of environmental effects

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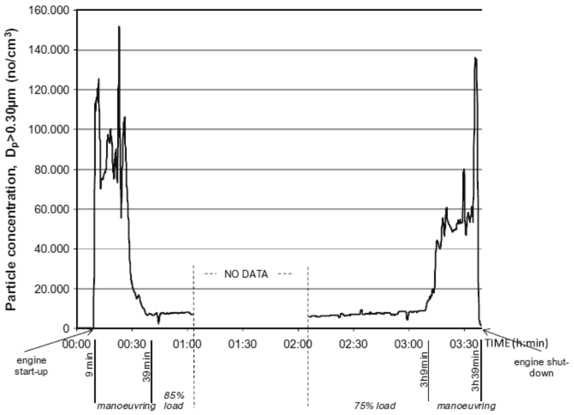
Results from real time measurements

State of the art research work



Source:
H. Winnes & E. Fridell (2010)

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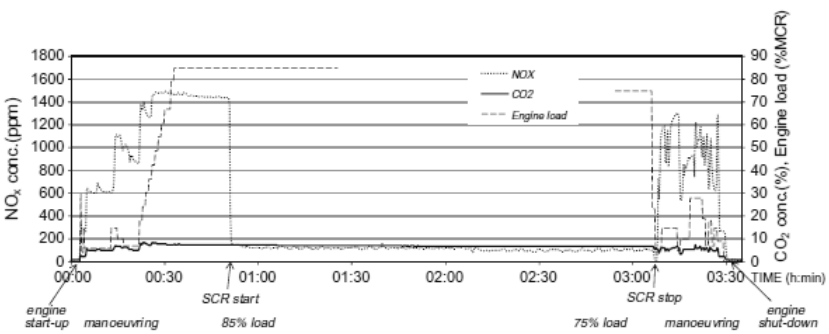
Results from real time measurements (2)

State of the art research work (2)



Source: H. Winnes & E. Fridell (2010)

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Results from real time measurements (3)

Experimental field study (1)

- Recording of series of harbour manoeuvres of a particular RoRo-ferry using VDR equipment onboard and further shore-based recordings including i.a. AIS)
- Recorded and analysed data:
  - POS, heading, course, speed (longitudinal, transverse, SOG), RoT
  - actual and commanded EOT (pitch and RPM), rudder, thrusters
  - wind (direction and force)

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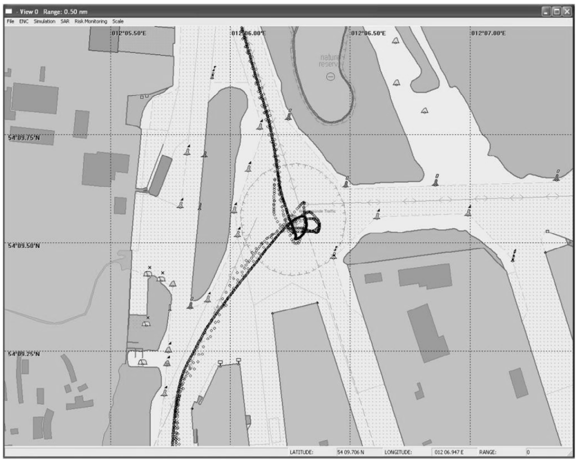
Results from real time measurements (4)

Experimental field study (2)



Real manoeuvre tracks of a series of harbour basin manoeuvres of a ferry using VDR recordings

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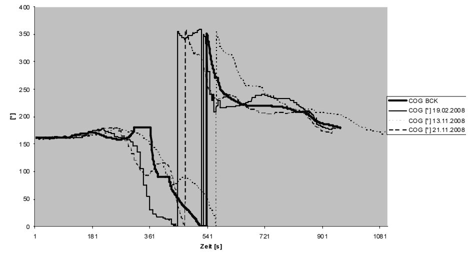
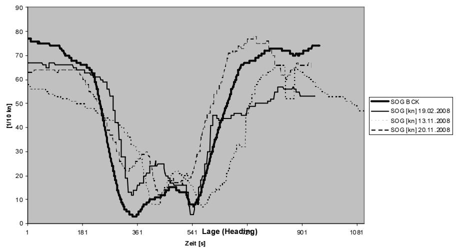
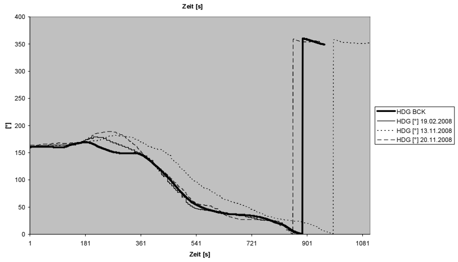
Results from real time measurements (4)

Experimental field study – detailed data analysis







Analysis of manoeuvre tracks and steering strategies

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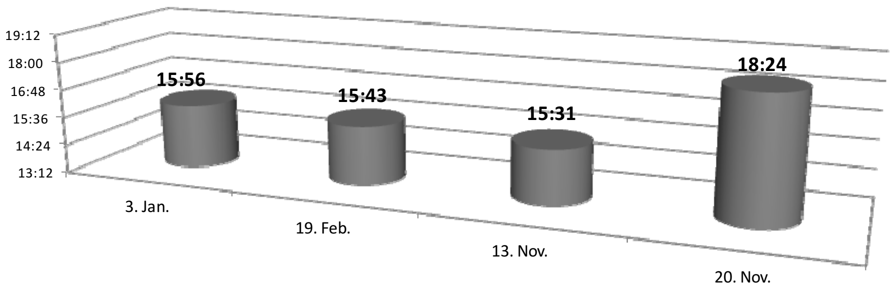
Results from real time measurements (5)

Experimental field study (4)

Measurements of Real Manoeuvring Times



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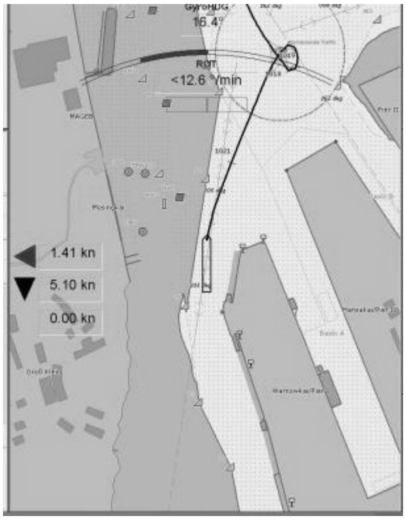
Results from real time measurements (6)

Experimental field study (5)



Manoeuvring phase with greatest potential for time and energy savings as well as for reduction of gas and particle emissions

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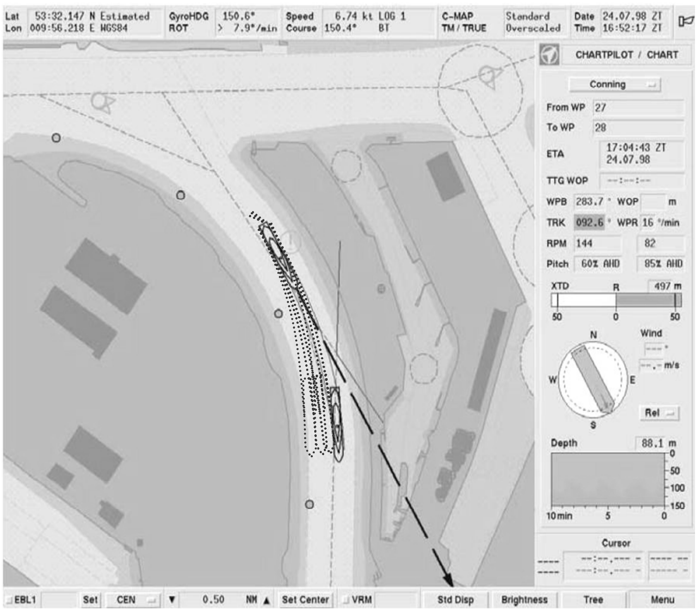
Introduction of dynamic path prediction



Integrated dynamic path prediction showing the expected path according to actual settings of manoeuvring handles (EOT, ordeered rudder)

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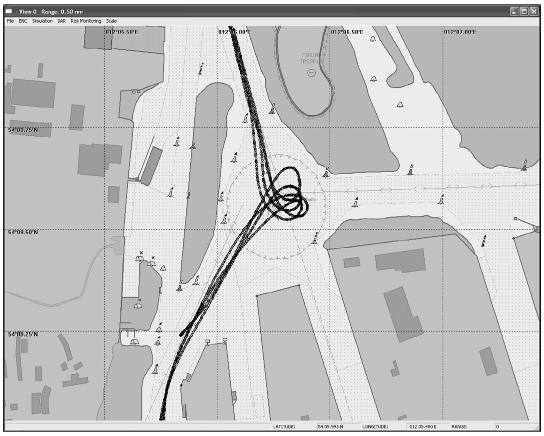
Conduction of a simulation study (1)

Application of Fast-Time Simulation for path prediction



Tracks of simulated harbour entrance manoeuvres using alternative strategy of smoothed combined manoeuvres

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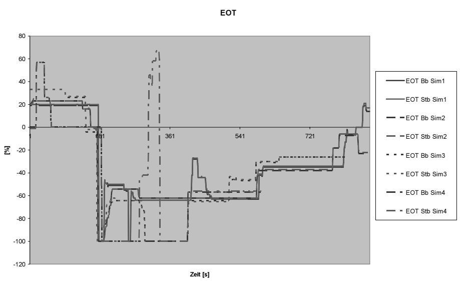
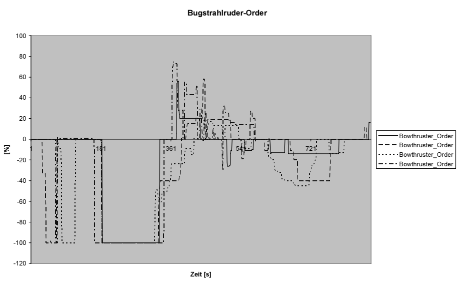
Conduction of a simulation study (2)

Analysis of steering orders





Analysis of simulation trial results – samples for use of engine, thrusters

- Total number of elementary manoeuvres varies up to more than 20
- time savings for the studied case of up to 10% compared to the real recorded manoeuvre tracks

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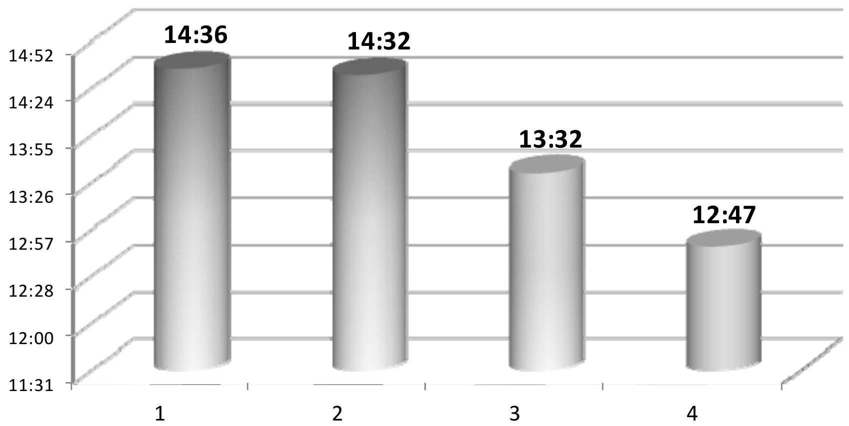
Conduction of a simulation study (3)

Manoeuvring Time Simulation Trials



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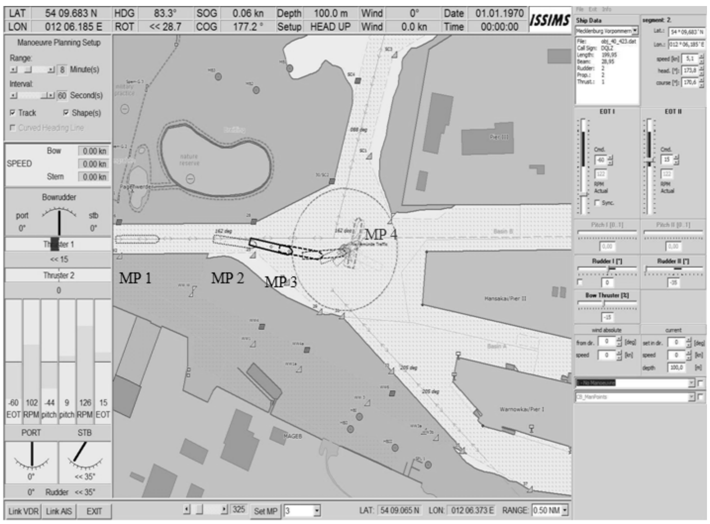
Green Ship Operation through pre-planning

Application of enhanced manoeuvre planning



Minimisation of the number of elementary manoeuvres

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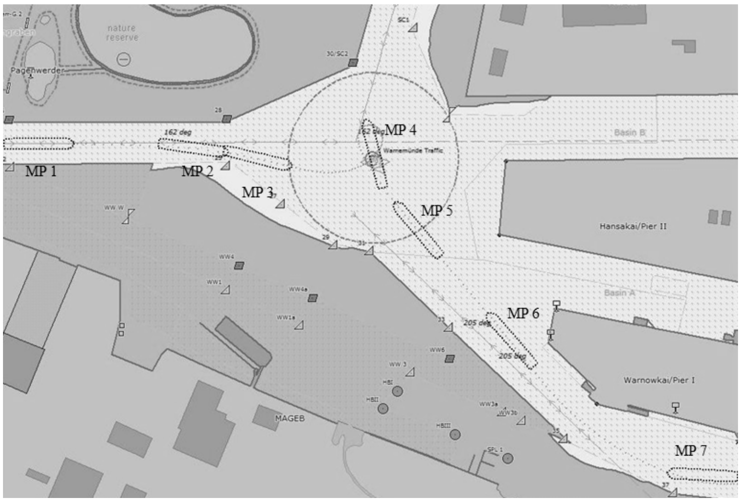
Green Ship Operation through pre-planning

Application of enhanced manoeuvre planning



Final manoeuvre plan with just only 7 elementary manoeuvres

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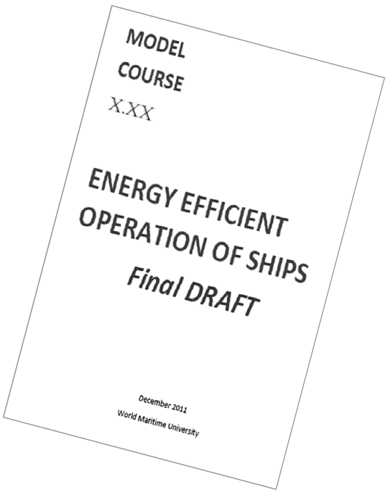
From simulation study to exercise development for application in model course

- Kyoto protocol, MARPOL conference (1997)
- EEDI, EEOI, SEEMP
- A.947(23), A.998(25)
- 60. MEPC: decided to develop a IMO Model course
- 1st draft developed especially on basis of of MEPC 59/24 (Annex 19), MEPC.1/Circ.683


MODEL COURSE

X.XX

ENERGY EFFICIENT OPERATION OF SHIPS

Final DRAFT

December 2011

World Maritime University

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Draft IMO - Model Course - structure and content

Foreword

Introduction

- Purpose of the model course
- Energy efficiency Management
- Use of the model course
- Lesson planning
- Meeting the required performance
- Course implementation

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IMO - Model Course - structure and content

Part A: Course Framework

- Aims
- Course objectives
- Entry standards
- Course certificate, diploma or document
- Course intake limitations
- Staff requirements
- Teaching facilities and equipment
- Teaching aids
- IMO references
- Textbooks and other references
- Bibliography

Part B: Course Outline and Timetable

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Part B: Course Outline and Timetable

■ **Course Outline**

	Subject Area	Course hours	Lecture	Practical activity
1.	**Background**	**4.0**		
1.1	Climate Change		2.0	-
1.2	IMO related work		2.0	-
2.	**Guidance on best practices for fuel-efficient operation of ships**	**18.0**		
	Section I: Fuel efficient operations			
2.1	Improved voyage planning			
2.2	Weather routing		2.0	2.0
2.3	Just in time			
2.4	Speed optimization			
2.5	Optimized shaft power			
	Section II: Optimized ship handling			
2.6	Optimum trim			
2.7	Optimum ballast		2.0	2.0
2.8	Optimum propeller and propeller inflow considerations			
2.9	Optimum use of rudder and heading control system (autopilots)			
	Section III: Hull and propulsion system			
2.10	Hull maintenance			
2.11	Propulsion system		2.0	2.0
2.12	Propulsion system maintenance			
2.13	Waste heat recovery			
	Section IV: Management			
2.14	Improved fleet management			
2.15	Improved cargo handling			
2.16	Energy management		2.0	2.0
2.17	Fuel type			
2.18	Other measures			
	Section V: Other issues			
2.19	Compatibility of measures		1.0	1.0
2.20	Age and operational service life of a ship			
2.21	Trade and sailing area			
3.	**Application**	**6.0**		
3.1	Planning			
3.2	Ship-specific measures			
3.3	Company-specific measures		4.0	2.0
3.4	Human resource development			
3.5	Self-evaluation and improvement			
3.6	Voluntary reporting/review			
4.	**Implementation and Monitoring**	**2.0**		
4.1	Implementation		1.0	1.0
4.2	Monitoring			
	Total Course hours	**30.0**	18.0	12.0

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IMO - Model Course - structure and content

Part C: Detailed Teaching Syllabus

- Learning objectives
- References and teaching aids
- Instructor manual
- **Detailed teaching syllabus**

Part D: Instructor Manual

- General
- Theory, demonstration and exercises
- Evaluation
- Lesson plans
- **Guidance on specific subject areas**
- **Guidance on simulator exercises**

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IMO - Model Course - Practical Exercises and simulation based exercises

Sample exercises

- Fuel efficient Ship operation I: Improved Voyage planning
- Fuel efficient Ship operation II:
  Response actions to changing environmental conditions
- **Optimized ship handling I:**
  Manoeuvre planning in Harbour basin and berthing operation
- Optimized ship handling II (including management issues):
  Energy efficient ship operation in engine room
- Sample Exercise V:
  Development of a Ship Energy Efficient Management Plan

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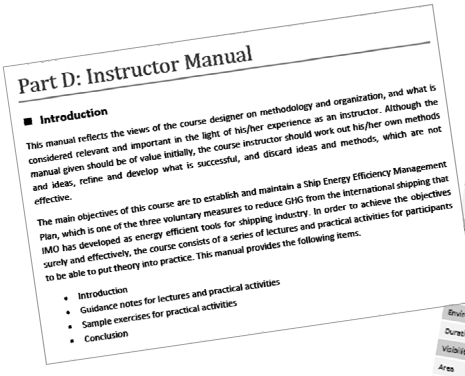
IMO - Model Course - Practical Exercises and simulation based exercises



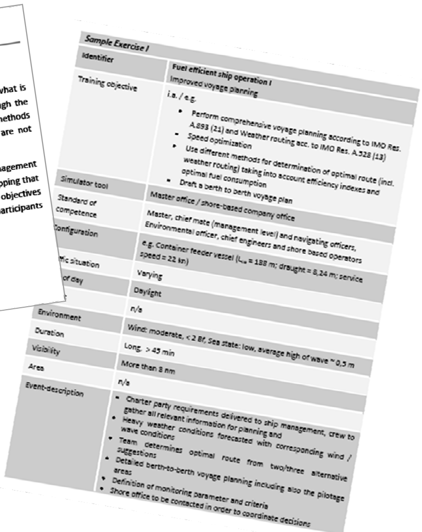
Part D: Instructor Manual

■ **Introduction**

This manual reflects the views of the course designer on methodology and organization, and what is considered relevant and important in the light of his/her experience as an instructor. Although the manual given should be of value initially, the course instructor should work out his/her own methods and ideas, refine and develop what is successful, and discard ideas and methods, which are not effective.

The main objectives of this course are to establish and maintain a Ship Energy Efficiency Management Plan, which is one of the three voluntary measures to reduce GHG from the international shipping that IMO has developed as energy efficient tools for shipping industry. In order to achieve the objectives surely and effectively, the course consists of a series of lectures and practical activities for participants to be able to put theory into practice. This manual provides the following items.

- Introduction
- Guidance notes for lectures and practical activities
- Sample exercises for practical activities
- Conclusion



Sample Exercise I	
Identifier	Fuel efficient ship operation I Improved voyage planning
Training objective	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 = 188 m; draught = 8,24 m; service speed = 22 kn)
...fic situation	Varying
...of day	Daylight
	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

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Draft simulation training module

Draft sample exercise scenario "energy-efficient ship operation in harbour areas"

Identifier	**Optimized ship handling I** Manoeuvre planning for harbour basin and berthing operation
Training objective	i.a. / e.g. • Manoeuvring in shallow water areas of harbour 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	Harbour area
Event-description	• Ferry/Passenger vessel (i.a. equipped with two propellers, bow thrusters) is approaching a harbour area for berthing operation, • Communication with shore-based VTS station • Passage to berth includes several rudder/engine manoeuvre, also use of thrusters is necessary • Passage planning to berth including pre-planning of manoeuvring up to berthing • Combined rudder/engine manoeuvres 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)

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Draft of a simulation training module

- Introduction of enhanced manoeuvring planning
- Module on integrated planning process:
  - 1. Step
    use of dynamic path prediction
  - 2. Step:
    use of enhanced manoeuvre planning (off-line)
  - 3. Step:
    integrated online use of planed complex manoeuvres for monitoring and online support

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Implementation of simulation exercise for energy efficient ship operation

Test setup for the assistance system for harbour manoeuvres in ship-handling simulators of partners

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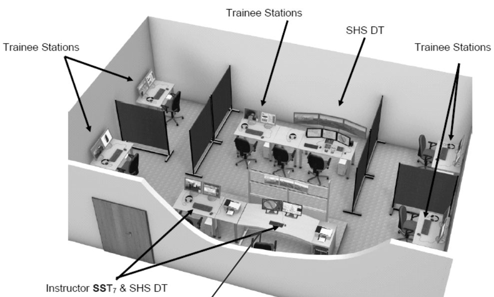
Implementation of simulation exercise for energy efficient ship operation – *The new simulation laboratory at WMU*



Integrated SAMMON - Station

- Overview
- Ship-handling simulation
- Safety & security simulation

Inauguration with IMO secretary general

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Summary and Conclusions

- Potential for "green ship operation" has been proven in a simulation study
- Manoeuvring assistance for complex harbour manoeuvres can contribute to time saving, more efficient use of steering equipment and consequently for efficient use of energy resources
- planning of complex manoeuvres contributes to more efficient use of controls for engine, rudder and thrusters
- related training is to demonstrate the effects and to train the integrated use of enhanced manoeuvring assistance tools

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Thank you for your attention!
Awaiting your questions!

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