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Set-up of integrated optimization platform and definition of optimization problem

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Document History

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SHOPERA-D5.1-rev1	18-09-2014	Initial version
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Document Control Sheet

Title: Set-up of integrated optimization platform and definition of optimization problem
Abstract *Within WP5 of the SHOPERA project, a multi-objective optimization procedure will be developed, in which a ship's performance is assessed holistically, thus, looking for the minimum powering requirement to ensure safe ship operation in adverse seaway/weather conditions, while keeping the right balance between ship economy, efficiency and safety of the ship and the marine/air environment.* *The objective of this report is to present (a) the definition of optimization problem (statement of the optimization problem, objective functions, constraints, design variables, design parameters) and (b) the set-up of an integrated optimization platform, with reference to the selected CASD software tools, optimization algorithms and optimization software tools.*
Summary Report: **Introduction** *A ship needs to be optimized for cost effectiveness, operational efficiency, improved safety and comfort of passengers and crew, and, last but not least, for minimum environmental impact (minimization of risk of accidental oil outflow, engine emissions etc.). Many of these requirements are clearly conflicting and a decision regarding the optimal ship design needs to be rationally made. This is the case of the problem which the SHOPERA project is dealing with: Environmental concern was the reason behind the introduction of the EEDI requirements by the IMO a few years ago. One way of fulfilling the demanding requirements of the EEDI regulation, is the reduction of speed of future ships. This would result however in under-powered designs, raising questions regarding the ability of these designs to operate safely in adverse weather conditions. The challenge of identifying the more suitable path between the conflicting requirements of reducing greenhouse emissions and at the same time maintaining adequate safety of ships in adverse sea conditions is the main objective of the SHOPERA project.* *The ultimate goal of the SHOPERA project is the development and submission to IMO of new guidelines for the required minimum propulsion power and steering performance required to maintain manoeuvrability in adverse conditions. To this end, a series of software tools for the analysis of the seakeeping and manoeuvring performance and safety of ships in adverse weather conditions will be refined and extended. Model tests will be carried out in order to provide the basis for the validation of the above-mentioned software tools. In addition to the above, a specific work package is foreseen (WP 5) for the development of a multi-objective optimization procedure, in which a ship's performance is assessed holistically, thus, looking for the minimum powering requirement to ensure safe ship operation in adverse seaway/weather conditions, while keeping the right balance between ship economy, efficiency and safety of the ship and the marine/air environment.* *This report presents (a) the definition of optimization problem (statement of the optimization problem, objective functions, constraints, design variables, design parameters) and (b) the set-up of an integrated optimization platform, with reference to the selected CASD software tools, optimization algorithms and*

optimization software tools.

State of the Art

The use of optimisation methods in ship design goes back to the mid-sixties and early-seventies, with the well-known works of Murphy et al. ([9]), Mandel et al. ([7]) and ([8]) and Nowacki et al. ([10]). A synopsis of key developments in Computer-Aided Ship Design during the last five decades is presented by Nowacki ([11] and [12]), where the introduction and evolution of optimization methods in ship design is highlighted. In recent years, the use of optimisation methods in various fields of ship design has been quite common. A comprehensive overview of the current state of the art in ship design optimization may be found in Birk and Harries, ([2]).

One of the more important fields of ship design, where optimisation methods are extensively applied is the design of hullform for improved hydrodynamic performance, with particular emphasis on calm water resistance. An overview of the evolution of hydrodynamic hull optimization methods from historic roots in the 1960s to formal hull optimization as performed today is presented by Hochkirch and Bertram ([3]). Another important field of application is the structural design optimisation, in association with advanced software tools (FEM).

The use of optimization methods in the preliminary design of ROPAX ships and Oil Tankers, based on the integration of state of the art software tools for the development and assessment of alternative designs is described by Papanikolaou et al. ([14]) and Sames et al. ([16]).

A systemic approach to ship design, considering the ship as a complex system integrating a variety of subsystems and their components, and at the same time addressing the whole ship's life-cycle and applying "holistic" ship design optimization procedures is presented by Papanikolaou ([13]).

Value added to SHOPERA

The work presented in this deliverable is the first step towards the implementation of a series of optimization platforms for selected ship-types, needed to carry-out the optimization studies in WP 5, aiming to investigate the impact of the EEDI requirements to the design and operational characteristics of future ships.

Achievements

(a) the definition of optimization problem and
(b) the set-up of an integrated optimization platform

Not achieved

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Input from other Deliverables

This task receives input from D1.3, D1.4, D1.5 and D6.1 and provides output to Tasks 5.2 and 5.3 in the form of requirements and specifications on the development of the parametric models and the elaboration of the optimization studies.

Exploitation of results

The work presented in this deliverable is the first step towards the implementation of a series of optimization platforms for selected ship-types, needed to carry-out the optimization studies in WP 5, aiming to investigate the impact of the EEDI requirements to the design and operational characteristics of future ships.

The optimization platforms, once developed, tested and validated will be valuable tools for the design of ships with enhanced operational, economic and safety characteristics. These tools will be exploited to the helping the WP5 partners to design new, highly competitive ships, or to provide services to design offices, shipyards and shipowners.

The optimization studies to be performed in WP5 will provide valuable data and information for the elaboration of the case studies in WP 6 and will assist the SHOPERA partners to investigate the impact of the EEDI requirements to the design and operational characteristics of future ships and to formulate a submission to IMO (in WP 7) of updated guidelines for minimum required power and steering performance of ships in order to maintain manoeuvrability under adverse conditions.

This executive summary may be published outside the SHOPERA consortium. *YES*

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Abbreviations / Acronyms

CASD	Computer Aided Ship Design
CFD	Computational Fluid Dynamics
DECC	Department of Energy & Climate Change, U.K.
EEDI	Energy Efficiency Design Index
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
MEPC	Marine Environment Protection Committee
NPV	Net Present Value
RFR	Required Freight Rate
RoPax	Roll On – Roll Off Passenger Ferry
SHOPERA	Acronym of the project (full title: Energy Efficient Safe SHip OPERAtion)

List of Project Partners

	Participant organisation name	Type	Country
1	National Technical University of Athens (NTUA) - (Coordinator)	UNIV	Greece
2	Germanischer Lloyd SE (GL)	CLASS	Germany
3	Det Norske Veritas (DNV)	CLASS	Norway
4	Lloyds Register EMEA (LR)	CLASS	UK
5	Norsk Marinteknisk Forskningsinstitutt AS (MRTK)	RES	Norway
6	Instituto Superior Tecnico (IST)	UNIV	Portugal
7	Universitaet Duisburg-Essen (UDE)	UNIV	Germany
8	RINA Services SPA (RINA)	CLASS	Italy
9	Flensburger Schiffbau Gesellschaft mbH & Co KG (FSG)	YARD	Germany
10	Uljanik Brodogradiliste DD (ULJ)	YARD	Croatia
11	Teknologian Tutkimuskeskus (VTT)	RES	Finland
12	Eigen Vermogen Flanders Hydraulics (EVFH)	RES	Belgium
13	Canal de Experiencias Hidrodinamicas de el Pardo (CEHIPAR)	RES	Spain
14	University of Strathclyde (SU)	UNIV	UK
15	Danmarks Tekniske Universitet (DTU)	UNIV	Denmark
16	Technische Universitat Berlin (TUB)	UNIV	Germany
17	Technische Universiteit Delft (DUT)	UNIV	Netherlands
18	Naval Architecture Progress (NAP)	DES	Greece
19	Danaos Shipping Company Ltd. (DAN)	OPER	Cyprus
20	FOINIKAS Shipping Company (FNK)	OPER	Greece
21	Calmac Ferries Ltd. (CAL)	OPER	UK

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1 Introduction

During the preliminary ship design stage, the designer, in search of the 'optimal vessel' for a specified operation scenario, is constantly faced with a series of important decisions, all of them having crucial impact on the vessel's performance. It is the nature of the designer's work that requires many of these decisions to be made during the early stages, usually based on limited, vague or in some extend unreliable information ([1]). In such cases, the designer needs to rely on his experience, human intuition and engineering judgment, occasionally supported by the exploitation of relevant data available from past designs. In such cases, advanced design tools, making use of modern CASD technology to facilitate the elaboration of a vessel's preliminary design in limited time and with reduced human effort, yet at the same time with reasonable detail and accuracy, would be undoubtedly of great assistance to the designer.

A systemic approach to ship design needs to consider the ship as a complex system, integrating a variety of subsystems and their components, all serving well-defined ship functions ([13]). Employing the parametric design, or parametric modelling procedure, the design of a certain object, component or system, may be "automatically" elaborated, using specifically developed software tools. These tools are developed to undertake the elaboration of the corresponding design, for each particular set of values of the design variables defined by the designer. A parametric design procedure may be relatively easily implemented in the case of simple objects or components. In the case of integrated systems however, such as an industrial plant, or in the particular case a large commercial ship, the implementation of a parametric model is no more a simple task, if possible at all, as the level of complexity increases exponentially. In such cases, the design of the parametric model requires particular attention, in order to ensure its integrity, accuracy, robustness and functionality. The parametric model should be flexible and generic, so that it can be applicable to as many design alternatives as possible, detailed enough in order to depict all the essential characteristics of the design, and at the same time as simple as possible, to avoid any unnecessary complexities and implications during the development of the corresponding software tools. Such tools, if available, would enable the application, testing and verification of crucial assumptions and decisions regarding the ship's main technical characteristics on a large number of design alternatives, in order to identify the most suitable design according to a set of selected criteria, to serve as the basis for the subsequent detailed design stages. Going one step further, once developed, such a tool for the parametric modelling of the preliminary design of a ship, could be used as the core of a formal optimization procedure, facilitating the rational exploration of the design space and the identification of a series of "optimal", or "near-optimal" design solutions, according to a predetermined set of design criteria (objective functions or merit functions), while at the same time fulfilling a set of design constraints. Inherent to ship design optimization are the conflicting requirements, resulting from the design constraints and optimization criteria, reflecting the interests of the various stake holders: ship owners and operators, ship builders, classification societies, administrations, regulators, insurers, cargo owners/forwarders, port operators, etc.

A ship needs to be optimized for cost effectiveness, operational efficiency, improved safety and comfort of passengers and crew, and, last but not least, for minimum environmental impact (minimization of risk of accidental oil outflow, engine emissions etc.). Many of these requirements are clearly conflicting and a decision regarding the optimal ship design needs to be rationally made. This is the case of the problem which the SHOPERA project is dealing with: Environmental concern was the reason behind the introduction of the EEDI requirements by the IMO a few years ago. It is foreseen that one way of fulfilling the demanding requirements of the EEDI regulation, is the considerable reduction of the design speed of future ships, a solution which has also the very important advantage of considerable fuel savings. This would result however in comparatively under-powered designs, which in turn raises questions regarding the ability of these designs to operate safely in adverse weather conditions. The challenge of identifying the more suitable path between the conflicting requirements of reducing greenhouse emissions and at the same time maintaining adequate safety of ships in adverse sea conditions is the main objective of the SHOPERA project. According to the project's proposal:

> *The proposed project SHOPERA addresses the above outlined challenges by looking holistically at integrated ship design and operational environments, and implementing multi-objective optimisation procedures to optimise a ship's powering while ensuring safe ship operation; but at the same time seeking the right balance between the ship's efficiency and economy, safety and greenness.*

The ultimate goal of the SHOPERA project is the development and submission to IMO of new guidelines for the required minimum propulsion power and steering performance required to maintain manoeuvrability in adverse conditions. To this end, a series of software tools for the analysis of the seakeeping and manoeuvring performance and safety of ships in adverse weather conditions will be refined and extended. Model tests will be carried out in order to provide the basis for the validation of the above-mentioned software tools. In addition to the above, a specific work package is foreseen (WP 5) for the development of:

> *A multi-objective optimization procedure in which a ship's performance is assessed holistically, thus, looking for the minimum powering requirement to ensure safe ship operation in adverse seaway/weather conditions, while keeping the right balance between ship economy, efficiency and safety of the ship and the marine/air environment.*

Apart from the optimization studies, the impact of the new guidelines on the design and performance of ships will be investigated by the elaboration of a number of ship studies (WP6).

The main objective of this report is to present:

- the definition of optimization problem (statement of the optimization problem, objective functions, constraints, design variables, design parameters) and
- the set-up of an integrated optimization platform, with reference to the selected CASD software tools, optimization algorithms and optimization software tools.

2 Optimization methods in Ship Design

Following Nowacki ([11]), *Design in engineering is a decision-making process that leads from a set of given product requirements to a product definition with all salient features for design assessment and production*. The main elements of a design problem are shown in Fig. 1 extracted from the same reference:

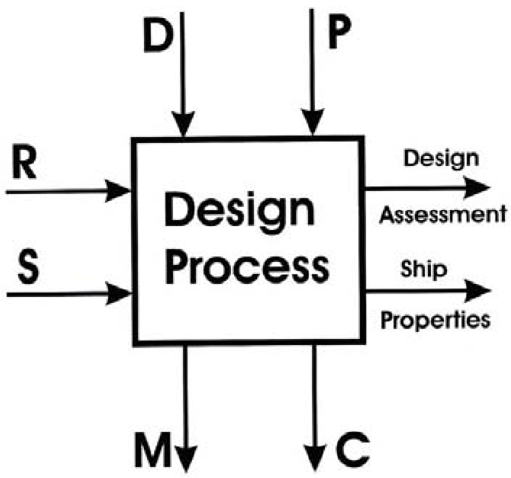

Figure 1: Elements of Design Process Definition

The symbols used in Figure 1 are explained below:

R: requirements, i.e., functional requirements with desired performance, regulatory and legal requirements, regulatory and safety constraints, owner's and user's demands, operational scenarios and constraints.

S: solution space, i.e., a delimitation of the domain in which solutions shall be sought with ranges of variation in concepts and design variables.

D: the set of design variables, that is free variables under the designer's control (e.g., principal dimensions, form coefficients etc.), assuming their values within the design space.

P: the set of parameters, which are variables not under the designer's control, but dictated by the specific case scenario, hence not known in advance, e.g., route, range, cargo availability, port water depth etc.

M: the measures of merit (or objective functions), such as economic criteria, or other types of measures of the performance of the design.

C: the constraints, equalities and inequalities, e.g., concerning stability, freeboard, capacities etc.

Design assessment: a proposed solution meeting all requirements described in terms of its characteristic features and performance measures.

Ship properties: an enumeration of the achieved design properties furnishing a complete product description and serving as a basis for production.

The Design Process Definition described above may be implemented within an optimization procedure, based on the integration of software tools for the development and assessment of the parametric model of the design with an appropriate optimization software. The optimization software is introduced in order to control and drive the overall process, selecting appropriate values for the design variables and passing them to the software tools responsible for the development and assessment of the parametric model. Based on the evaluation of past designs, the optimization software selects new values for the design variables following selected optimization algorithms and the process is repeated aiming to identify favourable combinations of the design variables, resulting to “optimal” designs.

The use of optimisation methods in ship design goes back to the mid-sixties and early-seventies, with the well-known works of Murphy et al. ([9]), Mandel et al. ([7]) and ([8]) and Nowacki et al. ([10]). A synopsis of key developments in Computer-Aided Ship Design during the last five decades is presented by Nowacki ([11] and [12]), where the introduction and evolution of optimization methods in ship design is highlighted. In recent years, the use of optimisation methods in various fields of ship design has been quite common. A comprehensive overview of the current state of the art in ship design optimization may be found in Birk and Harries, ([2]). One of the more important fields of ship design, where optimisation methods are extensively applied is the design of hullform for improved hydrodynamic performance, with particular emphasis on calm water resistance. An overview of the evolution of hydrodynamic hull optimization methods from historic roots in the 1960s to formal hull optimization as performed today is presented by Hochkirch and Bertram ([3]). Another important field of application is the structural design optimisation, in association with advanced software tools (FEM). The use of optimization methods in the preliminary design of ROPAX ships and Oil Tankers, based on the integration of state of the art software tools for the development and assessment of alternative designs is described by Papanikolaou et al. ([14]) and Sames et al. ([16]). A systemic approach to ship design, considering the ship as a complex system integrating a variety of subsystems and their components, and at the same time addressing the whole ship's life-cycle and applying “holistic” ship design optimization procedures is presented by Papanikolaou ([13]).

3 Adaptation/Integration of Tools - Multi-objective Optimization Platform

The objective of WP 5 of the SHOPERA project, as stated in the DoW is:

> *To integrate validated software tools for the hydrodynamic/manoeuvrability assessment of ships in adverse seaway/weather conditions into a ship design software platform and set-up of multi-objective optimization procedures in which ship’s performance is assessed holistically, thus, looking for the minimum powering requirement to ensure safe ship operation in adverse seaway/weather conditions, while keeping the right balance between ship economy, efficiency and safety of the ship and the marine/air environment.*

The planned optimization studies shall be implemented in two phases:

- The first phase consists of a *Global Optimization*, aiming to identify most favourable combinations of main dimensions, form parameters and other integrated characteristics of the ship, including powering and manoeuvring devices, for the selected operational profile.

  These studies should be carried out applying as far as possible simplified, semi-empirical models (level 1 methods) developed in previous work packages of the project.

- The second phase consists of a *Detailed Optimization*, including hullform details.

These studies should be carried out for selected ship types and sizes based on the outcome of the previous phase, applying as far as possible medium accuracy models (level 2 methods) developed in previous work packages of the project. Heavy-refined models (level 3, CFD type methods) could also be applied if necessary, but their use will be kept at minimum as possible.

The work is to be carried out by 11 project partners, namely NTUA, IST, UDE, FSG, ULJ, VTT, DUT, NAP, DAN, FNK and CAL[1]. The types of activities in WP5 and the involvement of the partners in these activities is presented in the following:

- Development of software tools and optimization procedures: NTUA, IST, VTT, DUT, NAP
- Expertise on the assessment of hydrodynamic behaviour of ships, interconnection with WP4: UDE
- Expertise on ship design and ship building: FSG, ULJ
- Data and expertise on the operation of ships and on the definition of the optimization problem and the development of the software tool: DAN, FNK, CAL
- Elaboration of the optimization studies: NTUA, IST, VTT, NAP

The list of ship types to be optimized is presented in Table 1.

Table 1: Ship types to be optimized

	Ship Type	Global optimization	Detailed optimization
1	Bulk carriers	2	1
2	Containerships	2	1
3	Tankers	2	1
4	Cruise ships	1	1
5	RoPax Ships	2	1
6	General cargo ships	1	
7	LNG carriers	1	
	TOTAL	11	5

The distribution of work between the WP5 partners has been discussed and agreed during the 1st Project Management Committee Meeting (Oslo, 03-04/04/2014):

- Global optimization:
  - Software development will be carried out by NTUA and NAP. Technical expertise will be provided by DUT, UDE, DAN, FNK, CAL, FSG, ULJ.
  - The optimization studies will be carried out by NTUA.
  - The evaluation of results will be carried out by NTUA and NAP in collaboration with DAN, FNK, CAL, FSG, ULJ.
- Detailed hullform optimization:
  - Software development by IST, VTT and DUT (engine dynamics). Technical expertise will be provided by UDE.

[1] See table in page 5 for an explanation of acronyms

- The optimization studies will be carried out by IST and VTT.
- The evaluation of results will be carried out by IST and VTT in collaboration with NTUA, UDE, DAN, FNK, CAL, FSG, ULJ.

WP5 consists of the following three tasks:

Task 5.1 Set-up of integrated optimization platform and definition of optimization problem (M1-M12)

Task 5.2 Development and implementation of parametric models (M10-M24)

Task 5.3 Optimisation studies (M23-M30)

4 Definition of the optimization problem

The objective of the Global Optimization is to identify most favourable combinations of main dimensions, form parameters and other integrated characteristics of the ship, for a specified operational profile. Going back to Figure 1, for each ship type and size the main elements of a design problem need to be specified:

Requirements (R). Depending on the ship type, requirements include:

- **Transport capacity**. Depending on ship type, transport capacity will be described using:
  - Number of passengers (Cruise ships and RoPax Ships).
  - Lane meters, or number of vehicles (RoPax Ships).
  - DWT (cargo ships).
  - TEU number in holds and on deck (Containerships and possibly General cargo ships).
  - Volume of holds (Bulk carriers and General cargo ships).
  - Volume of tanks (Tankers and LNG carriers).
- **Design speed** at calm water and with a specified power margin for adverse conditions.
- **Range** in sea miles and/or days at sea.
- **Main regulatory requirements**. Depending on ship type, regulatory requirements to be considered include (but are not limited to):
  - **Load Line Convention**
  - **Intact Stability Regulations**
  - **Damaged Stability Regulations** (to be considered in selected cases, since damaged stability calculations typically require a much more complex and refined ship model than usually available during the conceptual design phase and at the same time they result in a considerable increase of calculation time, which is not always affordable in an optimization study).
  - **MARPOL** requirements (for Tanker ships)
  - **IMO** Manoeuvrability Criteria
  - **EEDI** requirements
- **Functional requirements** with desired performance, owner's and user's demands, operational scenarios and constraints. These will be defined on a case by case basis, in collaboration between the WP5 partners. At this point, input from the representatives of the 'owners' (DAN, FNK, CAL) will be crucial.

Each ship will be optimized for a specified operational scenario to be decided between the partners, depending on the ship's size. In collaboration with the representatives of the 'owners', a business model will be developed for each study, which will be as detailed as possible, to be used during the optimization.

Solution space (S). The definition of the solution space is closely related with the selected design variables and hence with the particular parametric model, developed for each ship type. As a minimum, the design variables will include the main particulars of the ship (Length between perpendiculars, Beam, Draught, Depth) as well as a series of geometric characteristics specifying the design of the ship (i.e. the hullform and the internal layout). Apart from the main particulars, in general, it is possible to select between alternative sets of design variables in order to completely define the hullform and the internal layout. For example, it is possible to use either the midship section coefficient or the bilge radius to completely define the midship section. In addition, it is possible to use the remaining form coefficients and the longitudinal position of the centre of buoyancy, or the length of entrance, parallel midbody and run, along with additional variables defining local hullform characteristics (such us the waterline entrance angle, bulbous bow characteristics, transom stern and duck tail characteristics, when applicable), in order to completely define the hullform, according to the requirements and functionality of the employed parametric model. According to the initial considerations, and subject to subsequent revisions, the parametric models to be developed for the global optimization studies will make use of the following design variables:

- Main particulars (Length between perpendiculars, Beam, Draught, Depth).
- Length of entrance and parallel mid-body.
- Bilge radius.
- Volume coefficients of entrance and run (optionally).
- The entrance angle at the design waterline and variables controlling the local details of the bulbous bow and transom stern will be included in the set of design variables, if it is verified that the (simplified) software tools used during the optimization studies are capable of depicting correctly their impact on the hydrodynamic performance of the ship.
- Longitudinal position of engine room and superstructure (container ships, passenger ships).
- The number of transverse/longitudinal bulkheads and the corresponding number of holds/tanks will be treated either as a design variable, or as a design parameter.
- Propeller and rudder characteristics (if not calculated by the parametric modelling tool)
- Engine characteristics (unless the engine is selected by the parametric modelling tool, from a given list)

Once the parametric model is completed, and the design variables are specified, the definition of the Solution Space requires the definition of the range of variation of each design variable. This task will be performed on a case by case basis, depending on the ship type and size considered.

Design variables (D). Each design alternative will be developed by the parametric model, based on the actual values of a set of design variables. These values will be assigned by the optimization software, within the Solution Space defined by the user.

Parameters (P). A set of parameters will be determined for each design optimization study based on the "owner's requirements" and/or the specific operational scenario. For example, in the case of the optimization of a ROPAX ship, appropriate parameters will be used to specify the seasonal characteristics of the operational scenario (e.g. duration of high, medium, low season, corresponding occupancies, fares and freight etc.), along with specific requirements regarding the crew synthesis, the accommodation spaces, vehicles characteristics. Various parameters related to the physical properties of the cargo, owner's requirements regarding the cargo gear, or constraints resulting from the selected route (ports, terminals, berths, canals), or from the owner's preferred mode of operation will be identified. These parameters will be specified on a case by case basis, depending on the ship type and size considered.

Measures of merit, or objective functions (M) and constraints (C). In their simpler form, optimization problems are of the single-objective type, aiming to identify the appropriate combination of values of a set of design variables, maximizing or minimizing one objective function. However, in many practical applications, the designer needs to consider at the same time a series of objective functions, whereas the formulation of a multi-objective optimization problem is needed. The problem is that, the various objective functions are not accepting their optimum value for the same set of design variables, while they are frequently contradicting with each other (for example, in ship design the requirement to maximize safety is usually in contradiction with the requirement for minimum construction or operational cost). Multi-objective optimization problems are, therefore, considerably more demanding than single-objective ones, while the use of special optimization algorithms is required.

The proper selection of the objective functions in ship design depends on the problem at hand. In hullform optimization, suitable objective functions are those characterizing the hydrodynamic performance of the ship (calm water resistance and corresponding propulsion power, added resistance in waves, ship motions and accelerations in waves, operability characteristics for the required mission of the ship). In structural optimization studies, suitable objective functions might be the minimization of steel weight (and of the height of the corresponding weight centre), or of construction cost, or improved performance of the steel structure (e.g. increased resistance in bending moments, buckling stresses or fatigue, avoidance of resonance with external excitation etc.).

For the global optimization studies in WP 5, the obvious choice is the use of objective functions related with the economic performance of the design. The minimisation of building cost is an obvious choice, particularly in cases where the optimisation study is performed by (or for) a shipyard, seeking to find the most economic design, subject to a set of operational requirements, specified by the potential owner. In addition to the minimisation of building cost, other criteria, such as the minimisation of the required propulsion power, or the annual operating costs, or the maximisation of annual revenue on a selected route, are of particular interest from the ship owner's point of view. Accounting for all these objectives at the same time, requires the formulation and solution of a multicriteria optimisation problem. On the other hand, more complex economic criteria, such as the minimisation of the Required Freight Rate (RFR) or the maximisation of the Net Present Value (NPV) may be used, revealing the vessel's actual economic performance for a particular operational scenario. All the above-mentioned requirements, the minimisation of building and operating costs, the minimisation of the required propulsion power, and the maximisation of the annual revenue, are directly accounted in a rational way, both in the RFR and the NPV index. In this case, the optimization of the design of the ship, might be reduced to a single-objective optimization problem (i.e. the minimization of RFR or the maximization of NPV), while other aspects of the design (regulatory requirements related to the ship's safety, seaworthiness, operability, functional requirements etc.) might be treated as constraints. The alternative (and more complex) solution, is to formulate and solve a multi-objective optimization problem, taking into consideration all aspects of the design needed to be optimized, either of economic, safety, operational or functional nature. It should be noted that, the proper selection between the two alternatives presented above, depends on the specific interests of a particular stake-holder, and may very well vary from the one case to the other. The software tools to be used in the global optimization studies in WP 5, will be developed with the aim to be able to handle both alternatives, i.e. (a) single-objective optimization of complex economic indices (such as the RFR or the NPV index), treating all other aspects of the design as constraints and (b) multi-objective optimization of a series of objective functions related to the economic, technical, operational and safety characteristics of the design, under a set of constraints.

Of particular importance for the studies in WP 5 are the hydrodynamic/manoeuvring characteristics in adverse seaway/weather conditions of each design alternative. Their evaluation will be carried out applying as far as possible simplified, semi-empirical models (level 1 methods), developed in previous work packages of the project, while the formulation of the optimization problems will enable their treatment either as objective functions, or as constraints.

Additional constraints resulting from the selected route (ports, terminals, berths, canals), or from the owner's preferred mode of operation will be identified and implemented, on a case by case basis.

Design assessment and Ship properties. For each set of values of the design variables, the corresponding 3d model of the design will be developed, using the selected CASD software and its properties will be evaluated. The 3d model will be comprised by the hullform and the internal arrangement. The model of the internal arrangement will be of a simplified form, to an extend enabling the evaluation of the design but without unnecessary details and complications.

For the cargo ships, the internal arrangement model will include the engine room, the steering gear room, the cargo holds and cargo tanks, the ballast tanks, the fresh water tanks outside the engine room, the fuel tanks located outside the engine room and possibly the main fuel tanks in the engine room. Other important compartments for specific ship types will be also considered as necessary and to the extent possible. Spaces above the main deck (forecastle, poop deck, superstructure, funnel etc.) will be modelled as blocks without considering the details of their internal arrangement.

For the passenger ships, (either cruise ships or RoPax ships), the internal arrangement model shall consist of the main watertight compartments up to the subdivision deck (main engine room, auxiliary engine rooms, lower holds, water ballast, fuel oil and fresh water tanks outside of the engine room, void spaces), to an extend permitting preliminary damaged stability calculations, but without a detailed definition of smaller tanks, openings or cross flooding devices. A simplified model of the superstructures will be also created, to an extend enabling a reasonable estimation of windage areas, deck areas, transport capacity and weight of steel structure and outfitting.

The completion of the 3D model of each design will be followed by the evaluation its technical and economic properties, to the extend allowing the assessment of the design and a fair comparison with the other design alternatives. The technical and economic properties to be evaluated include (but are not limited to) the calm water resistance, required propulsion power, the hydrodynamic/manoeuvring characteristics in adverse seaway/weather conditions, the stability characteristics, the transport capacity, construction cost, operational cost, annual income, Required Freight Rate and Net Present Value Index for the selected business model.

5 Set-up of integrated optimization platform

A suite of software tools is going to be integrated, to facilitate the elaboration of the global optimization studies in WP5. Among them, a CASD software will be used for the development of the 3d model of each alternative design and for the evaluation of its performance. External software tools will be also linked, as needed, to take over specific tasks of the evaluation (for example external software tools for the evaluation of the hydrodynamic/manoeuvring performance in adverse seaway/weather conditions, in case that level 1 criteria are not available). The CASD software and other external software tools will be integrated with a general purpose optimization software.

The CASD software that is selected to be used in WP 5 is NAPA. The main advantage of this software tool, apart from a complete suite of modules and tasks, suitable for the detailed 3d modelling and analysis of ship designs, is the availability of NAPA Basic, an integrated programming language that facilitates the development of a parametric model with the level of detail needed for the work at hand. Using the functionality provided by the NAPA Basic programming language, it is possible to fully automate the development and evaluation of the 3d model, once NAPA is called by the optimization software, without the need of any user intervention.

The optimization software to be used in WP 5 is modeFRONTIER by E.STE.CO. This is a general purpose optimization software, offering a variety of optimization algorithms, and a very flexible graphical user interface, facilitating the set-up of complex optimization problems, the integration of various software tools, and the analysis of the obtained results. modeFRONTIER has been successfully applied by the Ship Design Laboratory of NTUA in several optimization studies related to various aspects of ship design. The role of modeFRONTIER will be to carry the overall control of the process flow, assigning appropriate values to the set of optimization variables and calling NAPA for the elaboration and assessment of the corresponding design alternative. Selected design characteristics will be returned to modeFRONTIER, to be evaluated by the selected optimization algorithm. Based on the results of the evaluation, the optimization algorithm assigns new values to the set of optimization variables and the above procedure is repeated, until it converges to an optimum solution, or the specified maximum number of iterations is reached. A graphical representation of the setup of the integrated optimization platform, to be developed and applied in WP5 is presented in Figure 2. Whenever possible (e.g. in case of single-objective optimization studies), optimization algorithms of the deterministic type will be selected, to take advantage of their efficiency and speed of convergence. When this is not possible, genetic algorithms will be selected, taking advantage of their inherent capability to deal with multi-objective optimisation problems with mixed continuous-discrete variables and discontinuous and non-convex design spaces.

Once NAPA is called by the optimization software, the parametric design methodology to be developed will be automatically executed and the following basic tasks will be elaborated:

1. Hull form development

2. Resistance and propulsion estimations
3. Development of internal layout
4. Weights estimation - Definition of Loading Conditions
5. Evaluation of Stability Criteria and other Regulatory Requirements
6. Evaluation of hydrodynamic/maneuvering performance in adverse seaway/weather conditions
7. Assessment of Building and Operational Cost, Annual Income and Selected Economic Indices

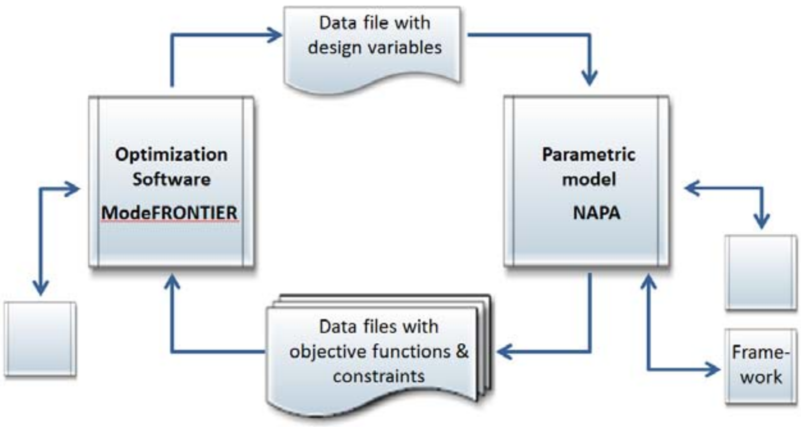

Figure 2: Graphical representation of the optimization setup to be developed and applied in WP5 is presented

Hull form development: The first step of the parametric design procedure will be the development of the hull form. Already available NAPA macros will be further refined, or new macros will be developed, to facilitate the fully automatic hullform definition. Considerable attention will be given to ensure that the resulting hullforms are of adequately high quality, to serve as the basis of the subsequent tasks, particularly the hydrodynamic and the intact and damaged stability calculations.

The hull will be divided in three parts: entrance, run and parallel mid-body. The development of each part of the hull will based on a set of relevant design variables. Additional parameters will be used to control local hull form details, such as the size and shape of the bulbous bow, the shape of the flat of side and flat of bottom, the immersion of the transom, or the existence of a propeller tunnel, a duck tail or a stern wedge (in the case of ROPAX ships), or the existence, shape and size of a stern bulb in case of cargo ships. Based on these parameters, three grids of definition curves will be created defining the vessel's entrance, mid-body and run. The definition curves, the cross-sections and a rendered representation of the resulting hull form of a typical ROPAX ship, created by a parametric design application are presented in Figure 3 to Figure 5, extracted from [14]. The resulting hull forms are typical of modern twin-screw RoPax vessels with fine fore-bodies and buttock-flow sterns.

Resistance and powering calculations: Following the definition of the hullform, the next step will be the preliminary resistance and powering calculations. This task will be performed applying semi-empirical methods (for example using the well-known Holtrop and Mennen method [4], [5]). A second approach that might be considered under different circumstances could be based on the use of CFD software tools. However, potential theory codes are not well suited for resistance calculations of low speed cargo ships, while the use of viscous flow solvers would be unrealistic, at least for the global optimization studies.

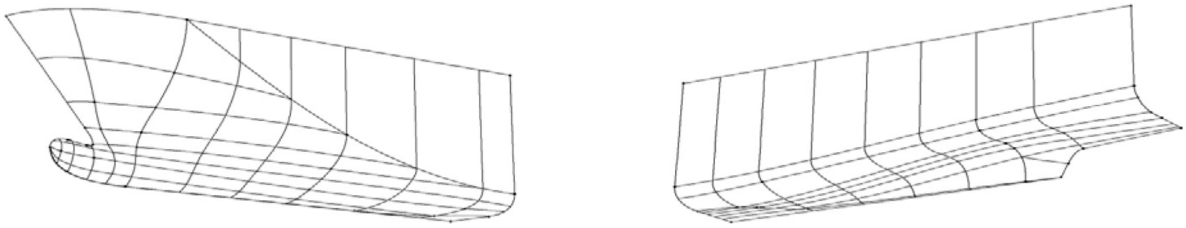

Figure 3: Definition grids of the fore- and aft-body of a typical RoPax ship

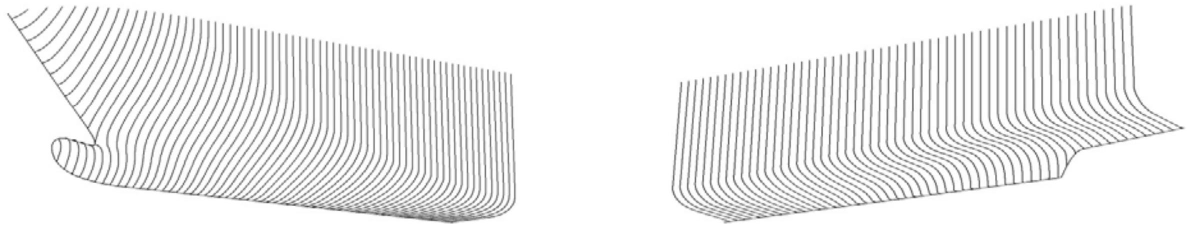

Figure 4: Transverse sections of the fore- and aft-body of a typical RoPax ship

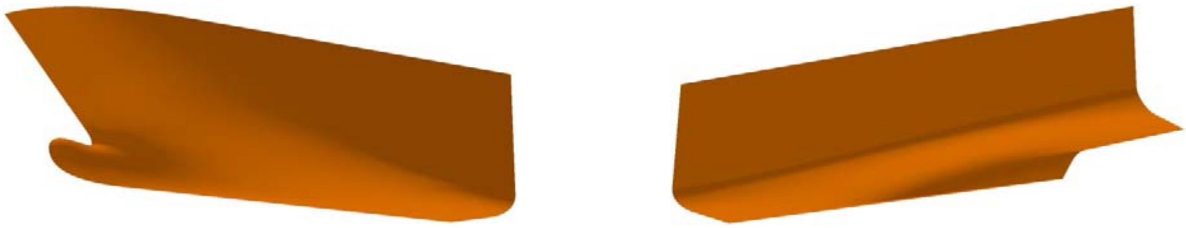

Figure 5: Resulting hullform

Internal layout: A parametric model for the development of the internal layout of a RoPax ship is presented in [18] and [14]. The development of the vessel's internal arrangement starts with the definition the watertight subdivision below the main car deck. A horizontal bulkhead deck and a piecewise horizontal double bottom deck are created according to user-defined parameters. The vessel is subsequently divided in two zones, aft and forward of the main engine room. If not supplied by the user, the size and position of the main engine room are determined first. The length of the engine room is derived from the size of the main engines, based on empirical formulae derived from the statistical analysis of data from existing vessels, considering also requirements implied by the SRTP regulation.

Subsequently, the main transverse bulkheads aft and forward of the engine room are positioned and the corresponding watertight compartments are created. The longitudinal position of the transverse bulkheads may be either explicitly defined by the user, or automatically selected by the developed software based on a series of rules of thumb. The number of car decks and the type of vehicles (mix of private cars and trucks) carried on each of them are controlled by a series of user-defined parameters, in accordance with the size of the designed vessel. Smaller vessels have usually only one deck for the carriage of trucks and private cars. For the larger vessels, an additional upper deck for the carriage of trucks and/or private cars and/or one or two lower holds, forward of the engine room, for the carriage of private cars may be created, according to the user's specifications. Alternative layouts with central or side casings may be modelled, as specified by the user. A number of upper decks are then generated, providing the necessary space and area for the accommodation of passengers and crew. An example of the resulting General Arrangement of a large RoPax vessel, developed by the parametric design software is presented in Figure 6 extracted from [14]. This vessel, with a transport capacity of 1600 passengers (750 berthed), 102 trucks and 125 private cars, has three accommodation decks, a main and an upper car deck for the carriage of trucks and two additional garage spaces in the lower holds, carrying private cars. This parametric model will be appropriately modified and developed in order to be used in WP 5 for the global optimization studies of the two Ro-Ro ferries and the cruise ship.

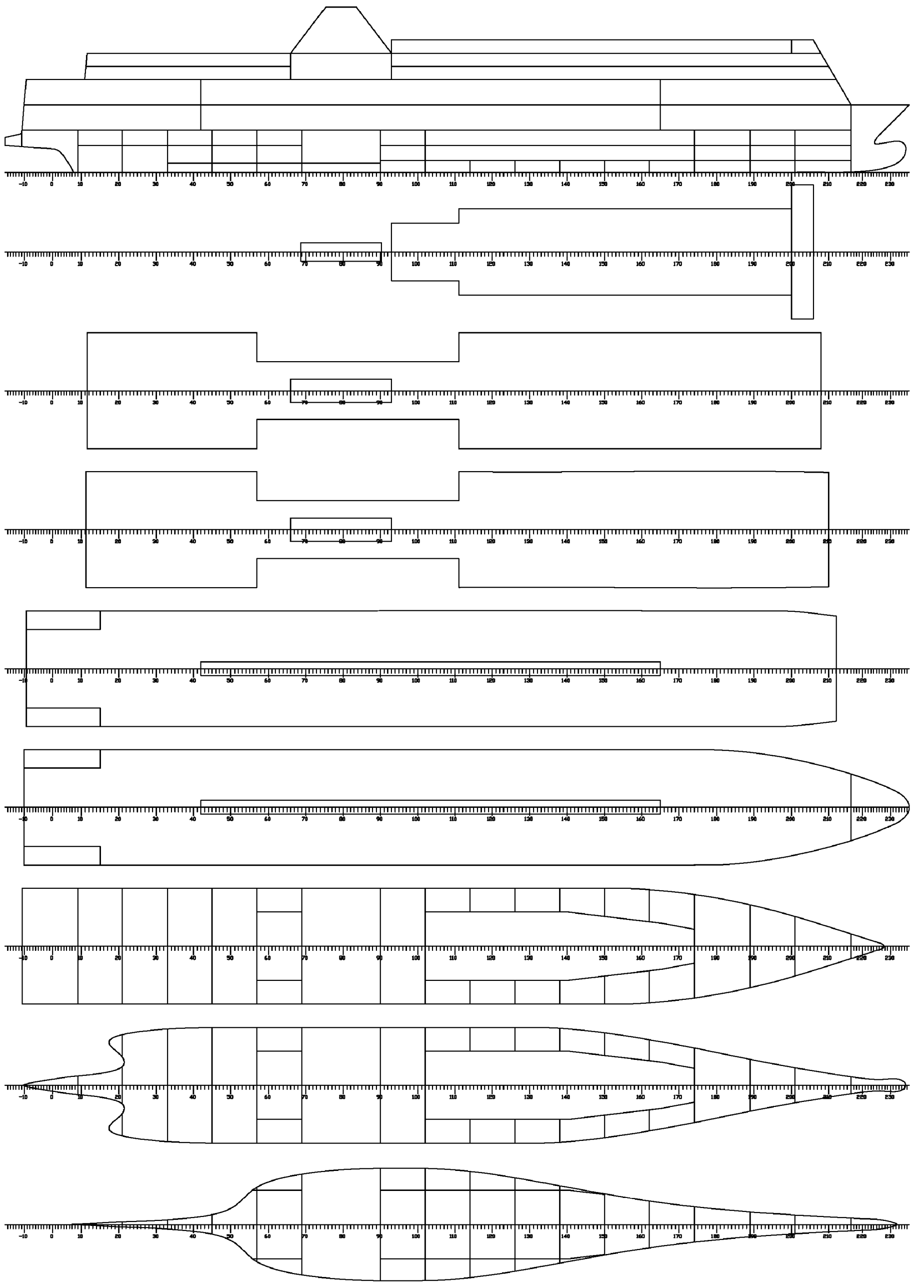

Figure 6: Typical GA of a large RoPax vessel

A parametric model for the design of AFRAMAX tankers is presented in [15] and further developed in [16]. The details of the internal layout and of the structural arrangement of the ship along the cargo area are controlled by a series of 41 design variables. The most important of them are summarised in the following:

- Number of longitudinal bulkheads. Arrangements with one (central) or two longitudinal bulkheads over the entire cargo block may be developed.
- Number of transverse bulkheads.
- A set of parameters is used to define the position of the transverse bulkheads in the cargo area.
- A set of parameters is introduced to control the type of inner hull and double bottom. The inner hull side and double bottom may be:
    - Parallel to the centre-plane and bottom
    - Inclined
    - Stepped
- A set of parameters is used to define the double bottom height within each main transverse zone. An additional set of parameters is used to define the inner hull clearance within each main transverse zone.
- The transverse and longitudinal bulkheads can be either flat or corrugated. The type of bulkheads is controlled by the corresponding design parameter.
- A set of parameters is used to control the details of the geometry of the hoper plates of the inner hull.
- In the case of two longitudinal bulkheads, the width of central tank as percentage of the ship's breadth is specified by the corresponding design parameter.
- A set of parameters is introduced to control the details of the geometry of the upper and lower stools for the case of corrugated bulkheads.
- A set of parameters is used to define the various structural details, such as the number and position of the stringer decks, stiffener spacing on shell, inner bottom, strength deck, transverse members, and longitudinal bulkheads etc.

Typical examples from the variety of configurations that may be parametrically defined are illustrated in Figure 7 and Figure 8. This parametric model will be appropriately modified and developed in order to be used in WP 5 for the global optimization studies of the two tanker ships. New macros for the evaluation of design characteristics that are of particular importance for the present study will be developed, while at the same time the model will be simplified by removing design features and capabilities that are irrelevant to the current study. Relevant parametric models will be developed for the other types of cargo ships to be optimized in WP 5.

Weights estimation - Definition of Loading Conditions: A procedure for the weight estimation of RoPax ships is presented in [14], based on the decomposition of the vessel's light ship weight in a series of main weight groups. In the RoPax ships optimization studies to be performed in WP 5, the structural weight estimation will be based on a reference design, using appropriate empirical formulae and unit weights to estimate the increment or reduction of steel weight, as a result of "small" design modifications. The weight estimation of the remaining weight groups will be based on the statistical formulae presented in [14]. Similar simplified methods for the weight estimation of cargo ships will be developed, with the support and technical expertise of the designers participating in WP 5. Once again, the structural weight estimation will be based on a reference design, using appropriate empirical formulae and unit weights to estimate the increment or reduction of steel weight, as a result of "small" design modifications. The weight of superstructures (both structural and outfitting) will remain constant, equal to that of the reference design. The weight estimation of the remaining weight groups will be based on the empirical formulae, with the support and technical expertise of the designers participating in WP 5, with the exception of the main engine(s) for which the weight specified by the engine manufacturer will be used. Following the lightship weight estimation, a series of loading conditions will be defined (e.g. full load departure/arrival, ballast departure/arrival), using the relevant NAPA software modules.

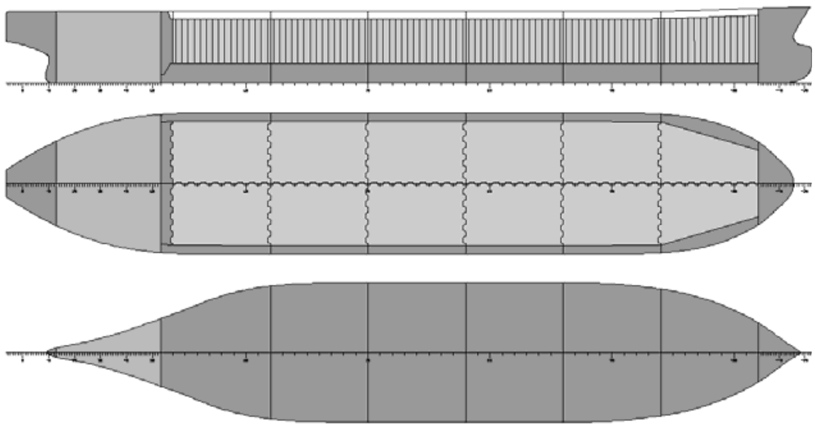

Figure 7: Internal layout of an AFRAMAX tanker with 6 x 2 cargo tanks, corrugated bulkheads and constant double-bottom height

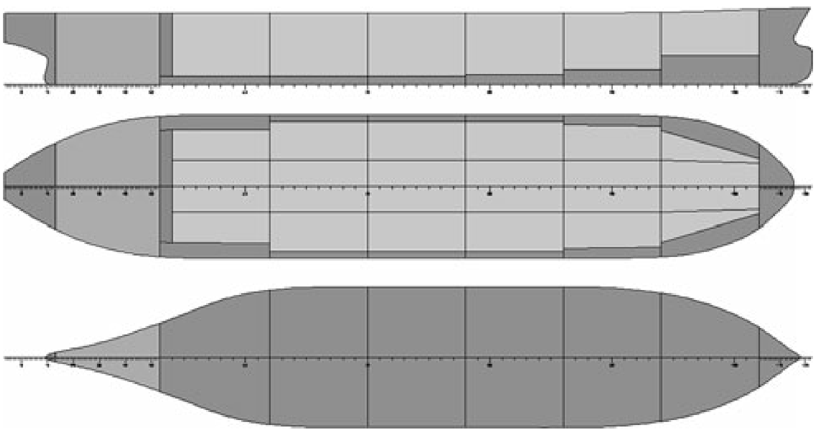

Figure 8: Internal layout of an AFRAMAX tanker with 6 x 3 cargo tanks, planar bulkheads and stepped double-bottom and inner hull

Evaluation of Stability Criteria and other Regulatory Requirements: Fulfillment of the regulatory intact stability requirements will be assessed for the already defined loading conditions. Compliance with the International Load Line Convention and other regulatory requirements, relevant to each specific ship type (e.g. accidental oil outflow index in case of tanker ships), will be also assessed. Damaged stability calculations can be also performed, although it is anticipated that the 3d model of the watertight subdivision might not be detailed enough to ensure full compliance with the regulatory requirements. Appropriate safety margins might be introduced to account for any inaccuracies in the results.

Evaluation of hydrodynamic/maneuvering performance in adverse seaway/weather conditions: As far as possible, the evaluation of hydrodynamic/maneuvering performance in adverse seaway/weather conditions will be based on Level 1 criteria, either already available, or developed in the course of the project. In case Level 1 criteria are not available, or they are considered to be not reliable enough, the use of more complicated procedures (e.g. the simplified assessment method outlined in Resolution MEPC.232(65)) will be considered. The use of even more comprehensive procedures is out of the scope of the global optimization studies, while they might be considered for the refined optimization studies (detailed hullform optimization).

Assessment of Building and Operational Cost, Annual Income and Selected Economic Indices: The calculation of building and operating costs will be based on their decomposition into a series of main cost items and sub-items, down to elementary cost items, along with the development of suitable procedures for their calculation. In general, building cost calculations will be based on unit construction or procurement costs (for example, cost of fabricated steel or aluminium per ton, cost of accommodation or public spaces outfitting per square meter, cost of propulsion machinery per kW). The operating cost and annual income will be calculated for the particular service conditions selected by the user, including length of route, service speed, fuel price, number of trips per year (or, in case of RoPax ships per week in the low, medium and high season, along with the estimated passenger and vehicles occupancies and the corresponding passenger's fare and vehicles freight for each of the three operating seasons etc.). The vessel's economic performance will be assessed using appropriate economic indices, such as the Required Freight Rate (RFR), or the Net Present Value (NPV). Two different procedures will be explored during the development of the software tools: the calculation of cost and revenue differences, in comparison with a reference existing design, or the calculation of the "absolute" costs and revenues for each alternative design. The most suitable procedure for each ship type and size will be selected and applied.

One of the more difficult tasks in the economic assessment of the elaborated designs, is to derive reliable estimations of the variations of fuel prices and freight rates, during the expected lifetime of the ship. For the fuel prices, short-term and long-term estimations are available by various organizations. Some of them extend only a few years from present (see Figure 9, extracted from [19]), while others are spanning one or more decades (Figure 10, extracted from [20]). The available sources of information will be evaluated by the partners in order to derive an acceptable scenario to be used thorough the studies. Based on the selected scenario for the future fuel prices, freight rates variation will be estimated based on suitable estimation procedures to be agreed between the partners.

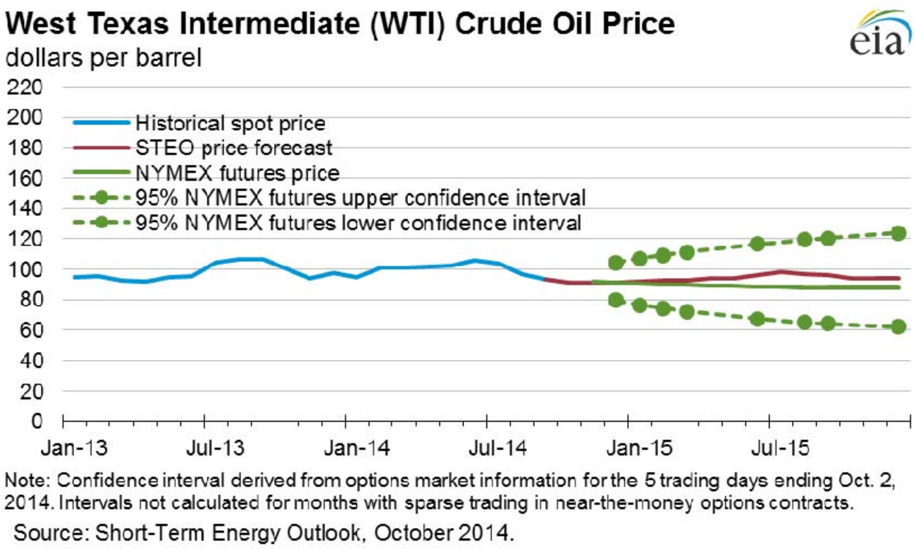

Figure 9: Crude oil price predictions according to U.S. Energy Information Administration ([19])

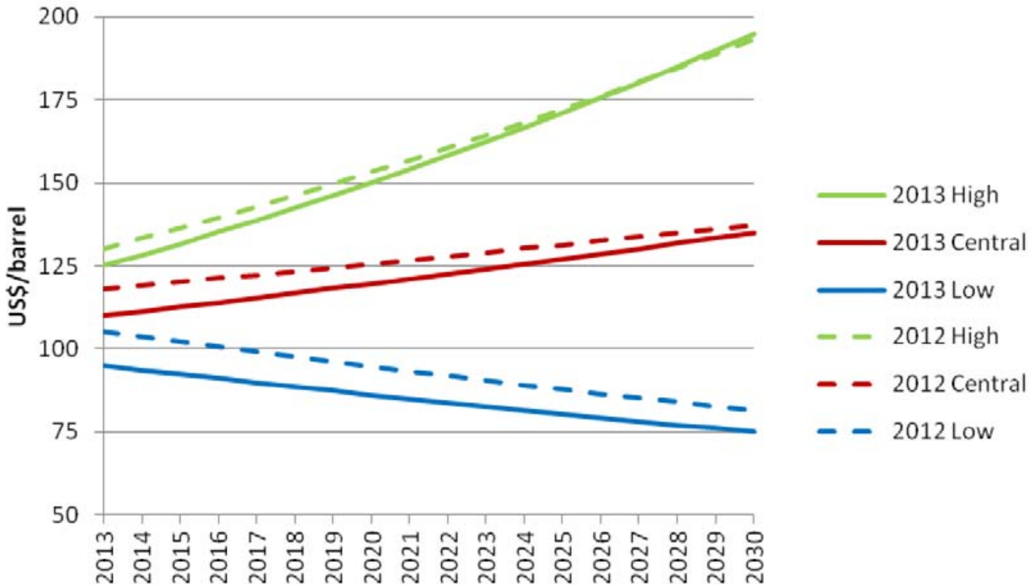

Figure 10: Comparison of 2013 DECC oil projections with those from 2012 ([20])

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