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Ship Lifecycle Software Solutions (SHIPLYS)

Project Deliverable Report

D4.2 Data Quality and Criticality Assessment

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EXECUTIVE SUMMARY

SHIPLYS is an EU funded project under the H2020 Research and Innovation programme that will provide an innovative ship design tool to be used by European SMEs in the ship industry. The tool will offer integrated modelling along with life cycle approaches to evaluate further and compare early ship designs. It will provide to its users the necessary tools for Life Cycle Cost Analysis (LCCA), environmental assessments, risk assessments and end-of-life considerations.

One of the key tasks of the project is the collection of the necessary data that will be required for the rapid virtual prototyping and life cycle tools to provide safe estimations and easily comparable results. The process of data collection was part of “T4.1 Collect data required for SHIPLYS rapid virtual prototyping and life cycle tools”.

Additionally, in Task 4.2 “Data analyses to determine its quality and its criticality regarding its impact on the outcomes” a number of approaches have been developed to evaluate the selected data. These approaches will aim to determine confidence in existing data, appropriate ways of factoring in uncertainty, identification of low confidence but high impact data and finally, methodologies performing a Sensitivity Analysis to key inputs in the various phases of the ship design process and life cycle estimations will be investigated.

Deliverable D4.2 presents the approaches above, offering a detailed description of the methodology for the evaluation of the selected data, and the assessment of their quality and criticality. Furthermore, the challenges in acquiring adequate and qualitative data are presented, along with the process of collecting data within the project. The development of various methodologies for gaining confidence in existing data, quantify and deal with uncertainty, and performing a Sensitivity Analysis to key inputs in the various phases of the ship design process and life cycle estimations are also described.

For SMEs to be able to validate and compare different ship designs and present an optimal proposal at an early bidding phase, the data used must provide certain reliability. To this end, the importance of qualitative data and the development of a complete database used by the SHIPLYS tools is highlighted.

Finally, a glimpse of the SHIPLYS Life Cycle Tool has been demonstrated, by presenting the Sensitivity Analysis approach that will be implemented in the LCT software, developed in WP5 of the SHIPLYS project.

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ABBREVIATIONS

CAPEX	Capital Expenditures
CI	Confidence Interval
D-E	Diesel - Electric
D-M	Diesel - Mechanic
DWT	Deadweight
ECA	Engineering Critical Analysis
ER	Engine Room
FAD	Failure Assessment Diagram
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Assessment
LCT	Life Cycle Tool
mle	Maximum Likelihood Estimation
OPEX	Operational Expenditures
PI	Prediction Interval
Pr	Profit
QL	Quality Level
QoI	Quantity Of Interest
Re	Profitability
RFR	Required Freight Rate
SA	Sensitivity Analysis
SHIPLYS	Ship Lifecycle Software Solutions (EU project)
SL	Sensitivity Level
SME	Small Medium Enterprises
TEU	Twenty-Foot Equivalent Unit
UP	Uncertainty Propagation
UQ	Uncertainty Quantification

1 Introduction

The main objective of the Ship Lifecycle Software Solutions (SHIPLYS) project is to develop a software tool that will include rapid virtual prototyping processes of the early ship design together with performing a life cycle cost analysis (LCCA) of the developed ship design as well as an environmental assessment, risk assessment and end-of-life considerations.

In order for the project to complete its goals, the collection of the required data for the implementation of the developed tools as well as the development of a SHIPLYS database is required. Confidentiality concerns of the data used within the SHIPLYS software have been taken into account and as a result end users will be the keepers of the database and of their information provided to the tool.

As part of WP4, a number of approaches have been developed to assess the selected data on their quality and criticality. In this deliverable, the approaches performing Uncertainty Analysis and the methodologies for Sensitivity Analysis will be presented in detail, while their efficiency will be evaluated using Conceptual Ship Design accounting for Risk-based Life Cycle Assessment Approach, which is under development in WP5 of the project.

Finally, Life Cycle and Cost for Sustainable Ship Power systems analysis will also be employed to perform sensitivity analysis, which is under development in WP5 of the project.

2 Availability of Data

2.1 Data collection and Data sources

In Task 4.1 the required data for the rapid virtual prototyping and life cycle tools have been collected based on the data requirements defined in Tasks 3.2 and 3.3.

To this end, a “Parameter List” excel database has been developed, listing all necessary parameters for usage by the developed tools. Parameters required for the virtual prototyping, cost assessment and life cycle and risk analyses, were identified and specified. The list provides an accurate description of the parameters, valid ranges and most common (or default) values acquired by various sources: existing theoretical methods and/or modern statistical trends (for the prediction of various ship parameters relative to ship design and dependent on the owner’s requirements), tender documents/papers in response to which the early design and life cycle assessments are required, previous similar projects, existing experience of partners and engineering judgement.

The following figure presents a possible source of useful data, based on the relation of the length LBP to the total number of transported TEU and its statistical trend.

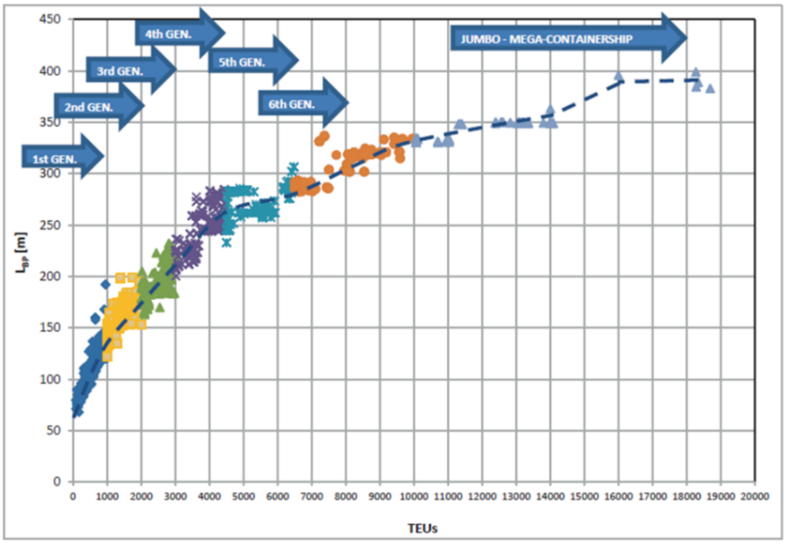


Figure 1: Statistical trend relation of ship length to total number of transported TEU) [1]

Furthermore, each parameter has been linked to the corresponding activity of the developed Activity Matrix (on the basis of ISO 10303, the Standard for the Exchange of Product model data, STEP), to which the parameter is related to (either as input or as output or as control).

The Parameters List categorises the various entities into the following main groups:

- Early design parameters
- LCCA parameters
- Risk assessment parameters

Specific information about each parameter is given as (see Figure 2):

- Parameter name,
- Physical quantity,
- Unit of measurement,
- Type (e.g. numerical, logical, alphanumeric, etc.),
- Short description,
- Source type,
- Source or link to the source (i.e. link to pdf, worksheets, tables, etc.),
- Activity to which this parameter is related to (designation following the ISO standard adopted in the SHIPLYS tool),
- Level of confidence (scale 0 to 2, 0 meaning user estimation and 2 meaningfully validated data).

For the LCCA and Risk assessment, parameters pertinent to costs are also included:

- Time reference (when the costs were estimated/defined),
- Geographical reference (where these costs were estimated/defined).

Parameters identified in T4.1 were linked to data sources for the most of the SHIPLYS activities in various formats (tables, formulas, graphs, worksheets, user specified entries). These values will be continuously updated with the use of additional existing databases (fees may be required) and data provided by the end-users (shipyards, naval architectures etc.).

Finally, the documented parameters have been grouped by the Activity of the ISO standard that they are related to. The Activities adopted for the SHIPLYS project are:

- A122 Create preliminary design,
- A124 Calculate the cost of the ship,
- A126 Create an initial design for retrofitting purposes,
- A127 Estimation of the environmental impact,
- A128 Estimation of risk,
- A129 Perform initial planning of production.

Figure 2 presents a part of the parameter list as developed for the SHIPLYS project. The full “Parameters List” can be found in the Appendix of this deliverable.

Parameter	Physical quantity	Unit (of value of the paramet	Type (para meter ty	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confiden ce
A1221 Create preliminary hull form									
A12211 Estimate main dimensions and parameters									
(Basic parameters)									
Vessel type	Non-dimensional	none	Character	definition of the vessel type, e.g. RORO, MPV, Bulk Carrier	Specific value	shipowner requirements	A1221 - Create preliminary hull form		1
Deadweight	Mass	tons	Real	vessel's deadweight - cargo capacity		shipowner requirements	A1221 - Create preliminary hull form		1
Number of containers (if applicable)	Non-dimensional	none	Real	number of cargo containers		shipowner requirements	A1221 - Create preliminary hull form		1
Number of cars (if applicable)	Non-dimensional	none	real	number of cars transported		shipowner requirements	A1221 - Create preliminary hull form		1
Number of passengers (if applicable)	Non-dimensional	none	real	number of passengers transported		shipowner requirements	A1221 - Create preliminary hull form		1
Operational range	Length	nm	real	maximum distance of the route on which the new vessel will operate (Nm)		shipowner requirements	A1221 - Create preliminary hull form		1
Service speed	Speed	knots	Real	vessel's service speed		shipowner requirements	A1221 - Create preliminary hull form		1
Year of built	Date	none	Integer	vessel's year of built	Other	ship data	A1221 - Create preliminary hull		1

A122 Create preliminary design | A124 Calculate cost of ship | A126 ...retroffiting purposes | A12: ...

Figure 2: Part of the SHIPLYS parameters list

2.2 Challenges and problems with data availability and quality

The preliminary ship design aims to determine the main characteristics of the designed vessel, taking into consideration the existing regulations and restrictions. Furthermore, it provides initial estimations of the general arrangement of the ship, profile and decks, machinery list, transport capacity, efficiency etc. and it enables uniform approaches. In the conceptual ship design are also introduced innovative design concepts, energy efficiency and environmental impact estimations [1].

During the early design stages, calculations enable the evaluation of various alternative designs and estimations of all costs created through the ship's life as well as its' environmental impact. The SHIPLYS tools will require the availability of up-to-date data to provide safe estimations and comparable results.

Data acquisition usually encounters numerous challenges and problems regarding the availability and the quality of the necessary data. The most significant challenges are:

- Insufficient databases: the existing databases may not be able to provide sufficient information for specific business and industrial sectors. As a result, data gaps regarding the shipping industry could occur, producing poor early ship design estimations. Furthermore, developed databases may not be updated with recent data that could improve the preliminary ship design results. Thus, the development of a database with updating facility to meet the requirements of the developed rapid virtual prototyping and life cycle tools is critical.
- The data format for Software integration: a specific issue associated with the quality of data is the capability to integrate between tools and formats for different software or ship design tools. Usage of standard formats could improve the efficiency and effectiveness of software processes.
- Innovation: the adaptation of modern and innovative ship designs and techniques may require additional data or updated databases to perform safe estimations. Close monitoring of the market's developments is necessary along with the continuous updating of the used databases.

- Changing market/data currency: the globalisation of the economy and the continuous changes taking place in the global shipping market have as a result of continuous changes in the set of data used in the LCCA estimations. Subsequently, LCCA calculations should continuously investigate the quality of the selected data, analysts should keep their databases up-to-date to the latest developments in the shipping market and take into consideration future developments that may affect projects taking place in the present.
- Confidentiality: Confidentiality of the data used by ship designers and shipyards raise availability issues. End users of different software usually demand to be the keepers of their database.
- Cost of accessibility: one of the main problems is the availability of relevant databases that can easily be accessed. Available databases require a subscription for an amount of money to allow access to its data. Usually, this subscription should be renewed annually, to have access to newly updated data. The cost may be dissuasive for SMEs and small naval architecture offices, who would like to adopt innovative tools in their design processes, in an attempt to produce innovative ship designs and reduce constructional, operational and other costs. A cost-benefit analysis could indicate the necessity of acquiring newly updated databases and ship design tools.

3 Approaches for Data Uncertainty Analysis

3.1 Uncertainty Treatment

3.1.1 Uncertainty definition

Uncertainty is a state of having limited knowledge where it is impossible to describe precisely the existing state or future outcome. There are mainly two kinds of uncertainties in data, Aleatoric uncertainty and Epistemic uncertainty. Aleatoric uncertainty is a kind of random uncertainty caused by the nature of the data, which cannot be avoided. Epistemic uncertainty is the uncertainty due to lack of knowledge. Deep data mining can reduce epistemic uncertainty or gain more understanding of the data. However, this may be costly so that such uncertainty is often just described and considered as the risk in the assessment. Generally, Aleatoric uncertainty decreases the precision of the evaluation while Epistemic uncertainty decreases the accuracy of the assessment [2].

3.1.2 Source of uncertainty

Uncertainty can be introduced into mathematical models and experimental measurements via various resources throughout the entire assessment process. Assumptions, sample data, prior beliefs, physical models, computing errors, etc. all can become uncertainties. It will affect the results of the assessment and the confidence level of such results in a different context. In general, it is categorised as follows [3] [4]:

<u>Parameter uncertainty</u>

Parameter uncertainty is introduced when the exact value of input parameters to the assessment is unknown or out of control, or cannot be inferred by statistical models. Example of parameter uncertainty is when deriving the ship material properties from testing a limited number of specimens. Modelling parameter uncertainty is not easy. There are some widely used treatment methods, for instance, bootstrapping, Bayesian techniques and classical statistics using maximum likelihood estimation (MLE).

<u>Parametric variability</u>

Parametric variability means the variability of input variables of the model. For example, when conducting analysis based on the design document that might not have been strictly followed by manufacturers or constructors, which would cause measurable variability in the analysis results. In some cases, parametric variability can be further defined as spatial or temporal variability where one wants to average over that variability.

<u>Structural uncertainty</u>

Structural uncertainty is also known as a systematic error, model bias, model inadequacy, or model discrepancy. This type of uncertainty comes from the lack of knowledge of the underlying physics in the assessment, resulting in how accurate a mathematic model describes the true system for a real-life situation is unknown. One example is to conduct ship stability analysis using the GZ curve, in which case even if there is no unknown parameter in the model, a discrepancy is still expected between the model and real physics. However, similar to the parameter uncertainty, structural uncertainty also cannot be adequately addressed by any general techniques.

Algorithmic uncertainty

Algorithmic uncertainty is also known as numerical uncertainty or discrete uncertainty. It occurs because the complicated majority models cannot be solved exactly, which means numerical errors and numerical approximations will be introduced as part of the problem-solving process. One example of algorithmic uncertainty is the numerical approximation when calculating the ship global bending moment using the simple beam theory.

Experimental uncertainty

Experimental uncertainty is also known as an observation error, which happens because of the variability of the experimental measurement. Uncertainty from this resource is considered as a kind of Aleatoric uncertainty which is inevitable. Statistical error and random variation of replicate measurements are also included in this category.

Interpolation uncertainty

This uncertainty resource refers to the scenario when there is no simulation data or experimental measurements for assessment, one must interpolate or extrapolate to predict the corresponding response.

3.1.3 Expression of uncertainty

There are a number of different ways to express the uncertainty. Each method has its advantages and disadvantages, one can choose to represent the uncertainty accordingly to fit the purpose of the analysis. Some of the commonly used ways are:

Variance, standard deviation and standard error of the mean

In statistics, the variance and standard deviation are the most important measurement of the statistical dispersion. The standard deviation is the square root of the variance. The estimation of the standard deviation is based on the deviation of any individual observation about the mean. The variance and standard deviation are calculated as follows:

$$Var(x) = s_x^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1} \quad (1)$$

$$s_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad (2)$$

where n is the size of the sample and the sample has a finite data set of x_1, x_2, x_3 ... with each value having the same probability. The estimation of the standard deviation is based on the deviation of any individual observation about the mean. Thus, s_x is read as the standard deviation of the individual x's.

The standard error, given by Eqn 3, is another similar way to express the uncertainty. The term standard error is most often used to express the uncertainty in the mean of x, but it is also applicable to the uncertainty associated with any form of a central estimate [4].

$$\varepsilon_x = \frac{s_x}{\sqrt{n}} \quad (3)$$

The standard error is the standard deviation of the sampling distribution of a statistic. It measures the spread, i.e. the higher the standard error is, the more spread out the data is.

The uncertainty expressed by the variance, standard deviation and standard error can be quantified and propagated using similar methods.

Confidence intervals

A confidence interval (CI) is an interval estimate combined with a probability statement. It represents a range of values defined so that there is a specified probability that the true value of a parameter lies within it. For instance, one has x% confidence that the value of a variable y is within the range z.

In general, CI can be calculated following the approach that is using the mean and deviation of the chosen samples to define the lower or upper confidence bounds, based on a given confidence level. In some cases, CI can also be estimated by providing the maxima, minima or most likely values. If the data is qualitative, the qualitative scoring system can be designed such as high, medium and low. This method based on the engineering judgement will be subjective; therefore, each optional score should be defined precisely.

The advantage of using CI is its broad applicability. It means this method can be used no matter the data is quantitative or qualitative, or combination of various types, or collected with an unknown level of knowledge. In the case where a uniform way to express uncertainty is required, CI will often be the preferred option. Therefore, the uncertainty treatment system in SHIPLYS database has chosen to build upon the concept of CI to develop the bespoke data-quality evaluation system.

Probability distribution

The data can be transferred to distributions and perform further analysis on the distribution. The commonly used distribution types are uniform, triangular (PERT), trapezoidal and normal distribution, etc. [6] as shown in Figure 3.

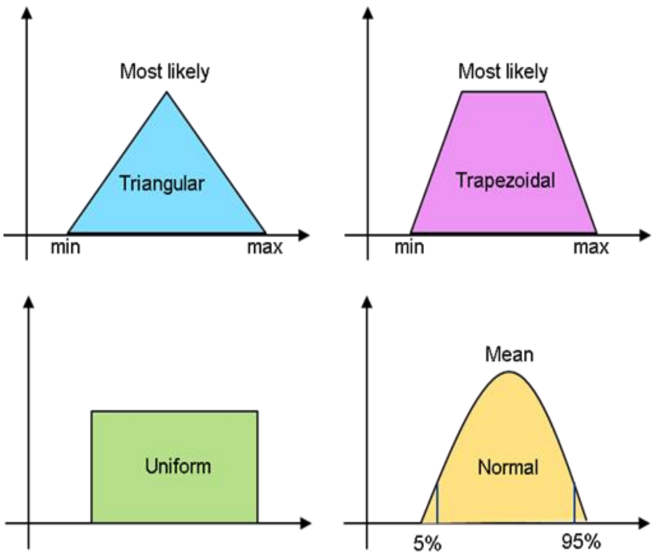


Figure 3: Commonly used probability distribution [7]

Comparing to a single measurement of spread, such as variance or standard error, the probability distribution can convey much more information about the variability in x, such as skew and shape of the distribution, or the characteristics of tails, etc. However, the applicability of this method is very limited. It requires a huge number of data set and / or strong belief that the parameter can be fitted to one of the well-known distributions. Otherwise, it is very difficult to verify the accuracy of the estimation. Especially, the tails will be particularly unstable.

3.1.4 Overview of the methods for uncertainty quantification

The Uncertainty Quantification (UQ) is the process by which the uncertainties in a system are characterised and propagated to a given Quantity of Interest (QoI) in both computational and real-world applications. UQ requires interdisciplinary skills combining statistics, numerical analysis and computational applied mathematics. In reality, uncertainty exists in the majority of analysis processes, raised from various resources, as discussed in the previous section. Ideally, UQ can support the reliable estimation and control of the difference between the mathematical model and the true physics, and subsequently to reduce the associated risks.

In general, there are two major types of UQ problems: one is called forward uncertainty propagation (UP), and the other is inverse UQ.

The forward UP

The problem solved by forwarding UP is how to predict the overall uncertainty in the system responses by propagating the various sources of uncertainty through the entire assessment process. In a simple word, by using forward UP, the uncertainties in inputs will be propagated to quantify the uncertainties in system outputs. This will help to evaluate the low-order moments (i.e. mean and variance) of the outputs as well as its reliability and complete probability distributions, etc. It should be noted that not all kinds of uncertainties can be propagated. In the following paragraphs, some well-established methods of forwarding UP will be discussed for parametric variability and experimental uncertainty.

The simulation-based methods, such as the Monte Carlo Simulation (MCS) or Latin hypercube sampling, are probably the most understandable and straightforward methods. It is also possible to quantify the contribution of each variable to the total uncertainty in final outputs by estimating the correlation between that variable and the outputs. Simulation-based methods permit direct computation of the uncertainty even when the numerical assessment is complicated and when the inputs variables cannot be described by usual moments. However, it is time-consuming and laborious to document. It is also not easy to estimate the correlation between each variable and the outputs, hence hard to infer the role of each variable in the total uncertainty [4].

When the uncertainty in the input variables is given as a variance, standard deviation or standard error, and the assessment process is a number of mathematical equations, the total uncertainty in the outputs can be calculated using moment equation method, where the output standard deviation is estimated as:

$$s_z = \sqrt{\sum_{j=1}^{m}\left(\frac{\partial z}{\partial x_j}s_{x_j}\right)^2 + 2\sum_{j=1}^{m}\sum_{k=j+1}^{m} r_{x_j x_k}\left(\frac{\partial z}{\partial x_j}s_{x_j}\right)\left(\frac{\partial z}{\partial x_k}s_{x_k}\right)} \qquad (4)$$

where: $x_1, x_2, x_3 \dots x_m$ is m different input variables, while $z = f(x_1, x_2, x_3 \dots x_m)$ is the final output and s_{x_m} is denoted the standard deviation of x_m . $r_{x_j x_k}$ represents the correlation in uncertainties between input variable x_j and x_k. If assuming they are independent to each other, this equation can be simplified as:

$$s_z = \sqrt{\sum_{j=1}^{m}\left(\frac{\partial z}{\partial x_j}s_{x_j}\right)^2} \qquad (5)$$

Eqn 5 is known as the Gaussian error propagation formula. This method is also applicable to propagate variance and standard error.

In some cases, the numerical model can be plot as a surface, and the uncertainty in the input variables will develop an envelope around this surface. Therefore, it is possible to apply surface respond method to find out the most probable point (MPP) which is the most representative of reality. One of the well-known mathematical applications for this is the FORM and SORM (first and second order reliability methods), which are a fundamental method for the structural reliability assessment.

Except the above, there are many other probabilistic approaches such as exact analytic methods, functional expansion-based methods, local expansion-based method, prediction of trend and difference throughout the time, and so on. There are also many non-probabilistic approaches widely used, such as the interval analysis, Fuzzy theory, etc. It is believed, in general, that the probabilistic approaches are more rigorous.

Forward UP is a well-established technique, especially when estimating the low-order moments of the data uncertainty. By examining the reliability of the outputs, the performance of the system can be reviewed, hence possible to optimise the utility of the system.

Inverse UQ

Unlike forward UP predicting the reliability of the final output from the uncertainty in input variables, the objective of inverse UQ is to investigate the difference between model prediction and true system responses. Types of uncertainties of interest for inverse UQ are the algorithmic uncertainty or structural uncertainty, etc. The inverse UQ has attracted increasing attention in the engineering design community; however, it cannot be adequately addressed by any general technique due to dimensionality and identifiability issues [3]. Commonly used concepts to solve inverse UQ are methodologies under the Bayesian framework or frequentist-based. The typical application of inverse UQ is to implement it in a model updating process.

To clarify, as inverse UQ is out of interest in SHIPLYS project, so the scope of work within SHIPLYS project will not include inverse UQ.

3.1.5 Uncertainty treatment in SHIPLYS

Since assessment procedures within SHIPLYS are very comprehensive and complicated, the SHIPLYS database has to experience uncertainties from almost all sources, as discussed in the previous section. Among all types of uncertainties, the project paid more attention to parametric variability, experimental uncertainty or sometimes, parametric uncertainty. In most cases, these uncertainties raised in SHIPLYS database is due to lack of knowledge, therefore, one cannot strongly believe the quality of these data. Moreover, the types of data is a mix of qualitative and quantitative, which increases the difficulties in measuring its uncertainty in a uniform format. The uniform format to indicate uncertainty will help the database management and easy for data collection. By considering the above, it has been decided in SHIPLYS that the uncertainty of input variables will be expressed by giving the level of data quality, so-called Quality Level (QL). This method is built upon the concept of CI and was developed specifically for SHIPLYS.

The QL reflects the confidence in the accuracy of the data provided to the database. Data with a higher QL should come from resources that are more trustable. As this method is qualitative and subjective, the database developer should give a rigorous definition of each level of QL. The QL can also be propagated, the overall QL of the assessment is calculated as the average QL among all input variables used in the evaluation.

Also, to support the evaluation of reliability, the uncertainty treatment is also an important factor to determining how crucial such input variable is and the possibility to improve the assessment reliability through searching for more certain input values. For this purpose, the sensitivity and uncertainty analysis should be viewed alongside each other to identify the key factors in the model [7]. The data that is uncertain and has a high contribution towards to the results (i.e. highly sensitive) are likely to be a key issue/ factor in the model as this is depicted in Figure 4.

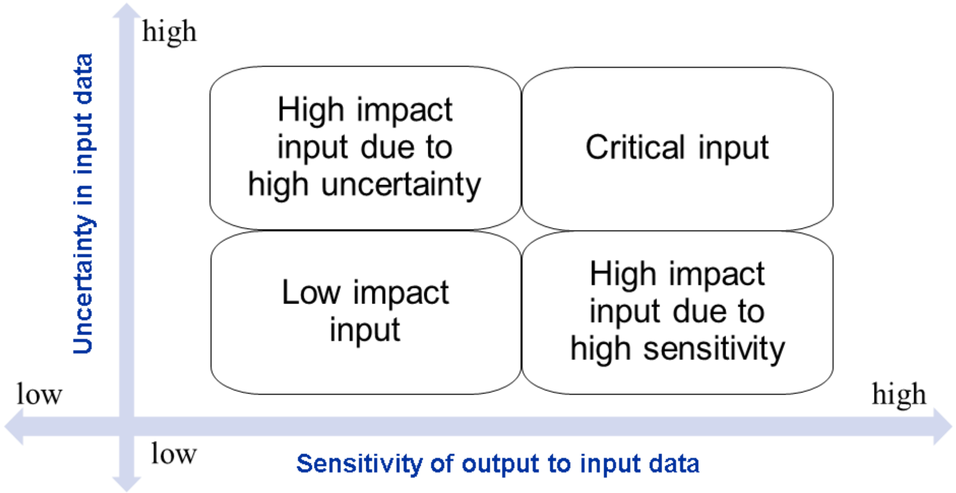


Figure 4: Key features depending on sensitivity and uncertainty

It is very important to emphasise that the calculations will never reduce uncertainty. Propagation of uncertainty is also a process to increase the uncertainty in the overall assessment. If the variable can be directly measured, uncertainty propagation should be avoided.

3.2 Confidence/Quality level of SHIPLYS tool parameters

During the development of the Parameters List a column named "Level of confidence" has been introduced, as an additional characterisation factor of each parameter identified to be used by the SHIPLYS tools.

The contributors to the development of the list had the opportunity to rate their confidence to the selected parameters, as well as to the provided data and data sources. The method has been implemented by selecting between 0 (user estimation), 1 (average confidence) and 2 (fully validated data). The results of this procedure will be used as a measure indicating the quality level of the collected data, using the scientific experience and professional judgement of the SHIPLYS partners.

The following Figure 5 presents the results collected during this procedure, per Activity used by the project (the results are given in absolute values and percentages), while Figure 6 shows the entire results of the Quality level scale for all SHIPLYS parameters, given in percentages.

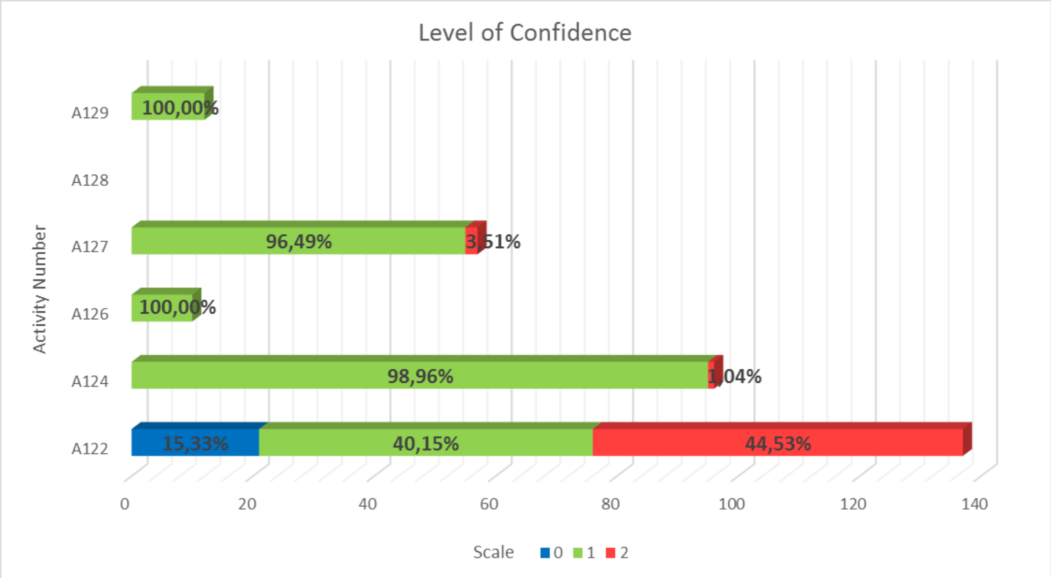


Figure 5: "Level of Confidence" procedure (x-axis represents the number of parameters dedicated to each activity number)

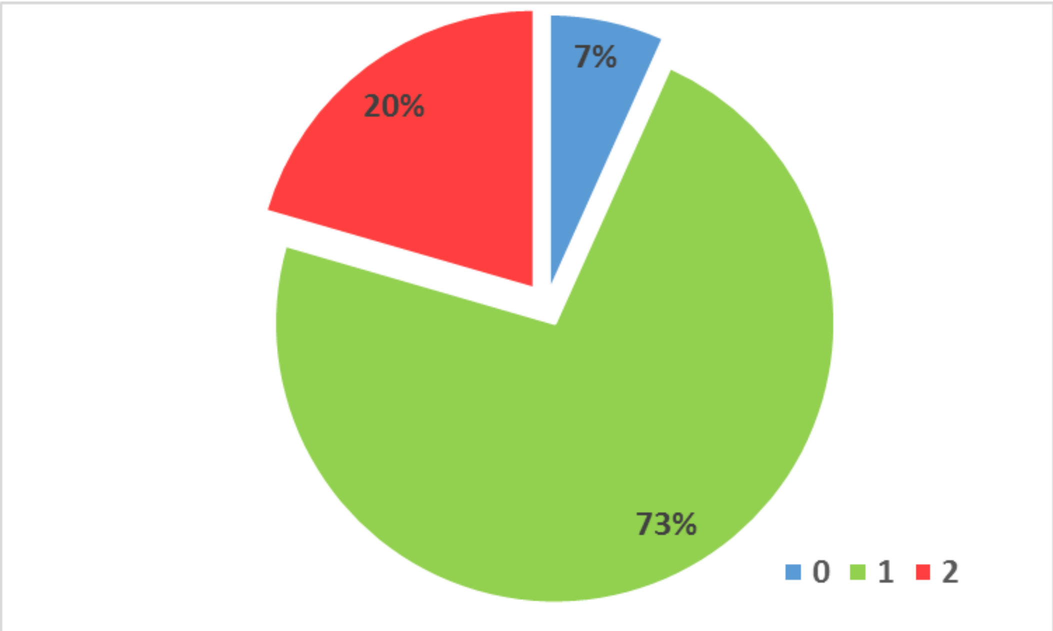


Figure 6: Total results of the "Level of Confidence" procedure (in percentages)

The nature of the parameters selected to be used in the developed SHIPLYS tools, the complexity of specific parameters and the interaction between them, gives a reasonable estimation of the parameters' quality level. Additionally, the continuously changing market and fluctuations in the values of parameters used for life cycle estimations have the same effect in the estimated level of confidence of Activities A124 and A127.

As a result, the implementation of a specific sensitivity methodology is necessary to evaluate the selected data for each parameter (at least of those of more significance) and discover appropriate ways of factoring in uncertainty.

4 Methodologies for Sensitivity Analysis

4.1 Endpoints/Key inputs for SA in Conceptual Ship Design, LCC and Environmental Assessment

A sensitivity analysis (SA) usually proceeds in the following steps:

1. Definition of sensitivity analysis end-points

The sensitivity of each parameter (data) will be evaluated according to the effect this parameter has on the final value of these end-points. The end-points will be a few essential and vital magnitudes like max speed, max draft, lightship weight, etc. regarding "ship design tool" and cost of ship construction, the environmental impact of construction, Global Warming Potential of operation etc., regarding "LCATool". Definition of different groups of data, both for the "design" and the "LCCA" phase.

2. Selection of most important parameters

From the "Parameters List", selection of the first fundamental group of parameters which are expected to have the most significant effect on the end-points. Selection based on literature and experience.

3. First sort of parameters

Using statistical data from the literature (e.g. curves of LS weight variation concerning ship length) and/or closed-form theoretical equations and methods, evaluation of the effect of the first group of parameters on the value of the end-points. Sorting of parameters in order of decreasing importance. Use of this first approach sorted list of parameters as input for the early stages of the uncertainty analysis.

4. Final sort of parameters

When the SHIPLYS tool is ready, repetition of stage 3 for most (if not all) parameters. Final parameters list sorted in order of decreasing importance. The input to the uncertainty analysis.

In the following paragraphs, the implementation of the SA into the various phases of the SHIPLYS scenarios is presented in more detail.

4.1.1 Conceptual ship design

Sensitivity analysis is carried out for the investigation of the impact of changing one or more key input parameters on specific project outcomes (endpoints of the analysis).

The end points are selected from the project outcomes by their significance, while the key inputs are chosen among the parameters about which there is uncertainty, and which are expected, at least from experience, to have a significant influence on the examined outcomes. The sensitivity analysis quantifies this influence by varying the key inputs (one at a time) and recording the impact on the outcomes. To this end, a suitable range of variation for each key input has first to be defined. A standard percentage of variation above and below a specific value, or a pessimistic, expected, and optimistic value might be chosen for an uncertain key input. Then, a suitable analysis (usually techno-economic) could be performed for each one of the three values to see how the outcome changes as they change, while other parameters are held constant.

The conceptual ship design has principally to fulfil the technical terms specified in the relevant order. Thus, the fulfilment of these constraints can be considered as the important outcomes of this phase, obviously being obligatory for a successful design. When such terms describe parameters that are not direct inputs to the design (e.g. vessel type, specified dimensions: length, breadth etc.) but rather form goals of the design, there is always an inherent uncertainty in their achievement (e.g.: does the ship achieve the contractual speed at the contractual loading condition?). In such cases, the sensitivity analysis can quantify the influence of key inputs on the examined outcome, supporting in this way the design decision process, also highlight in some cases the associated risk.

The cost estimation of the designed product (either new building or retrofitting) is among the important outcomes (endpoints) of the design. However, this should be considered as part of the LCCA analysis.

For the definition of the key inputs, it is convenient to distinguish the bulk of the input parameters in primal and derived ones. For example, if the basic dimensions L, B, D, T of the ship and the hull form coefficients (CB, CM, etc.) are considered as primal (thus independent) parameters, then the displacement and all the hydrostatic parameters are derived parameters (i.e. depended). Since the sensitivity analysis mathematically corresponds to partial differentiation, it is evident that it can't be applied on independent parameters while some dependent ones are kept fixed. Although the grouping above hasn't been done yet in the context of the project, it seems natural that this has to be implemented during the integration phase of the software. However, it is not always straightforward which parameter is primal and which dependent, and the selection should be made by the followed design spiral process, suitable for the examined scenario. To this end, the pertinent scenario flowchart can give a solution.

Summarising, in the conceptual ship design the sensitivity analysis (SA) can be implemented to support the achievement of the order requirements (endpoints) by examining the influence on them of adequately selected design parameters (key inputs). Furthermore, SA can also be used for the estimation of the cost of the design (endpoint) by examining the influence of design parameters (key inputs) on this cost, after having fulfilled the specific terms of the order, which are now considered as constraints of the analysis

The following table presents endpoints and corresponding key inputs for a sensitivity analysis pertinent to the conceptual ship design.

Table 1: Endpoints and Key inputs in the conceptual ship design

Design phase – Endpoints and Key inputs for SA	
Scenario 1 – Hybrid propulsion for a short route ferry	
Endpoints	**Key inputs**
DWT, Capacities (cars, passengers)	Main dimensions Hull form Compartmentation
Maximum Ship Speed	Total installed power Hull form Propeller design, coefficients
Propulsion efficiency Total energy efficiency	Power split between Diesel and Electric propulsion system and capacity of the systems. Electric system design
Cost efficiency (actually, part of the LCCA)	Operational speed selection Design to accommodate operation modes (Battery charging cycles, D-E load combination scenarios)
End of life scrapping, recycling	Material selection
Battery disposal	Battery selection

Scenario 2 – Conceptual ship design accounting for LCCA	
Endpoints	**Key inputs**
Ship owner requirements: DWT Speed Multi cargo capacities Etc. Shipyard building constraints	Main dimensions, Compartmentation Hull form, Main engine power, Propulsion system Compartmentation (Hold capacities, tank capacities) Main dimensions, Steel block weights
Operational profile, Seakeeping	Hull form
Maintenance	Steel thickness selection, corrosion additions
End of life scrapping, recycling	Material selection
Scenario 3 – Ship retrofitting accounting for LCCA	
Endpoints	**Key inputs**
End of life scrapping, recycling	Material selection

4.1.2 Life cycle cost

Sensitivity Analysis investigates the impact of the most critical parameters (Key inputs) to the estimated cost throughout the life cycle of the examined project or in certain stages of each life (development, construction, operation, dismantling etc.). This analysis supports the comparison between different scenarios and the optimisation of the ship design procedures.

Some endpoints and corresponding key inputs are presented below.

Table 2: Endpoints and Key inputs for LCC per SHIPLYS scenario

Life Cycle Cost – Endpoints and Key inputs for SA	
Scenario 1 – Hybrid propulsion for a short route ferry	
Endpoints	**Key inputs**
Cost of the novel hybrid propulsion system	Cost of materials Cost of machinery Cost of engine/ER Cost of steel per ton
Cost of operation	Average sailing days per year loaded Average days per year at port loading Average daily fuel/other consumption when sailing loaded Average daily fuel/other consumption when at port loading Average daily fuel/other consumption when at port discharging Cost per ton of fuel oil
Scenario 2 – Conceptual ship design accounting for LCCA	
Endpoints	**Key inputs**
Estimate cost of construction based on shipowner requirements	Cost of materials per ton for structures/compartment Cost of machinery Cost of engine/ER Welding cost per meter Cutting Steel/Cost per m length Sanding Steel/Cost per m2 Average Paint used/painting costs Cost of steel per ton
Estimate cost of maintenance	Average paint/chemicals consumed per year for scheduled & unscheduled maintenance Average paint/chemicals consumed during dry-docking/repair period
Estimate cost of scrapping	Scrap material Scrap recycled

Scenario 3 – Ship retrofitting accounting for LCCA	
Endpoints	**Key inputs**
Estimate cost of retrofitting	Cost of equipment and outfitting Cost of materials

4.1.3 Environmental assessment

The environmental impact or the environmental advantages produced by adopting different ship designs is also investigated through the SA.

The selected endpoints and corresponding key inputs are given next:

Table 3: Endpoints and Key inputs for EI

Environmental Impact – Endpoints and Key inputs for SA	
Scenario 1 – Hybrid propulsion for a short route ferry	
Endpoints	**Key inputs**
Benefits of applying hybrid propulsion	Average sailing emissions Average emissions at the port
Compare different propulsion options (D-M, D-E or Hybrid)	Average sailing emissions Average emissions at the port
Scenario 2 – Conceptual ship design accounting for LCCA	
Endpoints	**Key inputs**
Compare the environmental impact of construction of different developed ship designs	Construction emissions CO_2 emission factor NOx emission factor
Compare the environmental impact of the operation of different developed ship designs	Average sailing emissions Average emissions at port CO_2 emission constant at sea/ port NOx emission constant at sea/ port
Scenario 3 – Ship retrofitting accounting for LCCA	
Endpoints	**Key inputs**
Environmental impact of retrofitting activities	Retrofitting Emissions
Estimate environmental impact after retrofitting activities	Total change of SFOC (%) SO2 reduction (%) Particulate reduction (%)

4.2 Sensitivity Analysis of conceptual ship design

Sensitivity analysis is carried out in the investigation of the impact of one or more key design parameters on specific project outcomes (the endpoints of the analysis).

The conceptual ship design has principally to fulfil the technical terms specified in the relevant order. Thus, the fulfilment of these constraints can be considered as the important outcomes of this phase, obviously being obligatory for a successful design. When such terms describe parameters that are not direct inputs to the design, but rather form goals of the design, there is always an inherent variation in their achievement. In such cases, the sensitivity analysis can quantify the influence of key design input parameters on the examined outcome, supporting in this way the design decision process, also highlight in some cases the risk involved.

The cost estimate of the designed product (either new building or retrofitting) is among the important outcomes (endpoints) of the design.

For the definition of the key design input parameters, it is convenient to distinguish the bulk of the input parameters in primal and derived ones. For example, if the basic dimensions L, B, D, T of the ship and the hull form coefficients are considered as primal and thus independent parameters, then the displacement and all the hydrostatic parameters are derived parameters, i.e. depended. However, it is not always straightforward, which parameter is primal and which dependent, and the adopted design process should make the selection.

Summarising, in the conceptual ship design the sensitivity analysis can be implemented to support the achievement of the order requirements, defined as endpoints, by examining the influence on them of adequately selected design parameters, seeing as key inputs. Furthermore, the sensitivity analysis can also be used for the estimation of the cost associated with CAPEX, OPEX and DEPEX (endpoint) by examining the influence of the input design parameters (key inputs), after having fulfilled the specific terms of the order, which are now considered as constraints of the analysis

The following tables present three case studies related to the sensitivity analysis associated with the conceptual ship design accounting for life-cycle cost (see Table 4) and shipbuilding limitation of SME (see Table 5) and hybrid propulsion design and retrofitting for a short route ferry accounting for life-cycle cost and environmental impact (see Table 6) with some indicative endpoints and corresponding key inputs.

Table 4: Conceptual ship design accounting for life cycle cost

Endpoints	Key design input parameters
The total amount of cargo per year	Number of ships,
Number of voyages per year	Speed,
Transported cargo per ship per voyage	Length between perpendiculars,
DW of ships	Breadth,
Required Freight Rate;	Draught,
Profit;	Depth,
Profitability;	Block coefficient

Table 5: Conceptual ship design accounting for life-cycle cost and shipbuilding limitation of SME

Endpoints	Key design input parameters
The total amount of cargo per year	Number of ships,

Number of voyages per year Transported cargo per ship per voyage DW of ships Required Freight Rate; Profit; Profitability;	Speed, Length between perpendiculars, Breadth, Draught, Depth, Block coefficient Constraints derived from the limitation of SME to build new ships

Table 6: Hybrid propulsion design and retrofitting for a short route ferry accounting for life-cycle cost and environmental impact

Endpoints	Key inputs
Benefits of applying hybrid propulsion	Average sailing emissions Average emissions at the port
Compare different propulsion options (D-M, D-E or Hybrid)	Average sailing emissions Average emissions at the port

4.2.1 Conceptual ship design

4.2.1.1 Ship design set-up

To perform a sensitivity analysis of ship design governing parameters, the "Fleet composition" and "Conceptual design" tasks are defined for specific transportation conditions of a cargo flow, where the optimal design solution are related to a number of ships, speed and deadweight of required ships (external task) and the main dimensions and ship hull form coefficients (internal task) [9] [10].

The optimisation of the object function, F(**X, Q**) is formulated as:

$$F(\mathbf{X}^*) = minF(\mathbf{X},\mathbf{Q})\ ,\ \ \mathbf{X}\ \in \mathbf{E}^n \qquad (6)$$

which is subjected to design constraints:

$$\mathbf{H}\{h_i(\mathbf{X},\mathbf{Q})\} > 0, i = 1,2,\dots,m \qquad (7)$$

where **X** is the vector of design variables $x_1, x_2, \dots, x_n$, $\mathbf{X}^*(x_1^*, x_2^*, \dots, x_n^*)$ is the vector optimum design solution, $\mathbf{h}_i(\mathbf{X}, \mathbf{Q})$ are the inequality constraints as a function of the design variables **X** and uncontrollable parameters **Q**.

The components of the vectors of the design variables **X**, constraints, $\mathbf{h}_i$, and uncontrollable parameters, **Q** are part of the external and internal tasks. The vector of design variables, **X** includes the number and speed of the ships, $\mathbf{X}_E$ (external task); main dimensions and ship hull form coefficients, $\mathbf{X}_I$ (internal task).

Uncontrollable parameters, in most cases, are input variables in the mathematical model and are defined as descriptors of the transportation scenario and cargo flow (characteristics of the cargo, voyage distance, port performance, crew number, etc.); descriptors of the ship (coefficient of structures etc.); descriptors of the economic performance (normative and statistical coefficients etc.).

Similarly, the vector of constraints includes constraints related to the external task, $\mathbf{H}_E$ and internal task, $\mathbf{H}_I$. The optimal solution is obtained by employing the Sequential Unconstrained Minimization Technique, SUMT as defined by [11] [14].

This algorithm is based on the nonlinear programming (Eqn 6 and 7) without constraints by introducing a penalty parameter. The solution is based on a sequential unconstrained minimisation of the transformed objective functions **P**(**X**, **Q**, r_k) in the following form:

$$\mathbf{P}(\mathbf{X}, \mathbf{Q}, r_k) = \mathbf{F}(\mathbf{X}, \mathbf{Q}) + 1/r_k \sum \{min[0; \mathbf{H}(\mathbf{X}, \mathbf{Q})]\}^2 \quad (8)$$

$$\mathbf{F}(\mathbf{X}^*) = \lim\{min\, \mathbf{P}(\mathbf{X}, \mathbf{Q}, r_k\}, r_k \to 0 \quad (9)$$

where r_k is the penalty parameter, $r_k > 0$.

This algorithm allows eliminating the intermediate checks for the compatibility of the design solution with the constraints.

The transportation scenario involves transportation of cargo, mainly containers, from the terminal, T to Port 1, P1 and Port 2, P2 and return as can be seen in Figure 7 [9].

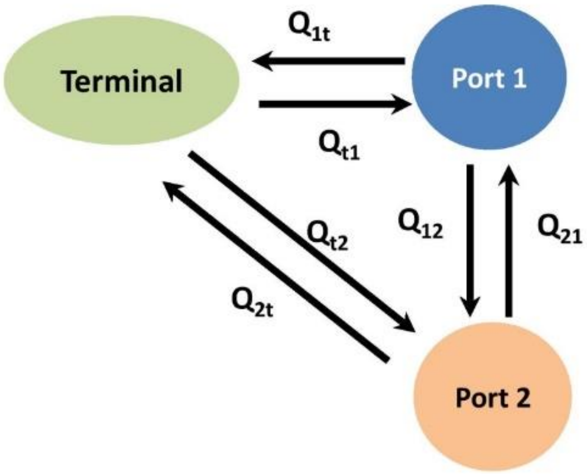


Figure 7: Transportation scenario

The amount of transported cargoes is as follows:

- The total amount of cargo from Terminal to Port 1 and Port 2 and vice versa per year is Q_{sum}=1,000,000 tons;
- Cargo from Terminal to Port 1 and vice versa is $Q_{t1} = Q_{1t} = k_{t1}.Q_{sum}$;
- Cargo from Terminal to Port 2 and vice versa is $Q_{t2} = Q_{2t} = k_{t2}.\ Q_{sum}$;
- Cargo from Port 1 to Port 2 and vice versa is $Q_{12} = Q_{21} = k_{12}.Q_{sum}$.

It is assumed that the cargo consists of 16-ton TEU containers. It is considered 10% void space in the transported containers, resulting in the average weight of one container of 14.65 tons.

The distances between the ports and terminal are:

- Terminal - Port 1 = 1161 nm;
- Port 1 - Port 2 = 339 nm.

The cargo handling time is:

- Terminal 630 TEU/day;
- Port 1 570 TEU/day;
- Port 2 520 TEU/day.

The freight rate per ton of cargo is:

- Terminal - Port 1 = 30 €/ton;

- Terminal - Port 2 = 40 €/ton;
- Port 1 - Port 2 = 10 €/ton.

The type of ships is multi-purpose, intended for the transport of bulk and other dry cargoes. The ships are equipped with cranes for loading and loading of containers.

The ships are single-decked, with an engine room located aft, a single propeller with a slow-speed diesel engine, and a superstructure located extremely aft. There is a bulb bow and transom stern.

The design parameters are defined as the number of ships, Ns, speed, kn, Vs, the length between perpendiculars, m, L_{pp}, breadth, m, B, draught, m, d, depth, m, D and block coefficient, C_B. There are no formal constraints to the design variables. The design solution of the transportation of cargo is controlled by an indicator, P_{Qsum}, which is defined as:

$$P_{Qsum} = TC_{sum} / Q_{sum} \tag{10}$$

where:

$$TC_{sum} = Ns\ Nv\ TCsv \tag{11}$$

where Nv is the number of voyages per year and TCsv is the transported cargo per ship per voyage. The condition when P_{Qsum} =1 indicates that the total amount of cargo is transported in one year. The required deadweight of the ships is provided by the condition when P_{Dw} =1 defined as:

$$P_{Dw} = DW / DWr \tag{12}$$

where DW is the estimated deadweight and DWr is the required one.

In the cases where the deadweight is a resultant value, the buoyancy index, P_{FL} is defined as:

$$P_{FL} = \Delta / (LW+DW) \tag{13}$$

where Δ is the weight displacement, tons, LW is the lightweight, tons and DW is the deadweight, tons.

The condition when P_{Qsum}=1 represent the case where the buoyancy equilibrium is satisfied. Additionally, some functional constraints are also satisfied including summer freeboard, P_{FB}; minimum stability with containers, P_{GMc}; sufficient cargo volume, P_v.

The objective function may use one of the following indicators: Required Freight Rate, RFR; Profit, Pr; and Profitability, Re. The required freight rate is defined as:

$$RFR = (OPEX + CFR.CAPEX)/Q,\ €/ton \tag{14}$$

where OPEX is the operational cost per year, CFR is the capital recovery factor, CAPEX is the capital expenditure, € and Q is the transported cargo per year, tons. A recent analysis about a CAPEX estimation in the condition of an SME shipyard was presented in [12].

The profit is defined as:

$$Pr = (Rev – OPEX) / Q,\ €/ton \tag{15}$$

where Rev= Q.FR is the revenue per year, €, FR is the market freight rate, €/ton and Q is the amount of transported cargo, tons.

The profitability is defined by:

$$Re = (Rev – OPEX) / CAPEX,\ \% \tag{16}$$

The above indicators are of a universal nature and are often used in assessing the economic efficiency of complex technical systems. The required freight rate assesses the rate of return on the initial investments; the profit includes only the revenues from the shipping activity. Through the profitability, the effectiveness of the investments, accounting for the operating costs and revenues from the shipping may be controlled.

4.2.1.2 Sensitivity analysis of conceptual ship design accounting for life cycle cost

The defined design tasks were solved considering the three indicators: RFR, Pr and Re and the design solution of the optimised design variables is presented in Table 7 [9].

Table 7: Design parameters

	Indicators	RFR (min)	Pr (max)	Re (max)
	Design variables			
1	Ns	3.078	3.072	2.561
2	Vs, kn	10.411	11.549	10.592
3	L_{pp}, m	123.734	126.436	129.811
4	B, m	23.796	23.711	24.961
5	d, m	7.156	7.108	7.322
6	D, m	9.639	10.181	10.181
7	C_B	0.728	0.700	0.813
	„Active” constraints			
1	P_{Qsum}	1.00	1.00	1.00
2	P_{FI}	1.00	1.00	1.00
3	P_{FB}	1.00	1.00	1.02
4	P_v	1.09	1.03	1.09
5	P_{GMc}	1.00	1.02	1.04
6	L_{pp}/B	5.20	5.33	5.20
	Output			
	DW, tons	11050	10500	14300
	L_{pp}/B	5.20	5.33	5.20
	B/d	3.33	3.34	3.41
	L_{pp}/D	12.84	12.42	12.75

Two of the economic indicators involved in the optimisation procedure, defining the design solution, RFR and Pr, lead to similar optimal ships with similar main dimensions and deadweight.

According to the profitability criterion, Re, the ship has a larger deadweight. For the three indicators, the L_{pp}/B ratio, which is associated with the ship propulsion and seakeeping performance, is close to the lower limit of 5.2. The ratio B/d is higher, which can be explained by the P_{GMc} limitation, which determines the minimum stability in the load cargo condition with containers.

For the assumed transportation scenario, the number of ships needed to transport the cargo in one year is tree units.

A more detailed analysis is needed to explain the relatively low optimum speed of the ship, which is close to the minimum one of 10 kn as a limit.

Figure 8 shows that the design speed for ships of deadweight between 8,000 and 12,000 tons is in the range of 15-17 kn for the analysed 32 multipurpose vessels. The reason for the lower speed can be related to the assumed economic conditions and transportation scenario.

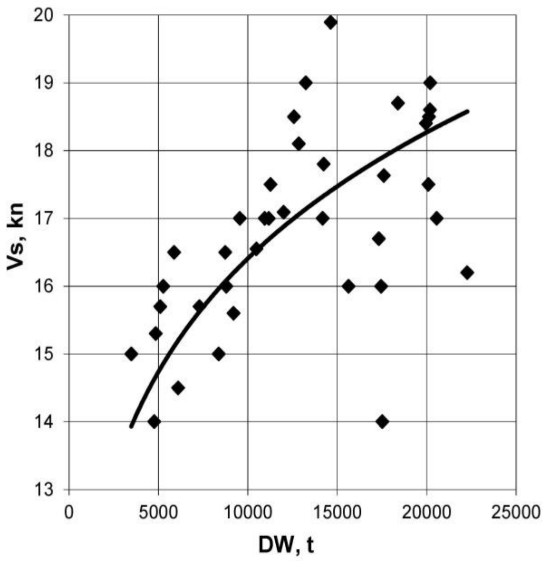


Figure 8: Speed as a function of DW.

In fact, it is a current practice to reduce the speed for relatively short voyages using so-called "economic speed". The reduction in the design speed results in a lowering in fuel and oil consumption, which may reduce the OPEX by 30%.

The optimum speed is influenced by the relation between the travel time and time for cargo handling. The change in the voyage descriptors: the voyage duration, Ts, cargo handling time, Th, the total time of one voyage, Tv and the number of voyages per year, Nv, for the assumed transportation scenario as a function of the deadweight and speed is presented in Figure 9 [9].

As the speed of the ship increases, the voyage time decreases. For the ship with greater deadweight, the time for handling the cargo also increases, which leads to an increase the total voyage time. In the case of a relatively short operational distance between the ports, the cargo handling time may be synchronised with the voyage time by reducing the higher ship speed.

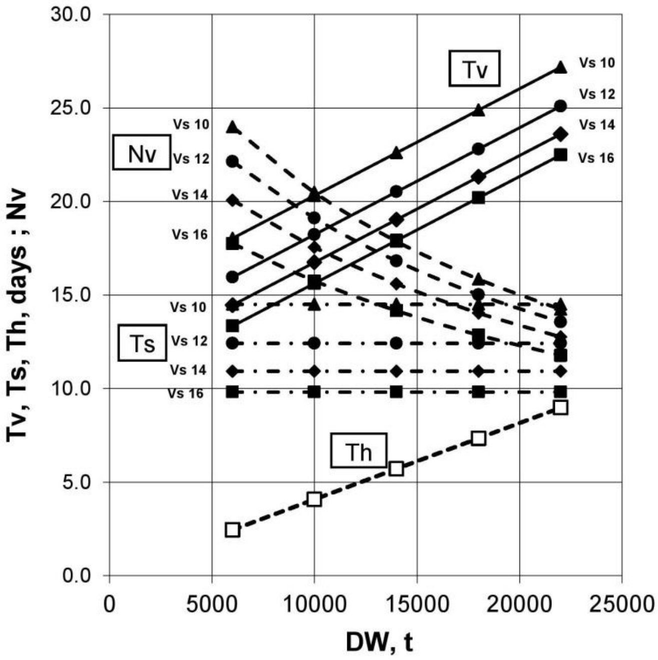


Figure 9: Voyage descriptors as a function of DW

In practice, the ship can operate in different operational conditions and to be effective the speed may need to be reduced. In this respect, a power margin that is related to the need to provide a higher speed to deliver the cargo on time and the use of controllable pitch propeller, CPP that may allow an effective load of the main engine at speed different of the design one is analysed.

One can see from Table 7 that the design solution depends on the chosen criterion as an objective function. For the deadweight range from 6,000 to 22,000 tons with a fixed speed of 15 kn the normalised indicators R_{RFR}, R_{PR} and R_{RE} are presented in Figure 10.

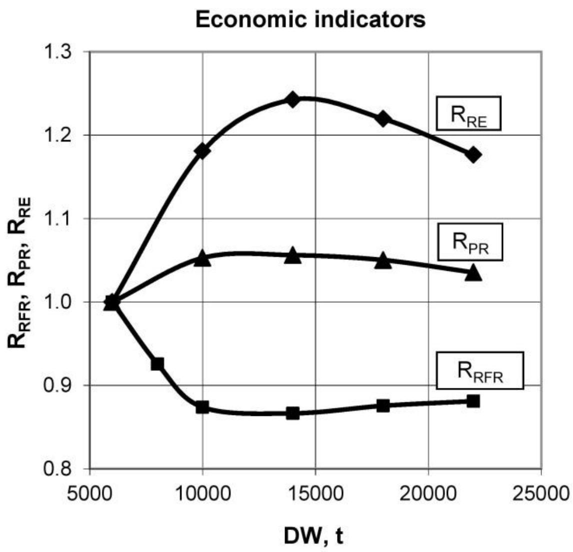


Figure 10: Relative economic indicators as a function of deadweight

It is commonly accepted that with increasing of the deadweight, the economic efficiency of the ship improves - initially sharply, and then smoothly to reach asymptotic (constant values).

In the case of RFR and Pr, the optimum ship deadweight is between 10,000 and 12,000 tons, and after that one can see a slight decrease in the efficiency. Profitability increases rapidly, reaching a clearly defined optimum of DW between 14,000 and 16,000 tons, followed by a reduction in the efficiency.

Figure 11 presents the required number of ships for transportation of a total amount of cargo Q_{sum}=1,000,000 tons per year. For the deadweight in the range of 10,000 – 14,000 tons and speed Vs=15 kn, the number of ships are 2.5 – 3.

The optimal length between the perpendiculars does not differ significantly for the presented economic indicators as can be seen in Figure 12.

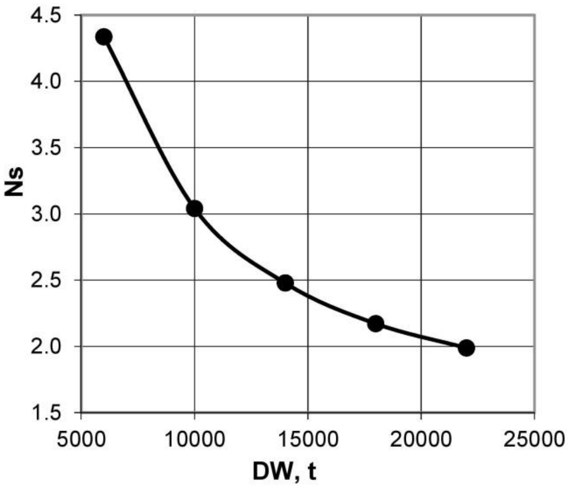


Figure 11: Number of ships, Ns as a function of DW

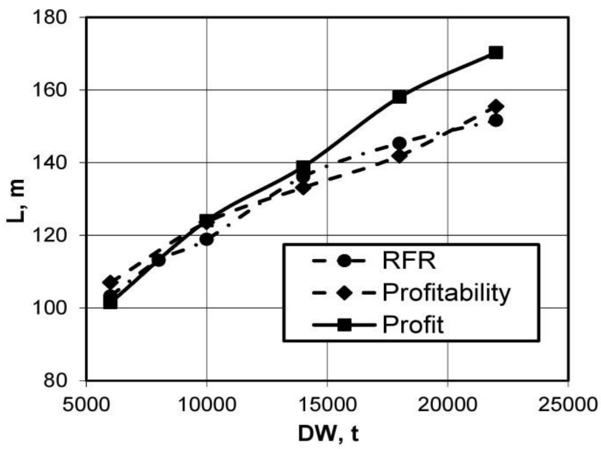


Figure 12: Ship length as a function of economic indicators

In the case of the profit indicator, for deadweight bigger than 15,000 tons, there is a significant increase in the optimal length between the perpendiculars.

The reason for this is that the profit indicator does not consider the increasing of CAPEX due to increasing of the ship length. The breadth of the vessel varies in narrow ranges for the three indicators as can be seen in Figure 13.

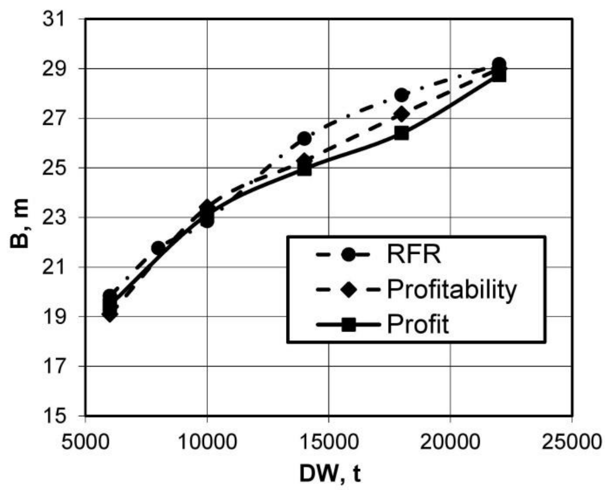


Figure 13: Ship breadth as a function of economic indicators

Table 8 presents some results of the analysed ship the main dimension ratios in the deadweight range of 14,000 to 16,000 tons [9].

Table 8: Dimension ratios

Indicator	L_{pp}/B	B/d	L_{pp}/D
Observed			
min	5.10	2.42	11.25
max	6.30	3.12	15.32
Constraints			
min	5.20	2.00	8.00
max	12.00	4.00	18.00

The L_{pp}/B ratio, which is commonly referred to as an indicator of the ship propulsion and seakeeping is at or close to the minimum values, typical for wider ships. The B/d ratio, which influences the stability, is close to its upper limit. The L_{pp}/D ratio as an indirect indicator of the stiffness of the ship structure takes values close to the average one.

4.2.2 Sensitivity analysis of conceptual ship design accounting for life-cycle cost and shipbuilding limitation of SME

To perform a sensitivity analysis, a study of the economic efficiency of cargo transportation with a ship built under the constraints of an SME shipyard is conducted, where ships with a DW range from 4,000 to 5,500 tons are analysed. Two case studies are analysed accounting for the SME constraint [9] [13]. The set-up of the design was presented in the previous section. Case Study 1, CS1, the transportation scenario was already presented in the previous section and Case study 2, CS2 is characterised with a cargo volume of Qsum = 500,000 tons.

Distance b/w ports:

- Terminal – Port 1: 340 nm
- Port 1 – Port 2: 420 nm

Freight rate:

- Terminal - Port 1 10 €/ton
- Terminal – Port 2 10 €/ton
- Port 1 – Port 2 12 €/ton

For both case studies, the constraints are related to the ship hull constructional capacity of the facilities of an SME shipyard [8] [9] [12], where the breadth of the ships cannot be bigger than 16 m.

The profitability, Re is considered an objective function, and a speed of 14 kn is adopted. Table 9 and Table 10 present the output design parameters in the case of restriction and without restriction concerning the breadth of the ships. The constraints that set up the optimum solution are related to the requirements of transportation of the cargo volume, minimum intact stability and summer freeboard waterline.

The imposed constraint in the breadth of the ship is active in the investigated range of the deadweight and leads to an increase of the length and block coefficient of the ship as can be seen in Table 10.

Table 9: Output design parameters, Case study 1, without restriction

DW, tons	4,000	4,500	5,000	5,500
Relative values of Re (RRe)				
RRe	1.000	1.058	1.107	1.168
Design variables				
Ns	5.841	5.295	4.869	4.520
L_{pp}, m	93.576	103.342	106.187	114.988
B, m	17.73	17.385	17.837	18.002
d, m	5.567	5.818	6.069	6.184
D, m	6.979	7.418	7.786	8.057
C_B	0.650	0.650	0.656	0.656
Main dimensions ratio				
L_{pp}/B	5.278	5.944	5.953	6.388
B/d	3.185	2.988	2.939	2.911
L_{pp}/D	13.408	13.931	13.638	14.272

Table 10: Output design parameters, Case study 1, with restriction

DW, tons	4,000	4,500	5,000	5,500
Relative values of Re (RRe)				
RRe	0.993	1.052	1.096	1.123
Design variables				
Ns	5.882	5.297	4.874	4.517
L_{pp}. m	96.49	105.923	113.199	119.477
B. m	16.001	16.005	16.001	16.001
d. m	5.662	5.716	5.553	5.406
D, m	7.171	7.392	7.423	7.564
C_B	0.678	0.695	0.743	0.792
Main dimensions ratio				
L_{pp}/B	6.030	6.618	7.074	7.467
B/d	2.826	2.800	2.882	2.960
L_{pp}/D	13.456	14.329	15.250	15.795

The relationship between the profitability, in the case of non-restricted design, and the deadweight is presented in Figure 14. The effectiveness of the ship with a restricted breadth decreases with increasing the length of the ship. The relation between the relative profitability for restricted Re(R) and non-restricted Re(NR) ships is presented in Figure 14 as a dotted line. The decreasing of Re due to the constraint related to the breadth varies from 0.7 – 3.1 %.

The profitability of ships with a deadweight in the range from 4,500 to 5,500 tons without a restriction on the breadth is about four times lower than for the ships with deadweight around 14,000 tons. With a limitation of the breadth, the profitability additionally drops down by about 4% [9].

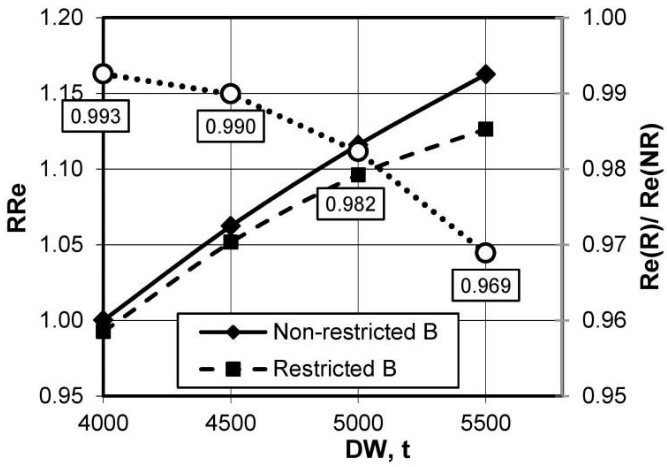


Figure 14: Relative profitability as a function of DW. CS1

The output design parameters for the Case study 2 are presented in Table 11 and Table 12.

The impact of the restricted breadth leads to a relative lengthening of the ship and increasing the block coefficient, which may explain the reduction of the efficiency (see Figure 15) [9].

The relatively short voyages and associated lower freight rate, in comparison to Case study 1, which reduces the profitability about two to three times.

Table 11: Output design parameters, Case study 2, without restriction

DW, tons	4,000	4,500	5,000	5,500
Relative values of Re (RRe)				
RRe	1.000	1.112	1.219	1.307
Design variables				
Ns	2.186	1.997	1.844	1.720
L_{pp}. m	98.809	101.332	104.215	109.985
B. m	16.145	16.878	17.229	18.075
d. m	5.74	5.859	5.861	5.858
D. m	7.258	7.461	7.551	7.633
C_B	0.65	0.662	0.693	0.695
Main dimensions ratio				
L_{pp}/B	6.120	6.004	6.049	6.085
B/d	2.813	2.881	2.940	3.086
L_{pp}/D	13.614	13.582	13.801	14.409

Table 12: Output design parameters, Case study 2, with restriction

DW. tons	4,000	4,500	5,000	5,500
Relative values of Re (RRe)				
RRe	0.983	1.094	1.188	1.220
Design variables				
Ns	2.193	2.002	1.854	1.737
L_{pp}. m	102.379	108.310	115.114	121.491
B. m	16.001	16.000	16.001	16.001
d. m	5.484	5.594	5.471	5.294
D, m	7.010	7.265	7.194	7.535
C_B	0.669	0.693	0.738	0.794
Main dimensions ratio				
L_{pp}/B	6.398	6.769	7.194	7.593
B/d	2.918	2.860	2.925	3.022
L_{pp}/D	14.605	14.908	16.001	16.124

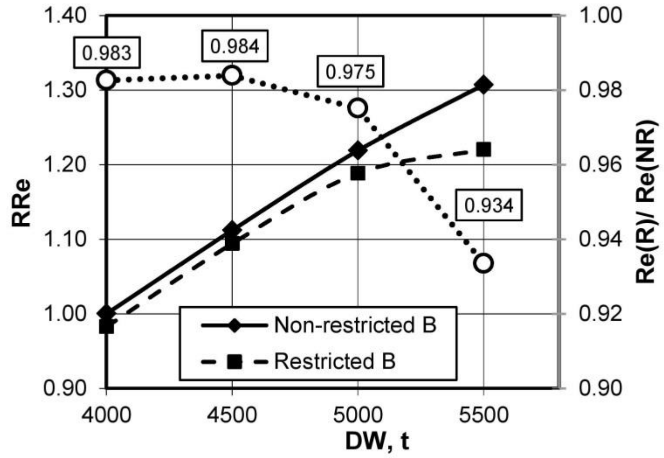


Figure 15: Relative profitability as a function of DW for restricted and non-restricted breadth, CS2

However, in the case of a ship with a design constraint due to the SME construction limitation and without shipbuilding restriction in the cargo transportation condition of Case study 2, the effectiveness of the two design ships is not very different, which is in the range of 2 % (see Figure 15).

4.3 Sensitivity Analysis in SHIPLYS LCT

Regarding the application of sensitivity analysis in SHIPLYS LCT software, developed in WP5 of the project, the same approach is implemented. The database is designed to consider the sensitivity analysis and results to be determined from the analysis.

4.3.1 Sensitivity considerations

Since the sensitivity approach is presented in previous sections, it is significant to present how the analysis is carried out in the software. First of all, the structure of the software is designed to consider four life stages: construction, operation, maintenance and scrapping. Under different life stages, there are various activities associated with different data types, such as engine prices, fuel prices, transportation fees and so on. However, concerning the data availability, default database with considerations of sensitivity levels (SL) are provided, i.e. average, minimum and maximum level. All data are collected from various realistic sources, in particular, literature, technical guidelines, manufacturers' information and so on. The average level dataset uses the average values of all gathered data for concerned parameters; the minimum level dataset uses the minimum values of these data, and the maximum values will be chosen for the maximum level dataset. Table 13 presents an example of an established database including three levels of the dataset which are considered as default values.

Table 13: An example of an established database of engines

	Engine	Average	Minimum	Maximum	Unit
1	No. of Engines	3	3		
2	Engine weight	3.2	1	10	ton
3	Engine price	10000	5000	15000	€
4	Engine output	106.8	50	200	kW
5	SFOC	212.6	190	230	g/kWh
6	SFOC_LO	50	35	65	g/kWh

With these three sets of data in the database, the user will be able to select to analyse three different scenarios: 1) all data/parameters are under average level; 2) all data/parameters are under minimum level; 3) all data/parameters are under maximum level. As a default function included in the LCT software, it will allow the user to use the software even in the case that the real data are not available and also it provides the freedom of end user to modify the values of any parameters based on their data.

To make this analysis meaningful to the user, the investigation of sensitivity from the perspective of local and global will be presented in the following sections.

4.3.2 Local Sensitivity Analysis

The purpose of local sensitivity analysis is to investigate the impact of one parameter on the final result. Task 5.1 in WP5 of this project is supportive of this analysis. Task 5.1 will define the LCA and LCCA algorithm and develop LCT software, and together with the database, it will be able to test how individual parameter could affect the final result. The process is as follow:

a) Selection of default sensitivity level (0-average; 1-minimum and 2-maximum): a set of data from the database will be selected and associated with the algorithm and used for calculation;

b) Selection of a database for different activities: the database contains three datasets considering three sensitivity levels;

c) Change of the default value of the concerned parameter in the selected database and dataset;

d) Run the software and compare results.

For fuel price as an example, the following table presents the total life-cycle cost under different fuel prices. The fuel price used in the shipyard is 280 $/ton. It is assumed that there is a higher price of fuel as 500 $/ton as a comparison. This table indicates that as fuel price increases from 280 to 500 $/tonnes, the total life-cycle cost increases accordingly. However, the new fuel price is 1.79 times the default one, but the increment of total life cycle cost is only increased by 1.67 times. Therefore, it provides the end user with an indication or a trend of total life-cycle cost under different fuel oil prices.

Applying the same analysis process, the impacts of selected parameters with alternative values on the final result (total life-cycle cost) can be determined. With a range of designated values, the trend of the impacts can be obtained as a recommendation to end users.

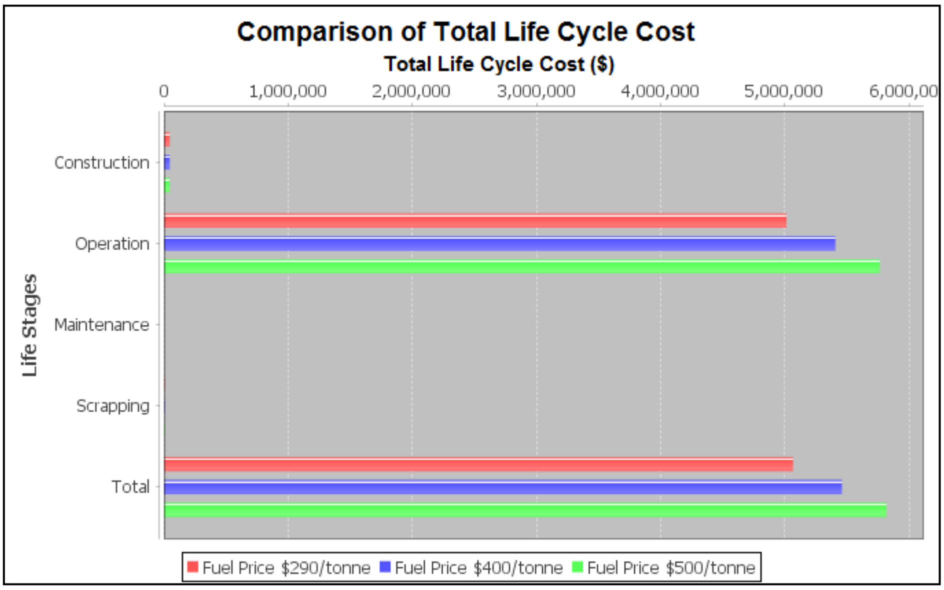


Figure 16: Comparison of Life Cycle Costs for Two Different Fuel Oil Prices

4.3.3 Global Sensitivity Analysis

Apart from the local sensitivity analysis, the sensitivity of a set of data at a global level can also be possible. The purpose is to provide the end user with an overall insight into the range of final results considering minimum, average and maximum conditions. The procedures are listed as follows:

Selection of a sensitivity level (Average, Minimum or Maximum);

Modify the data in the dataset according to end users' data (optional);

Run the software (with different datasets, either using build-in or modified versions);

Compare results.

An example of global sensitivity analysis considers original data as average values, and minimum and maximum values will be 10% different from the original/average values. The result is presented in Figure 17. This figure also indicates the range of the results due to the variation of sensitivity levels which is from around 3.9 million dollars to 4.9 million dollars to 6.1 million dollars.

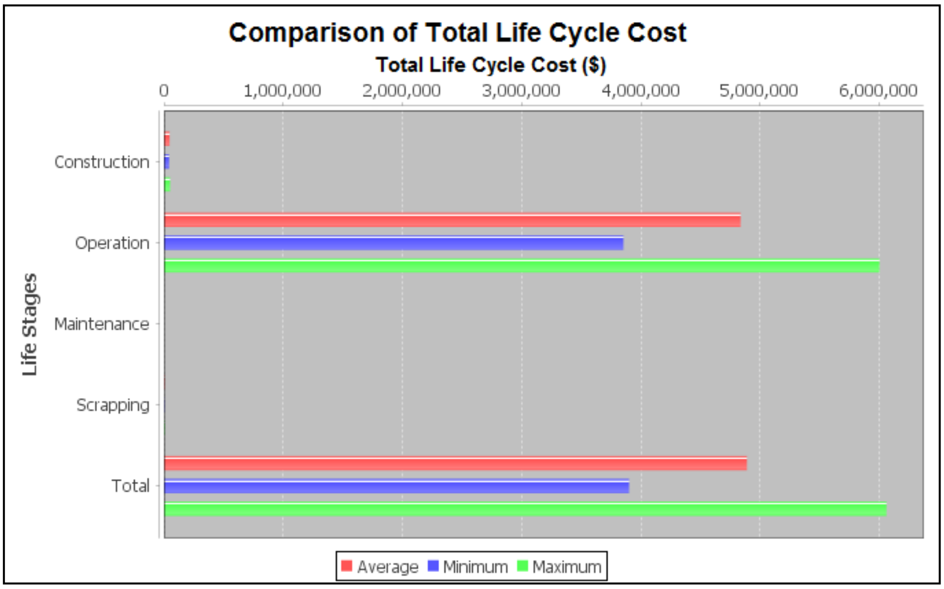


Figure 17: Comparison of Life Cycle Costs under Three Different Sensitivity Levels

5 Conclusions

The current deliverable has presented the challenges in acquiring adequate and qualitative data, the process of collecting data within the project and the development of different methodologies for gaining confidence in existing data, quantify and deal with uncertainty, and performing a Sensitivity Analysis to key inputs in the various phases of the ship design process and life cycle estimations. Finally, a glimpse of the SHIPLYS Life Cycle Tool has been demonstrated, by presenting the Sensitivity Analysis approach that will be implemented in the LCT software, developed in WP5 of the SHIPLYS project.

The importance of good quality data and the development of a complete database used by the SHIPLYS tools is highlighted throughout this deliverable. For SMEs to be able to validate and compare different ship designs and present an optimal proposal at an early bidding phase, the data used must provide certain reliability.

Thus, the development of an efficient methodology to assess the quality and criticality of the data used in the development of innovative ship design is critical for the success of the bidding process.

6 References

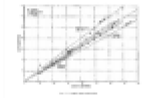
1. Papanikolaou A., 2014. Ship Design - Methodologies of Preliminary Design. Springer Dordrecht Heidelberg New York London
2. Bevington, P. R. &Robinson, D. K. 2003. Data Reduction and Error Analysis for the Physical Sciences, 3rd edition, McGraw-Hill, New York
3. Marc C. Kennedy, Anthony O'Hagan, Bayesian calibration of computer models, Journal of the Royal Statistical Society, Series B Volume 63, Issue 3, pages 425–464, 2001
4. Kirchner, James, 2001. Data analysis toolkit#5: Uncertainty analysis and error propagation, University of California, Berkeley, Analysis of environmental data course pages
5. Christopher L. Stevenson, 2000. The Statistics of Measurements, University of Richmond
6. U.S. Government Accountability Office (GAO), 2009. GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs. GAO-09-3SP, Washington, D.C
7. X. Cui, U. R. Bharadwaj and P. Zhou, 2017, A framework for multi-criteria decision analysis (MCDA) applied to conceptual stage of ship design: Maritime Transportation and Harvesting of Sea Resources. 2017: pp 897-904 LONDON: TAYLOR and FRANCIS GROUP ISBN 978-0-8153-7993-5
8. Atanasova, I., Damyanliev, T. P., Georgiev, P. & Garbatov, Y. 2018. Analysis of SME ship repair yard capacity in building new ships. Proceedings of MARTECH. London: Taylor & Francis Group.
9. Damyanliev, T., Georgiev, P., Atanasova, I. & Garbatov, Y. 2018. Design and optimisation of multipurpose ship fleet accounting for the constraints of SME shipyard and cargo transportation needs of regional economy. Proceedings of MARTECH. London: Taylor & Francis Group.
10. Damyanliev, T. P., Georgiev, P. & Garbatov, Y. 2017. Conceptual ship design framework for designing new commercial ships. In: Guedes Soares, C. & Garbatov, Y. (eds.) Progress in the Analysis and Design of Marine Structures. London: Taylor & Francis Group, 183-191.
11. Fiacco, A. V. & McCormick, G. P. 1968. Nonlinear Programming: Sequential Unconstrained Minimization Techniques, Chichester, England, Wiley.
12. Garbatov, Y., Ventura, M., Georgiev, P., Damyanliev, T. P. & Atanasova, I. 2017. Investment cost estimate accounting for shipbuilding constraints. In: Guedes Soares, C. & Teixeira, A. (eds.) Maritime Transportation and Harvesting of Sea Resources. London: Taylor & Francis Group, 913-921.
13. Garbatov, Y., Ventura, M., Guedes Soares, C., Georgiev, P., Koch, T. & Atanasova, I. 2017. Framework for conceptual ship design accounting for risk-based life cycle assessment. In: Guedes Soares, C. & Teixeira, A. (eds.) Maritime Transportation and Harvesting of Sea Resources. London: Taylor & Francis Group, 921-931.
14. Himmelblau, D. 1972. Applied Nonlinear Programing, New York, McGraw – Hill.

Appendix: SHIPLYS Parameters list

(Sorted by activity/ including data sources)

SHIPLYS

A122 Create preliminary design

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
A1221 Create preliminary hull form									
A12211 Estimate main dimensions and parameters									
(Basic parameters)									
Vessel type	Non-dimensional	none	Character	definition of the vessel type, e.g. RORO, MPV, Bulk Carrier	Specific value	shipowner requirements	A1221 - Create preliminary hull form		1
Deadweight	Mass	tons	Real	vessel's deadweight - cargo capacity		shipowner requirements	A1221 - Create preliminary hull form		1
Number of containers (if applicable)	Non-dimensional	none	Real	number of cargo containers		shipowner requirements	A1221 - Create preliminary hull form		1
Number of cars (if applicable)	Non-dimensional	none	real	number of cars transported		shipowner requirements	A1221 - Create preliminary hull form		1
Number of passengers (if applicable)	Non-dimensional	none	real	number of passengers transported		shipowner requirements	A1221 - Create preliminary hull form		1
Operational range	Length	nm	real	maximum distance of the route on which the new vessel will operate (Nm)		shipowner requirements	A1221 - Create preliminary hull form		1
Service speed	Speed	knots	Real	vessel's service speed		shipowner requirements	A1221 - Create preliminary hull form		1
Year of built	Date	none	Integer	vessel's year of built	Other	ship data	A1221 - Create preliminary hull form		1
(Dimensions and hull form parameters)									
L/B	Non-dimensional	none	Real	The L/B ratio has significant influence on hull resistance and maneuverability	Formula	- Thomas Lamb Chapter 11 - D.G.M. Watson "Practical Ship Design" Chapter 3 $L/B = 4.0$, for $L \le 30$ m $= 4.0 + 0.025\,(L - 30)$, for $30 \le L \le 130$ m $= 6.5$, for $130\text{ m} \le L$	A12211 - Estimate main dimensions and parameters		1
L/D	Non-dimensional	none	Real	The length depth ratio L/D is primarily important in its influence on longitudinal strength	Graph	- D.G.M. Watson "Practical Ship Design" Chapter 3 Pag. 73– Graph 3.11 	A12212 - Estimate form parameters		1
B/T	Non-dimensional	none	Real	The beam dratf ratio is primarily important though its influence on residuary resistance, transverse stability, and wetted surface. In general, values ranges betwen 3.25 < B/T < 3.75, but values as high as 5.0 appear to heavily draft-limited design	Formula	1. Thomas Lamb chapter 11 Volume 1 REF : 26. Saunders, H., Hydrodynamics in Ship Design , Vol. II,SNAME, NY, 1957 $B/T|_{\min C_S} = 5.93 - 3.33\,C_M$ REF 27. Roseman, D. P., Gertler. M., and Kohl, R. E., "Characteristics of Bulk Products Carriers for Restricted-Draft Service,"Transactions SNAME, 82, 1974 $(B/T)_{max} = 9.625 - 7.5\,C_B$	A12212 - Estimate form parameters		1

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Length	Length	meters	Real	vessel length	Formula	shipowner requirements-Geometric characteristics and statistics databases, e.g. "Ship Design for Efficiency and Economy, H. Schneekluth, V. Bertram, 2nd edition, page 8". 1. Ship's length recommended by Ayre: $\frac{L}{\nabla^{1/3}} = 3.33 + 1.67\frac{V}{\sqrt{L}}$ 2. Ship's length recommended by Posdunine, corrected using statistics of the Wageningen towing tank: $L = C\left(\frac{V}{V+2}\right)^2 \nabla^{1/3}$ $C = 7.25$ for freighters with trial speed of $V = 15.5$–18.5 kn. In both formulae, L is in m, V in kn and ∇ in m^3. 3. Völker's (1974) statistics $\frac{L}{\nabla^{1/3}} = 3.5 + 4.5\frac{V}{\sqrt{g\nabla^{1/3}}}$ V in m/s. This formula applies to dry cargo ships and containerships. For reefers, the value $L/\nabla^{1/3}$ is lower by 0.5; for coasters and trawlers by 1.5.	A12211 - Estimate main dimensions and parameters		1
Breadth	Length	meters	Real	vessel breadth	Formula	shipowner requirements-Geometric characteristics and statistics databases $B = \frac{L}{L/B}$	A12211 - Estimate main dimensions and parameters		1
Depth	Length	meters	Real	vessel depth	Formula	shipowner requirements-Geometric characteristics and statistics databases $D = \frac{D}{4D}$	A12211 - Estimate main dimensions and parameters		1
Draught	Length	meters	Real	vessel draught	Formula	shipowner requirements-Geometric characteristics and statistics databases $T = \frac{B}{B/T}$	A12211 - Estimate main dimensions and parameters		1
Displacement	Mass	cubic meters	Real	vessel displacement		shipowner requirements-Geometric characteristics and statistics databases	A12211 - Estimate main dimensions and parameters		1
A12212 Estimate form parameters									
Block Coefficient Cb	Non-dimensional	none	Real	Block Coefficient Cb The block coefficient Cb measures the fullness of the submerged hull, the ratio os the hull volume to its surrounding parallelepiped LBT	Fórmula	. Thomas Lamb Chapter 11 volume 1 . D.G.M. Watson, Practical Ship Design, Chapter 3 . Townsim, R.L. - Transaction RINA 1979 . Mb: Formula de Towsin Cb=0,7+0,25 atan(25(0,23 - Fn)) $C_b = K - 0.5\, V_k / \sqrt{L_f}$	A12212 - Estimate form parameters		1
Midship Section Coefficient CM	Non-dimensional	none	Real	vessel's midship coefficient	Fórmula	.Thomas Lamb Chapter 11 volume 1 pag 12 Benford Formula e - CM = 0,977+ 0,085 (Cb - 0,60) - Schmeekluth/Kerlen Formula e CM= 1,006 - 0,0056 Cb - 3,56 CM= (1+(1-CB) 3.5) -1 $C_M = 0.977 + 0.085\,(C_B - 0.60)$ $C_M = 1.006 - 0.0056\, C_B^{-3.56}$ $C_M = (1 + (1 - C_B)^{3.5})^{-1}$	A12212 - Estimate form parameters		1
Longitudinal prismatic coefficient Cp	Non-dimensional	none	Real	Longitudinal Prismatic Coefficient Cp The Longitudinal Prismatic describes the distribution of volume along the hull form.	Fórmula	Ricardo Alvariño, Juan J. Azpirar, Manuel Meizao, Proyecto Bistro del Buque Merrante, Chapter 3.4 Thomas Lamb, Chapter II $FN = Froude\ Number$ CP = CB / CM. CP = 1,20 - 2,12 × FN	A12212 - Estimate form parameters		1

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Waterplane Coefficient Cwp	Non-dimensional	none	Real	An initial estimate of Cwp is used to estimate the transverse and longitudinal inertia properties of the waterplane needed to calculate BM_T and BM_L	Formula	Thomas Lamb, Chapter 11, volume 1 page 16 *Equation* — *Applicability/Source* $C_{WP} = 0.180 + 0.860\ C_P$ — Series 60 $C_{WP} = 0.444 + 0.520\ C_P$ — Eames, small transom stern warships (2) $C_{WP} = C_B/(0.471 + 0.551\ C_B)$ — tankers and bulk carriers (17) $C_{WP} = 0.175 + 0.875\ C_P$ — single screw, cruiser stern $C_{WP} = 0.262 + 0.760\ C_P$ — twin screw, cruiser stern $C_{WP} = 0.262 + 0.810\ C_P$ — twin screw, transom stern $C_{WP} = C_P^{2/3}$ — Schneekluth 1 (17) $C_{WP} = (1 + 2\ C_B/C_M^{1/2})/3$ — Schneekluth 2 (17) $C_{WP} = 0.95\ C_P + 0.17(1 - C_P)^{1/3}$ — U-form hulls $C_{WP} = (1 + 2\ C_B)/3$ — Average hulls, Riddlesworth (2) $C_{WP} = C_B^{1/2} - 0.025$ — V-form hulls	A12212 - Estimate form parameters		1
LBD - cubic number	Volume	cubic meters	Real	length*breadth*depth -	Other	calculated, depend of parameter L,B,D	A12211 - Estimate main dimensions and parameters		1
A12213 Do parametric variations									
A12214 Generate initial hull form definition									
Bulbous bow (0 No, 1 = Yes)	Non-dimensional	none	Character	Existance of bulbous bow	non neccesary, user defined	user defined	A12214 - Generate initial hull form definition		
Stern form (U, V, normal)	Non-dimensional	none	Character	Type of stern form	non neccesary, user defined	user defined	A12214 - Generate initial hull form definition		
Normal hull (1) or twin skeg (2)	Non-dimensional	none	Character	Type of hull - aft	non neccesary, user defined	user defined	A12214 - Generate initial hull form definition		
Initial hydrostatic properties									
Waterplane area	Length	m^2	Real	The area of a hull at a particular horizontal plane, i.e. within the waterline.	Formula	calculated, e.g. "Ship Hydrostatics and Stability, A. Biran" $A_W = 2\int_a^b y dx$	A12224 - Calculate stability and trim		2
Moment of waterplane area about a transverse axis	Moment	Nm	Real	Moment of waterplane area about a transverse axis	Formula	calculated, e.g. "Ship Hydrostatics and Stability, A. Biran" $M_x = 2\int_a^b xy dx$	A12224 - Calculate stability and trim		2

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Longitudinal centre of floatation (LCF)	Length	m	Real	The longitudinal centre of the waterplane on which a vessel floats. It is expressed as the ratio of the moment of the waterplane area about a transverse axis to the waterplane area.	Formula	calculated, e.g. "Ship Hydrostatics and Stability, A. Biran" $LCF = \frac{M_x}{A_W}$	A12224 - Calculate stability and trim		2
Transverse moment of inertia of waterplane area	Moment	Nm	Real	Transverse moment of inertia of waterplane area	Formula	calculated, e.g. "Ship Hydrostatics and Stability, A. Biran" $I_T = \int_a^b \frac{2}{3} y^3 dx$	A12224 - Calculate stability and trim		2
Moment of inertia of waterplane about a transverse axis	Moment	Nm	Real	Moment of inertia of waterplane about a transverse axis	Formula	calculated, e.g. "Ship Hydrostatics and Stability, A. Biran" $I_y = 2 \int_a^b x^2 y dx$	A12224 - Calculate stability and trim		2
Longitudinal moment of inertia of waterplane area	Moment	Nm	Real	Longitudinal moment of inertia of waterplane area	Formula	calculated, e.g. "Ship Hydrostatics and Stability, A. Biran" $I_L = I_y - x_F^2 A_W$	A12224 - Calculate stability and trim		2
Moment of displacement volume above base line	Moment	Nm	Real	Moment of displacement volume above base line	Formula	calculated, e.g. "Ship Hydrostatics and Stability, A. Biran" $M_B = \int_0^{T_0} T A_W dz$	A12224 - Calculate stability and trim		2
Longitudinal centre of buoyancy (LCB)	Length	m	Real	Longitudinal position of the centre of gravity of the displaced water.	Other	calculated	A12224 - Calculate stability and trim		2
Vertical centre of buoyancy	Length	m	Real	The vertical distance between the keel and the center of buoyancy (KB). It is expressed as the ratio of the moment of displacement volume to the displacement volume.	Formula	calculated, e.g. "Ship Hydrostatics and Stability, A. Biran" $VCB = \frac{M_B}{\nabla}$	A12224 - Calculate stability and trim		2
A1222 Create preliminary general arrangement									
A12221 Define Compartments									
(Ship compartmentation)									
Frame spacing	Length	mm	Real		Specific value	user defined	A12221 - Define compartments		2
Longitudinal Bulkheads position	Length	mm	Real		Specific value	user defined	A12221 - Define compartments		2
Transverse Bulkheads position	Length	mm	Real		Specific value	user defined	A12221 - Define compartments		2
Number of decks	Non-dimensional	None	Integer		Specific value	user defined	A12221 - Define compartments		2
Number of superstructure decks	Non-dimensional	None	Integer		Specific value	user defined	A12221 - Define compartments		2
Location of engine room	Length	m	Real		Specific value	user defined	A12221 - Define compartments		2
Height of the deck.	Lenght	m	Real	Real parameter. Vertical distance between deck	Specific value	user defined	A12221 - Define compartments		1

SHIPLYS

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Deck definition	Non-dimensional	none	Character	Definition of the decks or decks where the retrofitting works will be developed.	Ohter	user defined	A12221 - Define compartments		1
New spaces definition	Non-dimensional	none	Character	Definition of new spaces needed for install new equipment.	Other	user defined	A12221 - Define compartments		1
Aft Body Frame spacing	Length	m	Real	Length of the ship's aft body frame spacing (mm). There are occasions that is necessary to carry out retrofitting works (cutting) which it has influence in the frame spacing.	Specific value	user defined	A12221 - Define compartments		2
Fore Body Frame spacing	Length	m	Real	Length of the ship's fore body frame spacing (mm). There are occasions that is necessary to carry out retrofitting works (cutting) which it has influence in the frame spacing.	Specific value	user defined	A12221 - Define compartments		2
Central Body Frame spacing	Length	m	Real	Real parameter. Length of the ship's central body frame spacing (mm). There are occasions that is necessary to carry out retrofitting works (cutting) which it has influence in the frame spacing.	Specific value	user defined	A12221 - Define compartments		2
A12222 Calculate capacities									
Cargo density of each compartment	Density	T/m^3	Real		Specific value	user defined	A12221 - Define compartments		2
Freeboard calculations									
Type of ship for determining freeboard	Non-dimensional	n/a	Character	There are two kinds of freeboard, Type A and Type B, defined in International Convention on Load Lines (ICLL) Regulation 27 Type A : It is designed to carry out only liquid cargoes in bulk. Type B All ships which do not come within the provisions regadting type A	Other	by owner's requirements; defined in ICLL Regulation 27	A122223-Calculate tonnage, freeboard		2
Freeboard length	Length	m	Real	Length from the fore side of the stem to the axis of the rudder stock on a waterline at 85 % depth	Other	defined by hull form and ICLL Regulation 3	A122223-Calculate tonnage, freeboard		2
Deck plate thickness	Length	m	Real	Thickness of the freeboard deck	Other	defined by bending moment requirement	A122223-Calculate tonnage, freeboard		2
Design depth	Length	m	Real	Design depth	Other	defined by draft and hull form	A122223-Calculate tonnage, freeboard		2

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Freeboard depth	Length	m	Real	Design depth + Deck plate thickness	Formula	defined by ICLL Regulation 27	A122223-Calculate tonnage, freeboard		2
Tabular freeboard	Length	m	Real	Tabular freeboard	Other	calculated	A122223-Calculate tonnage, freeboard		2
Correction for length	Length	m	Real	Correction for freeboard length	Formula	defined by ICLL Regulation	A122223-Calculate tonnage, freeboard		2
Correction for depth	Length	m	Real	Correction for reeboard depth	Formula	defined by ICLL Regulation 31	A122223-Calculate tonnage, freeboard		2
Correction for Cb	Length	m	Real	Correction for block coefficient	Formula	defined by ICLL Regulation 30	A122223-Calculate tonnage, freeboard		2
Correction for deck sheer	Length	m	Real	Correction for deck sheer	Formula	defined by ICLL Regulation 38	A122223-Calculate tonnage, freeboard		2
Correction for superstructure and trunk	Length	m	Real	Correction for superstructure and trunk	Formula	defined by ICLL Regulation	A122223-Calculate tonnage, freeboard		2
Minimum bow height	Length	m	Real	Minimum required bow height	Formula	defined by ICLL Regulation 39	A122223-Calculate tonnage, freeboard		2
Summer freeboard	Length	m	Real	Freeboard at summer waterline	Formula	defined by ICLL Regulation 40	A122223-Calculate tonnage, freeboard		2
A12223 Estimate weight									
(Weight Analysis)									
Hull weight	Mass	tons	Real	Plates and sections forming Shell, Outer Bottom, Inner Bottom, Girders, Upper Deck, Tween Decks, Bulkheads, Superstructure(s), Seats for equipment & Appendages together with Forgings/Castings for Stem, Sternframe, Rudder Stock(s) and Shaft Brackets.	Formula	statistics, calculated;Cubic Number Method; Rate per Metre Difference Method • When the arrangement of the superstructures is already known, a criteria based in the average weight per unit area (Wu) can be used, assuming that the corresponding height of the decks is equal to 2,40 m. $W_{SPS} = W_U \cdot A$ with: A – covered area of decks W_u = 190 kg/m2 (castles) W_u = 210 kg/m2 (superstructures amidships) W_u = 225 kg/m2 (superstructures aft)	A12223 - Estimate weight		1
Superstructures weight	Mass	tons	Real			statistics, calculated; Cargo liner (10~12% of Hull weight); Tanker (6~8%); Bulk carrier(6~7%); or it can be proportional to its volume: C*V	A12223 - Estimate weight		1

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Machinery weight	Mass	tons	Real	Representing: - Main Engine(s), Gearbox (if fitted), Bearings, Shafting, Propeller(s), Generators, Switchboards, Cabling, Pumps, Valves, Piping etc.	Formula	statistics, calculated; for ME: $\text{Weight} = 12 \left(\frac{MCR}{RPM}\right)^{0.84}$ (tonnes) where MCR = Maximum Continuous Rating (kW) RPM = Engine crankshaft revs per minute at MCR The weight of the remainder of the machinery was given by $\text{Weight} = k\,(MCR)^{0.7}$ (tonnes) where k = 0.56 for Bulk Carriers and General Cargo Ships 0.59 for Tankers (due to additional weight for cargo pumping) 0.65 for Passenger Ships and Ferries (additional weight devoted to power for hotel services, lighting and heating, ventilation & air conditioning (HVAC)) slow-speed engines (110–140 rpm) 0.016–0.045 t/kW medium-speed engines in series (400–500 rpm) 0.012–0.020 t/kW medium-speed V-type engines (400–500 rpm) 0.008–0.015 t/kW	A12223 - Estimate weight		1
Ship systems	Mass	tons	Real	tal weight of systems on board = i.e. switchboards, transformers, firefighting	Specific value		A12223 - Estimate weight		
Other weight (equipment+accomodation)	Mass	tons	Real	Hatch covers, Cargo handling equipment, Equipment and facilities in the living quarters (such as furniture, galley equipment, heating, ventilation & air conditioning, doors, windows & sidelights, sanitary installations, deck, bulkhead & deckhead coverings & insulation and non-steel compartment boundaries) and Miscellaneous items (such as anchoring & mooring equipment, steering gear, bridge consoles, Refrigerating plant, paint, lifesaving equipment, firefighting equipment, hold ventilation and radio & radar equipment)		statistics, calculated; for outfit weight: square number method	A12223 - Estimate weight		1

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Lightship weight (LS)	Mass	tons	Real	Steel Weight + Outfit Weight +Machinery Weight + Margin	Specific value	statistics, calculated;Lightweight = Steel Weight + Outfit Weight (Including Refrigeration & Insulation) + Machinery Weight	A12223 - Estimate weight		1
LCG of LS	Length	m	Real	Position of the centre of gravity (C of G) -Longitudinally	Formula	statistics, calculated;Scaled C of G (early design stages); Real C of G (later design stages)	A12223 - Estimate weight		1
VCG of LS	Length	m	Real	Position of the centre of gravity (C of G) - Vertically	Formula	statistics, calculated;Scaled C of G (early design stages); Real C of G (later design stages)	A12223 - Estimate weight		1
Weight of cargo	Mass	tons	Real	Payload	Formula	Shipowner requirement	A12222 - Calculate capacities		1
Weight of fuel oil	Mass	tons	Real	The requirement for fuel is based on Engine Power, Fuel Consumption (SFC) and the duration of the voyage	Formula	statistics, calculated; FO consumption = SFOC*Power*Duration	A12222 - Calculate capacities		1
Weight of diesel oil	Mass	tons	Real	The requirement for fuel is based on Engine Power, Fuel Consumption (SFC) and the duration of the voyage	Formula	statistics, calculated; FO consumption = SFOC*Power*Duration	A12222 - Calculate capacities		1
Weight of UREA	Mass	tons	real	The requirement of UREA for Scrubber.	Specific value		A12222 - Calculate capacities		1
Weight of waste from gas cleaning process	Mass	tons	real	total weight of waste at 98% capacity (t)	Specific value		A12222 - Calculate capacities		
Weight of lubricant oil	Mass	tons	Real	The requirement for Lubricating Oil is based on Engine Power, Lubricating Oil Consumption and the duration of the voyage.	Formula	statistics, calculated; LO consumption = SLOC*Power*Duration	A12222 - Calculate capacities		1
Crew members	Mass	tons	Real	The present allowance for an average crew member is 75 kg and if effects (personal belongings, luggage, baggage etc.) are included then the value should double.	Specific value	Calculated based on ship type and size	A12222 - Calculate capacities		2
Weight of fresh water	Mass	tons	Real	Fresh water carried based on duration, crew member and whether a fresh water generator equiped	Formula	statistics, calculated; estimated:100 litres per person per day	A12222 - Calculate capacities		1
Weight of provisions and stores	Mass	tons	Real	Stores, in the sense of food, drink etc, are normally assessed on the basis of so much per person per day.	Formula	statistics, calculated; proportional to the product of crew no. and duration(days)	A12222 - Calculate capacities		1

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Weight of ballast	Mass	tons	Real	Water ballast is required to give adequate propeller immersion in the lightest seagoing condition and to ensure that the minimum draught forward is sufficient to avoid excessive slamming.	Formula	Calculated from initial trim and stability calculation	A12222 - Calculate capacities		1
Deadweight	Mass	tons	Real	Deadweight is the difference between the Displacement at any draught and the Lightweight	Formula	statistics, calculated;Deadweight = Cargo Deadweight (Payload) + Fuel Oil + Diesel Oil + Lubricating Oil + Hydraulic Fluid + Boiler Feed Water + Fresh Water + Crew & Effects + Stores + Spare Gear + Water Ballast	A12222 - Calculate capacities		1
LCG of DWT	Length	m	Real	Position of the centre of gravity (C of G) -Longitudinally	Formula	Determined by trim and stability requirements	A12222 - Calculate capacities		1
VCG of DWT	Length	m	Real	Position of the centre of gravity (C of G) - Vertically	Formula	Determined by trim and stability requirements	A12222 - Calculate capacities		1
Weight of displacement	Mass	tons	Real	Design Displacement or Full Load Displacement is the displacement of the ship at its Summer Load Draught in salt water of density 1.025 tonne/m3	Formula	statistics, calculated;Displacement = Lightweight + Deadweight	A12223 - Estimate weight		1
A12224 Calculate stability and trim									
Stability (Intact & Damage)									
Intact stability calculations									
Fore draft	Length	m	Real	The distance between the intersection of this auxiliary line with the aft perpendicular and the load line.	Formula	calculated, e.g. "Ship Hydrostatics and Stability, A. Biran"	A12224 - Calculate stability and trim		2
Aft draft	Length	m	Real	The distance between the load line and the intersection of the auxiliary line with the forward perpendicular	Formula	calculated, e.g. "Ship Hydrostatics and Stability, A. Biran"	A12224 - Calculate stability and trim		2
Midship draft	Length	m	Real	The draft measured in the midship section	Other	measured by software; or by reading the hydrostatic curves	A12224 - Calculate stability and trim		2
Trim	Length	m	Real	The difference between the forward and aft draft.	Formula	calculated	A122243-Calculate trim		2

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Angle of flooding	Angle	deg	Real	Downflooding angle related to intact stability is the angle of heel at which the lower edge of openings in the hull, superstructures or deckhouses that cannot be closed weathertight immerse.	Other	shipowner requirement, calculated	A12224 - Calculate stability and trim		2
Transverse metacentric radius	Length	m	Real	The magnitude of the metacentric radius (BM) is equal to the ratio of the waterplane moment of inertia, about the axis of inclination, to the volume of displacement	Formula	calculated	A12224 - Calculate stability and trim		2
Longitudinal metacentric radius	Length	m	Real		Formula	calculated	A12224 - Calculate stability and trim		2
Intact stability (righting arm curve)	Length	m	Real	The righting arm curve (GZ) as a function of heeling angle is used to check the stability criteria.	Graph	calculated by a stability software example given in Graph 3	A12224 - Calculate stability and trim		2
Intact stability (heeling arm curve)	Length	m	Real		Graph	calculated by a stability software	A12224 - Calculate stability and trim		2
A1223 Estimate hydrodynamics and power									
A12231 Estimate resistance and power									
(Power and engine parameters)									
Preliminary main engine power	Power	kW	Real	vessel's main engine power	Formula	Calculated. e.g. by the Admiralty coefficient: $C_N = \frac{Displacement(t)^{2/3} \cdot Speed\,(kn)^3}{Propulsion\ Power\ (HP)}$ CN can be derived either from similar ships or from the following formula: $C_N = 3.7 \cdot \left(\sqrt{Length(m)} + \frac{75}{Speed(\frac{m}{s})}\right)$ resulting in propulsion power in [kw]. Alternatively: 1) Calculation of the propeller curve (i.e. EHP-RPM), e.g. software module GKpower 2) Use of statistical or empirical data, see examples in sheet "Graphs-1" for Bulk Carriers.	A12231 Estimate resistance and powering		1
(Propeller parameters)									
Propeller type	Non-dimensional	None	Character		Specific value	User defined. Two main groups: Fixed pitch propeller (FP-propeller); Controllable pitch propeller (CP-propeller)			
Number of propellers	Non-	None	Integer		Specific	User defined. Depends on ship type and power plant	A122313 - Predict		

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Propeller thrust	Force	kN	Real		Worksheet	Appropriate approximation method . Starting source: "Basic Principles of Ship Propulsion" - MAN Diesel & Turbo	A122313 - Predict propeller performance		
Propeller diameter	Length	m	Real		Worksheet	Appropriate approximation method	A122313 - Predict propeller performance		
Number of blades	Non-dimensional	None	Integer		Specific value	User defined.The less number of blades the more efficiency, the higher number of blades the smoothest and uniform performance.	A122313 - Predict propeller performance		
Conventional or ducted propeller	Non-dimensional	None	Character		Specific value	User defined.Depends of ship type, power plant, ship mission.	A122313 - Predict propeller performance		
Blade area ratio AE/AO	Non-dimensional	None	Real	The ratio of the total area of the blades, divided by imaginary circle area that the propeller diameter creates.	Specific value	user defined	A122313 - Predict propeller performance		
A12232 Estimate seakeeping									
(Seakeeping)									
Natural period of roll	Time	sec	Real	Roll period is how quickly return to upright position while rolling. So it is the time a ship takess from upright position to going to a particular angle on port side and then going to a angle on starboard side and then again returning back to upright position (zero list position) during natural rolling.	Formula	Department of Civil and Environmental Engineering. Division of water Enviroment Technology CHALMERS UNIVERSITY OF TECHNOLOGY Göteborg, Sweden, 2009 Report Nº. 2009;1 $\omega_{N4} = \sqrt{\frac{C_{44}}{I_4 + A_{44}}}$ in roll For the box-like ship one can approximately write $\omega_{N4} = \sqrt{\frac{C_{44}}{I_4 + A_{44}}} = \sqrt{\frac{\rho g L B (B^2 + T(z_B - z_G))}{I_4 + a_{44} L}}$ in roll Typical resonance periods are in heave 10 s, in roll 8 – 12 s and in pitch 10 20 s. For anchored ships the resonance periods in surge may be > 200 s, in sway > 100 s and in yaw >100 s and are highly dependent on the mooring system.	A12232 - Estimate sea-keeping		1

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Natural period of heave	Time	sec	Real		Formula	Department of Civil and Environmental Engineering. Division of water Enviroment Technology CHALMERS UNIVERSITY OF TECHNOLOGY Göteborg, Sweden, 2009 Report Nº. 2009;1 $\omega_{N3} = \sqrt{\frac{C_{33}}{\rho V + A_{33}}} = \sqrt{\frac{\rho g A_w}{\rho V + A_{33}}}$ in heave For the box-like ship one can approximately write $\omega_{N3} = \sqrt{\frac{C_{33}}{\rho V + A_{33}}} = \sqrt{\frac{\rho g B}{\rho B T + a_{33}}}$ in heave Typical resonance periods are in heave 10 s, in roll 8 – 12 s and in pitch 10 20 s. For anchored ships the resonance periods in surge may be > 200 s, in sway > 100 s and in yaw >100 s and are highly dependent on the mooring system.	A12232 - Estimate sea-keeping		1
Natural period of pitch	Time	sec	Real		Formula	Department of Civil and Environmental Engineering. Division of water Enviroment Technology CHALMERS UNIVERSITY OF TECHNOLOGY Göteborg, Sweden, 2009 Report Nº. 2009;1 $\omega_{N5} = \sqrt{\frac{C_{55}}{I_5 + A_{55}}} \approx \sqrt{\frac{\rho g I_{w5}}{I_5 + A_{55}}}$ in pitch. The pitch approximation can be used because the hydrodynamic stiffness dominates in pitch. A_w is the water-plane area and $I_{w5} = BL^3/12$ is the area moment in pitch of the water-plane area. For the box-like ship one can approximately write $\omega_{N5} = \sqrt{\frac{C_{55}}{I_5 + A_{55}}} \approx \sqrt{\frac{\rho g I_{w5}}{I_5 + A_{55}}} = \sqrt{\frac{\frac{\rho g}{12} BL^3}{I_5 + a_{55} L}}$ in pitch. Typical resonance periods are in heave 10 s, in roll 8 – 12 s and in pitch 10 20 s. For anchored ships the resonance periods in surge may be > 200 s, in sway > 100 s and in yaw >100 s and are highly dependent on the mooring system.	A12232 - Estimate sea-		1
A12233 - Estimate manoeuvrability									
Turning ability							A12233 - Estimate manoeuvrability		

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Turning diameter (DG)	Length	m	Real	Turning diameter is the diameter of the smallest circular turn that the ship can make.	Formula	1.Vessel with one propeller $DG = LPP\ [\ 4{,}19 - 203\ CB / DELR + 47{,}4\ TRI / LPP - 13\ B / LPP + 194 / DELR - 35{,}8\ AR / (LPP \times T) + 7{,}79\ AB / (LPP \times T)\ ]$ 2, Vessel with two propellera: $DG = LPP\ [\ 0{,}727 - 197\ CB / DELR + 4{,}65\ B / LPP + 41\ TRI / LPP + 188 / DELR - 218\ AR / (LPP \times T)\ (NTI - 1) + 1{,}77\ V / \sqrt{LPP} + 25{,}66\ AB / (LPP \times T)\ ]$ Source: "Proyecto del buque mercante MADRID 1997 FONDO EDITORIAL DE INGENIERÍA NAVAL COLEGIO OFICIAL DE INGENIEROS NAVALES" Chapter 3.6 "Maniobrabilidad"	A12233 - Estimate manoeuvrability		1
Tactical diameter (DT)	Lenght	m	Real	Tactical diameter is the distance travelled in the direction of the original course by the midship point of ship from the position at which the rudder order is given to the position at which the heading has changed 180° from the original course. It is measured in a direction perpendicular to the original heading of the ship.	Formula	1.Vessel with one propeller $DT = LPP\ (0{,}91\ DG / LPP + 0{,}234\ V / \sqrt{LPP} + 0{,}675)$ 2, Vessel with two propellera: $DT = LPP\ (0{,}14 + DG / LPP)$ Source: "Proyecto del buque mercante MADRID 1997 FONDO EDITORIAL DE INGENIERÍA NAVAL COLEGIO OFICIAL DE INGENIEROS NAVALES" Chapter 3.6 "Maniobrabilidad"	A12233 - Estimate manoeuvrability		1
Advance (ADVC)	Lenght	m	Real	Advance is the distance travelled in the direction of the original course by the midship point of ship from the position at which the rudder order is given to the position at which the heading has changed 90° from the original course.	Formula	1.Vessel with one propeller $ADVC = LPP\ (\ 0{,}519\ DT / LPP + 1{,}33\ )$ 2, Vessel with two propellera: $ADVC = LPP\ (\ 0{,}514\ DT / LPP + 1{,}10\ )$ Source: "Proyecto del buque mercante MADRID 1997 FONDO EDITORIAL DE INGENIERÍA NAVAL COLEGIO OFICIAL DE INGENIEROS NAVALES" Chapter 3.6 "Maniobrabilidad"	A12233 - Estimate manoeuvrability		1

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Course keeping ability	Non-dimensional	none	Character	The course-keeping ability is a measure of the ability of the steered ship to maintain a straight path in a predetermined course direction without excessive oscillations of rudder or heading. This parameter is related with the type of vessel.	formula	1. Tankers and bulk carriers, first angle of overshoot in the Z (zig – zag) maneuver of 10°/10° $DELO / DELR = 3{,}20\ (CB \times B / LPP + 0{,}10)$ 2. Cargo Ship, first angle of overshoot in the Z (zig – zag) maneuver of 10°/10° $DELO / DELR = 2{,}33\ (CB \times B / LPP + 0{,}14)$ 3, Tankers and bulk carriers. first angle of overshoot in the Z (zig – zag) maneuver of 20°/20° $DELO / DELR = 5{,}20\ (CB \times B / LPP + 0{,}019)$ 4,Carg $DELO / DELR = 14{,}29\ (CB \times B / LPP - 0{,}047)$ maneuver of 20°/20° Source: "Proyecto del buque mercante MADRID 1997 FONDO EDITORIAL DE INGENIERÍA NAVAL COLEGIO OFICIAL DE INGENIEROS NAVALES" Chapter 3.6 "Maniobrabilidad"	A12233 - Estimate manoeuvrability		1
Stopping ability	Length	m	Real	Stopping ability is measured by the "track reach" and "time to dead in water" realized in a stop engine-full astern manoeuvre performed after a steady approach at full test speed. This parameter is related with the distance traveled (RH) in the crash stop maneuver.	Formula	Source: "Proyecto del buque mercante MADRID 1997 FONDO EDITORIAL DE INGENIERÍA NAVAL COLEGIO OFICIAL DE INGENIEROS NAVALES" Chapter 3.6 "Maniobrabilidad" $RH = 0{,}305 \exp (0{,}773 - 5 \times 10^{5}\ PP + 0{,}617 \ln (PP)) \times DISW^{1/3}$	A12233 - Estimate manoeuvrability		1
A1224 Create preliminary structure design									
A12241 Calculate longitudinal strength									
Weight distribution curve	Mass	tons/m	Real	The curve plots the weight of each structure and equipment with respect its location along the length of the ship.	Graph	calculated by existing software	A12241-Calculate longitudinal strength		2
Buoyancy curve	Mass	tons/m	Real	The curve plots the buoyancy force with respect its location along the length of the ship.	Graph	calculated by existing software	A12241-Calculate longitudinal strength		2

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
Shear force curve	Force	tons	Real	The integral of the load curve (the difference between the weight distribution curve and the buoyancy curve).	Graph	calculated by existing software	A12241-Calculate longitudinal strength		2
Bending moment curve	Moment	tons*m	Real	The integral of the shear force curve.	Graph	calculated by existing software	A12241-Calculate longitudinal strength		2
A12242 Define midship section scantlings									
Midship section modulus	Length	cm^3	Real	Section modulus of the main	Formula	calculated by existing software	A12242-Define midship		2
Section area of main frame	Length	m^2	Real	Section area of main frame	Formula	calculated by existing software	A12242-Define midship		2
Section modulus of a cross-section of frame	Length	cm^3	Real	Section modulus of the specific	Formula	calculated by existing software	A12243-Define other		2
Section area of a cross-section of frame	Length	m^2	Real	Section area of a cross-section of	Formula	calculated by existing software	A12243-Define other		2
A12243 Define other transverse sections scantlings									
A12244 Carry out preliminary superstructures structural design									
A1225 Create preliminary machinery									
A12251 Select main engine									
Main engine type (slow, medium speed)	Non-dimensional	None	Character		Specific value	User defined. Depends mainly on ship type and route. Selection based on standard practice (e.g. "Marine Diesel and Power Plant Practices", The Society of Naval Architects and Marine Engineers (SNAME), Technical & Research Bulletin No. 3-49, 1990, p. 6,	A12251 Select main engine		2
Main engine service rating (for non derated engines only)					Specific value	User defined (determined together with main engine selection)	A12251 Select main engine		1
Fuel type (HFO, Diesel/Gas Oil, LNG, Dual fuel)	Non-dimensional	None	Character		Specific value	User defined Depends on engine type and route.	A12251 Select main engine		2
Sulphur content in heavy fuel (YES/NO)	Non-dimensional	None	Real		Specific value	User defined Depends on engine type and route.	A12251 Select main engine		2
Sulphur content in diesel oil or gas oil (YES/NO)	Non-dimensional	None	Real		Specific value	User defined Depends on engine type and route.	A12251 Select main engine		2
Derated 2 stroke main engine? (YES/NO)	Non-dimensional	None	Character		Specific value	User defined Depends on engine type.	A12251 Select main engine		2
Fuel optimised main engine? (YES/NO)	Non-dimensional	None	Character		Specific value	User defined Depends on engine type.	A12251 Select main engine		2

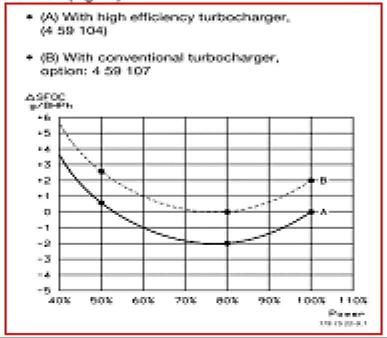
Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
TIER 1, 2 or 3 engine? (1 - 3)	Non-dimensional	None	Integer		Specific value	User defined Depends on engine type. See IMO "1997 Protocol" to MARPOL, Annex VI (Tier I) and 2008 Annex VI Amendments (Tier II/III).	A12251 Select main engine		2
NOx reduction technology: (Exhaust Gas Recirculation, Selective Catalyic Reduction, other)	Non-dimensional	None	Character		Specific value	User defined Depends on engine type and route.	A12251 Select main engine		2
Use of scrubbers if oil is used (YES/NO)	Non-dimensional	None	Character		Specific value	User defined Depends on engine type and route.	A12251 Select main engine		2
A12252 Design transmission system									
Reduction gear type	Non-dimensional	None	Character		Table	User defined (determined together with main engine selection)	A12252 Design transmission system		2
Reduction ratio	Non-dimensional	None	Integer		Specific value	User defined (determined together with main engine selection)	A12252 Design transmission system		1
A12253 Select auxiliary equipment									
Gen set Power	Power	kW	Real		Formula	User defined $P_e(kW) = 100 + 0.55 \cdot Main\ Engine\ Power(kW)^{0.7}$ Marine Diesel Power Plant Practices 1990 SNAME	A12253 Select auxiliary equipment		1
A1226 Create preliminary oufitting design									
A12261 Calculate equipment number									
Equipment number	Non-dimensional	n/a	Integer	A dimensionless parameter used to determine the size and number of anchors and chain cables for a new ship.	Formula	calculated using the following formula ("Common structural rules for oil tankers", IACS, 2008).	A12261-Calculate Equipment number		2
A12262 Generate equipment list									
Pending assignment to activity									
Damage stability criteria									
Still water and wave induced loads??									
Buckling??									
Fatigue??									
Ultimate strength??									
Vessel information									
Flag and Register port	Non-dimensional		Character						
Class (if applicable)	Non-dimensional		Character						
Maximun Bending moments	Moment	kNm	Real						
Maximun Shear Force	Force	kN	Real						

SHIPLYS

A124 Calculate cost of ship

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
A1241 Calculate cost of design (Design)										
Labour cost	Currency	Euros	Real	labour cost per hour	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1241	1		
Existing designs purchase	Currency	Euros	Real	cost for the purchase of existing designs	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1241	1		
Software cost	Currency	Euros	Real	cost for the purchase of software	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1241	1		
Database cost	Currency	Euros	Real	cost for the purchase of databases	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1241	1		
Design procedures energy footprint	Currency	Energy units, CO2, euros	Real	Total energy footprint of the design procedures, i.e. energy footprint from the use of software/hardware	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1241	1		
Classification cost	Currency	Euros	Real	cost for classification	Specific value	cost quote from classificaiton society	A1241	1		
A1242 Calculate cost of construction (Construction)										
Cost of materials per ton for structures / compartment	Mass	ton	Real	cost of structural/compartment materials	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1242 Calculate cost of construction	1		
steel used for construction	Mass	ton	Real	cost of structural/compartment materials	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1242	1		
aluminium used for construction	Mass	ton	Real	cost of structural/compartment materials	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1242	1		
plastics used for construction	Mass	ton	Real	cost of structural/compartment materials	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1242	1		
Cost of machinery	Currency	Euros	Real	cost of machinery	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1242	1		
Cost of equipment	Currency	Euros	Real	analytical cost of equipment or cost per ton when analytical data is not available	Specific value	costs database/Input from the SMEs	A1242	1		
Cost of outfitting	Currency	Euros	Real	analytical cost of outfitting or cost per ton when analytical data is not available	Specific value	costs database/Input from the SMEs	A1242	1		
Cost of piping	Currency	Euros	Real	analytical cost of piping or cost per ton when analytical data is not available	Specific value	costs database/Input from the SMEs	A1242	1		
Cost of wiring	Currency	Euros	Real	analytical cost of wiring or cost per unit length when analytical data is not available	Specific value	costs database/Input from the SMEs	A1242	1		
Cost of engine/ER	Currency	Euros	Real	cost of the main engine	Specific value	costs database/Input from the shipyards	A1242	1		
Cost of machinery	Currency	Euros	Real	cost of the various machinery	Specific value	costs database/Input from the shipyards	A1242	1		
Welding length	Currency	Euros	Real	total length of welds	Specific value	design tool	A1242	1		
Welding cost per meter	Currency	Euros	Real	welding cost per meter	Specific value	costs database/Input from the shipyards	A1242	1		
Cutting Steel/Cost per m length	Currency	Euros	Real	cutting cost per meter	Specific value	costs database/Input from the shipyards	A1242	1		
Sanding Steel/Cost per m2	Currency	Euros	Real	sanding cost per m2	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1242	1		
Shipyard average energy consumptions	Power	kW/day	Real	Average energy consumptions of all shipyard's procedures	Specific value	Shipyard's database	A1242	1		

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
Average waste for the ship construction	Mass	ton,m3	Real	Total waste/sludge/garbage of various procedures in the shipyard	Specific value	Shipyard's database	A1242	1		
Average Paint used/painting costs	Mass	kg,m3,currency	Real	Average paint used or total painting costs	Specific value	Shipyard's database	A1242	1		
Other Chemicals	Mass	kg,m3	Real	Other chemicals used costs	Specific value	Shipyard's database	A1242	1		
Labour cost	Currency	Euros	Real	Overall labour cost	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1242	1		
Cost of steel per ton	Currency	Euros	Real	cost of structural/compartment materials	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1242	1		
Cost of aluminium per ton	Currency	Euros	Real	cost of structural/compartment materials	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1242	1		
Cost of plastics per ton	Currency	Euros	Real	cost of structural/compartment materials	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1242	1		
Cost of wood per ton	Currency	Euros	Real	cost of structural/compartment materials	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1242	1		
Indicative Construction Profit	Currency	euro		indicative ratios attributed to Large, Medium and Small enterprises. Calculations carried out on actual information supplied by market statistics	Specific value	user defined: indicative ratios attributed to Large, Medium and Small enterprises. Calculations carried out on actual information supplied by market statistics $Profit\ Margin = \frac{Revenues - Construction\ Cost}{Revenues} \times 100$	A1242	1		
Indicative Construction Overhead	Percentage	%		Construction overhead costs are defined as the percentage of the construction's cost that the contractor failed to adequately project	Specific value	user defined: Construction overhead costs are defined as the percentage of the construction's cost that the contractor failed to adequately project $Overhead\ Costs = \frac{Actual\ cost - Predicted\ cost}{Actual\ cost}\ x\ 100$	A1242	1		
Required net profitability rate	Percentage	%		Net profit ratio is a profitability ratio that shows relationship between net profit after tax and net sales.	Specific value	user defined: Net profit ratio is a profitability ratio that shows relationship between net profit after tax and net sales. The required net profit ratio (margin) is estimated as: $Net\ Profit\ Ratio = \frac{Net\ profit\ after\ tax}{Net\ sales} \times 100$	A1242	1		
A1243 Calculate cost of operation										
Average sailing days per year loaded	Date	days	Real	Average sailing days per year based on ship schedule	Specific value	Ship operating scenario	A1243 Calculate cost of	1		
Average sailing days per year in ballast	Date	days	Real	Average sailing days per year based on ship schedule	Specific value	Ship operating scenario	A1243	1		
Average days per year at port loading	Date	days	Real	Average days at port per year based on ship schedule	Specific value	Ship operating scenario	A1243	1		

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
Average days per year at port discharging	Date	days	Real	Average days at port per year based on ship schedule	Specific value	Ship operating scenario	A1243	1		
Average days per year idling or at anchorage	Date	days	Real	Average idling or at anchorage days per year based on ship schedule	Specific value	Ship operating scenario	A1243	1		
Average days per year for maintenance/dry-docking/surveys	Date	days	Real	Average maintenance days per year based on ship schedule	Specific value	Ship maintenance scenario	A1243	1		
Crew number/position	Volume	number	Integer	Crew members per position	Specific value	Input from flag	A1243	1		
Average daily fuel /lube oil/other consumables consumption when sailing loaded	Mass	ton/day	Real	Average consumptions	Table	Engine/machinery database and project guide:curve of engine load vs SFOC (Figure) 	A1243	1		
Crew wages & fees	Currency	Euros	Real	Wages and fees for crew members	Table	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.) http://marinecrewwages.blogspot.co.uk/	A1243	1		
Average daily fuel/lube oil/other consumables consumption when sailing in ballast	Mass	ton/day	Real	Average consumptions	Graph	Engine/machinery database and project guide:curveof engine load vs SFOC	A1243	1		
Average daily fuel/lube oil/other consumables consumption when at port loading	Mass	ton/day	Real	Average consumptions	Graph	Engine/machinery database and project guide:curveof engine load vs SFOC	A1243	1		
Average daily fuel/lube oil/other consumables consumption when at port discharging	Mass	ton/day	Real	Average consumptions	Graph	Engine/machinery database and project guide:curveof engine load vs SFOC	A1243	1		
Average daily fuel/lube oil/other consumables consumption when Idling/anchorage	Mass	ton/day	Real	Average consumptions	Graph	Engine/machinery database and project guide:curveof engine load vs SFOC	A1243	1		
Average waste/sludge/garbage produced	Mass	tons	Real	Average waste/sludge/garbage produced	Table	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.) emsa.europa.eu/news-a-press-centre/external-news/download/4557/2925/23.html	A1243	1		
Cost per ton fuel oil	Currency	tons	Real	Fuel/oil cost	Table	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.) http://www.bunkerindex.com/index.php	A1243	1		
Port duties	Currency	Euros	Real	Port duties	Specific value	Ports/End-user entry	A1243	1		
Docking cost	Currency	€	Real	Docking cost	Specific value	Shipyards/End-user entry	A1243	1		
Depreciation applicable	Percentag	%	Real	Depreciation applicable	Specific value	End-user entry	A1243	1		
Cargo insurance cost	Currency	Euros	Real	Cargo insurance cost	Specific value	End-user entry	A1243	1		

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
Ship insurance cost	Currency	Euros	Real	Ship insurance cost	Specific value	End-user entry	A1243	1		
Administrative costs	Currency	Euros	Real	Administrative costs	Specific value	End-user entry	A1243	1		
SFOC change due to engine type (%) derated versus normal	Percentage	%	Real	SFOC change due to engine type (%) derated versus normal engine	Specific value	Engine constructor	A1243	1		
Extra energy demand due to scrubber (%)	Percentage	%	Real	Extra energy demand due to scrubber (%)	Specific value	Shipyards	A1243	1		
Extra energy demand due to Nox reducing EGR technology (%)	Percentage	%	Real	Extra energy demand due to Nox reducing EGR technology (%)	Specific value	Shipyards	A1243	1		
Income tax rate	Percentage	%		Tax rate is imposed by the government of each country where the shiyard is located.	Specific value	user defined: Tax rate is imposed by the government of each country where the shiyard is located.	A1243	1		
Tax correction, CRFT	Currency	euro		Tax return is estimated by the tax system of each country that the shipyard is located.	Specific value	user defined: Tax return is estimated by the tax system of each country that the shipyard is located.	A1243	1		
A1244 Calculate cost of maintenance/retrofitting/risk										
(Maintenance)										
Optimal replacement interval	Date	Time	Real	Optimal replacement interval	Specific value	Shipyard	A1244 Calculate cost of maintenance/ret	1		
Optimal replacement age	Date	Time	Real	Optimal replacement age	Specific value	Shipyard	A1244	1		
Optimal inspection interval to maximize the availability	Date	Time	Real	Optimal inspection interval to maximize the availability	Specific value	Shipyard	A1244	1		
Assessment of condition prior to maintenance/ repair and after	Currency	Euros	Real	Some methology will be required to assess condition. Basically what we need is: cost of repair/ maintenance and improvement in condition after such action is carried out. If there are multiple conditions possible post-action, then a probabilistic assessment will need to be taken by allocating probability to each state (condition). In terms of structural reliability, what is the impact of repair on Beta? Connected to 'Degradation' profile in	Other	Databases at shipyards; Classification bodies? Expert judgement	A1244	1		
Date of assessment	Date	Time	Real	Date of assessment	Other	End-user entry	A1244	1		
Average paint/chemicals consumed per year for scheduled & unscheduled	Volume	kg,m3	Real	Average paint/chemicals consumed per year for scheduled & unscheduled maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1244	1		
Average paint/chemicals consumed during dry-docking/repair period	Volume	kg,m3	Real	Average paint/chemicals consumed during dry-docking/repair period	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1244	1		
Spares cost during dry-docking/repair period	Currency	Euros	Real	Spares cost during dry-docking/repair period	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1244	1		

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
Spares cost for scheduled & unscheduled maintenance	Currency	Euros	Real	Spares cost for scheduled & unscheduled maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1244	1		
Average waste during maintenance	Mass	tons,m3	Real	Wastes due to maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1244	1		
Average energy consumed	Energy	kW	Real	Energy footprint of the maintenance procedures	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1244	1		
Cost of preventive maintenance	Currency	€/hour	Real	Cost of preventive maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1244	1		
Cost of corrective maintenance	Currency	€/hour	Real	Cost of corrective maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1244	1		
(Retrofitting)										
Description of the system(s) to retrofit	Volume	items	Character	retrofit process is engineering process of the vessel, which in many cases could involve fundamental changes in the architecture, functionality or operation of the vessel, but the nature of repair and retrofitting projects differs substantially from long-term new building projects.	Other	Shipyard's database	A1244	1		
Energy consumption for the installation of the equipment	Energy	kW	Real	It is the efficient use of energy, in this way optimizing the production processes and the use of energy using the same or less to produce more goods and services efficient.	Specific value	Shipyard's database	A1244	1		
Cost of Guaranty	Currency	€	Real	Cost that is not earned or incurred by not doing things well in the first time	Specific value	Shipyard's database	A1244	1		
Cost of cleaning	Currency	€/h	Real	how much is your cleaning fee per hour in the vessel the jobs specific.	Specific value	Shipyard's database	A1244	1		
Cost of insurance	Currency	€	Real	An economic contribution to be paid by an insured or contractor to an insurance company for the transfer of risk under the coverages that the latter offers its clients during a certain period of time	Specific value	Shipyard's database	A1244	1		
Cost of testing	Currency	€	Real	Cost of checking that a job meets the contracted specifications	Specific value	Shipyard's database	A1244	1		
Labor Cost (include financial cost)	Currency	€/h	Real	It is known as labor to both physical and mental effort that is applied during the process of making a good. In the field of business accounting, labor is understood as the absolute cost linked to workers	Specific value	Shipyard's database	A1244	1		

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
Cost equipment and outfitting	Currency	€	Real	cost the main equiptmen and auxiliary sistems (example principal motor, auxiliary motor, electrical, air condicional, etc..)	Specific value	Shipyard's database	A1244	1		
cost material	Currency	€/ton	Real	Cost of raw materials consumed in the industrial process retroffiting/repair or new construction	Specific value	Shipyard's database	A1244	1		
Cost of commissioning	Currency	€/h	Real	Cost of testing a complete contracted system works correctly before delivering to the customer	Specific value	Shipyard's database	A1244	1		
Cost environmental inspection	Currency	€/tons €/m³ €	Real	They are those that are incurred, because there is or can be a poor environmental quality. These costs are associated with the creation, detection, remedy and prevention of environmental degradation	Specific value	Shipyard's database	A1244	1		
Cost safety engineering inspections	Currency	€/h	Real	Cost arising from or to prevent accidents at work	Specific value	Shipyard's database	A1244	1		
Inspection retrofitting	Currency	€/hour	Real	Cost derived from the monitoring of the work	Specific value	Shipyard's database	A1244	1		
Number of year of ship operation	Date	Time		The year in the life of a ship that retrofiting is selected	Specific value	user defined: The year in the life of a ship that retrofiting is selected	A1244, A1274	2		
A1245 Calculate cost of scrapping										
Transport to scrap yard	Currency	euros	Real	Total cost of transport to scrap yard	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1245 Calculate cost of scrapping	1		
Scrap material	Currency	Euros per ton	Real	Profit from selling the remaining materials	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1245	1		
Scrap recycled	Currency	Euros per ton	Real	Cost/profit of the materials recycled	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1245	1		
Equipment reused	Currency	Euros per ton	Real	Profit from reusing equipment of the ship	Specific value	costs database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1245	1		
Cost environmental inspection	Currency	€/tons €/m³ €	Real	They are those that are incurred, because there is or can be a poor environmental quality. These costs are associated with the creation, detection, remedy and prevention of environmental degradation	Specific value	Shipyard's database	A1244	1		
Cost safety engineering inspections	Currency	€/h	Real	Cost arising from or to prevent accidents at work	Specific value	Shipyard's database	A1244	1		
Labor Cost (include financial cost)	Currency	€/h	Real	It is known as labor to both physical and mental effort that is applied during the process of making a good. In the field of business accounting, labor is understood as the absolute cost linked to workers	Specific value	Shipyard's database	A1244	1		

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
General Information										
Average annual inflation rate	Percentage	%		inflation rate predictions are used for estimating present value of future prices (costs & incomes). Usually historic data and financial forecast are used to predict future iflation	Specific value	user defined: inflation rate predictions are used for estimating present value of future prices (costs & incomes). Usually historic data and financial forecast are used to predict future iflation rates.	A1242, A1243, A1244, A1245	1		
Life span of the ship	Date	Years		Estimated life of the ship according to ship designs, O&M	Specific value	user defined: Estimated life of the ship according to ship designs, O&M	A1241, A1242, A1243, A1244,	1		
Interest rate	Percentage	%		Interest rate for raising loans is imposed by the banking system of each country where the shipyard is located.	Specific value	user defined: Interest rate for raising loans is imposed by the banking system of each country where the shipyard is located.	A1242, A1243, A1244	1		

A126 Create preliminary design for retrofitting purposes

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence (scale 0 to 2, 0 meaning user estimation and 2 meaning fully validated data)
A1261 Create preliminary machinery and outfitting design via scanning 3-D									
File of scanning area for 3D Model	Non-dimmensioal		Real	This parameter is a data group that they are useful to introduce in Shiplys tools	Other	Shipyard's database	A1261		1
A1262 Create preliminary machinery and outfitting design via 2-D drawings									
Equipment information of the retrofitting	Non-dimmensional		Real	This parameter is an output of Faro software and define all the spaces that are necessary for retrofitting works	Worksheet	Shipyard's database	A1262 and A1263		1
Dimensions data	Length	m	Real	Define the data group of dimensions that it is necessary for carry out the retrofitting	Specific value	Shipyard's database	A1262		1
2D Final model	Length	m	Real	Data file that include the model and basic dimmensions of the retroffitng	Other	Shipyard's database	A1262		1
Coordination Drawings	Non-dimmesional		Real	Group of drawings (2D or 3D) that they are neccesary for the retrofittig	Other	Shipyard's database	A1262 and A1263		1
Material list data	Non-dimmensional		Real	Material list is necessary to define the offer. It is useful for define the cost of the retrofiting in terms of material.	Worksheet	Shipyard's database	A1263		1
Material characteristics for Retrofitting	Non-dimmensioal		Real	This parameter define the type of material that retrofitting works used. Exist differents options of materials for carry out the retrofitting works and it is necessary to know it.	Worksheet	Shipyard's database	A1264		2
Basic dimensions of the retrofitting	Length	m	Real	This parameter define the dimmensions of the retrofitting	Specific value	Shipyard's database	A1262 and A1263		1
Retrofitting requeriment	Mass/Lenght/Volume	kg/m/m^3	Real		Worksheet	Shipyard's database	A1262 and A1263		1
A1263 Create preliminary machinery and outfitting design via 3-D drawings									
3D Final model	Length and volume	m or m^2	Real	Data file that include the model and basic dimmensions of the retroffitng	Other	Shipyard's database	A1262		0

A127 Estimation of environmental impact

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
A1271 Estimate environmental impact of										
Average waste for the ship construction	Mass	ton,m3	Real	Total waste/sludge/garbage of various procedures in the shipyard	Specific value	Shipyard's database	A1271	1		
Construction emissions	Mass	kg (CO2)	Real	Emission conversion to CO2	Specific value	Shipyard's database	A1271	1		
CO2 emission factor	Mass	g/kW/hour	Real	Emissions due to ship construction	Specific value	Shipyard's database	A1271	1		
Nox emission factor	Mass	g/kW/hour	Real	Emissions due to ship construction	Specific value	Shipyard's database	A1271	1		
CO emission factor	Mass	g/kW/hour	Real	Emissions due to ship construction	Specific value	Shipyard's database	A1271	1		
HC emission factor	Mass	g/kW/hour	Real	Emissions due to ship construction	Specific value	Shipyard's database	A1271	1		
Particulates factor	Mass	g/kW/hour	Real	Emissions due to ship construction	Specific value	Shipyard's database	A1271	1		
SO2 emission factor	Mass	g/kW/hour	Real	Emissions due to ship construction	Specific value	Shipyard's database	A1271	1		
Other Chemicals	Mass	kg,m3	Real	Other chemicals used costs	Specific value	Shipyard's database	A1271	1		
Shipyard average energy consumptions	Energy	kW/day	Real	Average energy consumptions of all shipyard's procedures	Specific value	Shipyard's database	A1271	1		
A1272 Estimate environmental impact of										
Average sailing emissions	Mass	tons,m3	Real	Emissions due to ship operation	Formula	Ship operating scenario: $\sum_{1}^{n} \mathit{Quantity\ of\ emission}_n = \sum_{1}^{n} \mathit{Constant\ of\ emission}_n * \mathit{Engine\ Power} * \mathit{Operation\ hour}$	A1272 Estimate environmental impact of operation	1		
CO2 emission constant	Mass	g/kW/hour	Real	Emissions due to ship operation	Specific value	Ship operating scenario	A1272	1		
Nox emission constant	Mass	g/kW/hour	Real	Emissions due to ship operation	Specific value	Ship operating scenario	A1272	1		
CO emission constant	Mass	g/kW/hour	Real	Emissions due to ship operation	Specific value	Ship operating scenario	A1272	1		
HC emission constant	Mass	g/kW/hour	Real	Emissions due to ship operation	Specific value	Ship operating scenario	A1272	1		
Particulates constant	Mass	g/kW/hour	Real	Emissions due to ship operation	Specific value	Ship operating scenario	A1272	1		
S content in oil	Percentag	%	Real	Emissions due to ship operation	Specific value	Ship operating scenario	A1272	1		
SO2 emission constant	Mass	g/kW/hour	Real	Emissions due to ship operation	Specific value	Ship operating scenario	A1272	1		
fuel calorific value	Energy	MJ/kg fuel	Real	Emissions due to ship operation	Specific value	Ship operating scenario	A1272	1		
Oil calorific value	Energy	MJ/kg oil	Real	Emissions due to ship operation	Specific value	Ship operating scenario	A1272	1		
LNG calorific value	Energy	MJ/kg LNG	Real	Emissions due to ship operation	Specific value	Ship operating scenario	A1272	1		
Average emissions at port	Mass	tons,m3	Real	Emissions of the ship at port	Formula	Ship operating scenario: $\sum_{1}^{n} \mathit{Quantity\ of\ emission}_n = \sum_{1}^{n} \mathit{Constant\ of\ emission}_n * \mathit{Power\ at\ Port} * \mathit{Operation\ hour}$	A1272 Estimate environmental impact of	1		
CO2 emission constant	Mass	g/kW/hour	Real	Emissions of the ship at port	Specific value	Ship operating scenario	A1272	1		
Nox emission constant	Mass	g/kW/hour	Real	Emissions of the ship at port	Specific value	Ship operating scenario	A1272	1		

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Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
CO emission constant	Mass	g/kW/hour	Real	Emissions of the ship at port	Specific value	Ship operating scenario	A1272	1		
HC emission constant	Mass	g/kW/hour	Real	Emissions of the ship at port	Specific value	Ship operating scenario	A1272	1		
Particulates constant	Mass	g/kW/hour	Real	Emissions of the ship at port	Specific value	Ship operating scenario	A1272	1		
S content in oil	Percentag	%	Real	Emissions of the ship at port	Specific value	Ship operating scenario	A1272	1		
SO2 emission constant	Mass	g/kW/hour	Real	Emissions of the ship at port	Specific value	Ship operating scenario	A1272	1		
Fuel calorific value	Energy	MJ/kg fuel	Real	Emissions of the ship at port	Specific value	Ship operating scenario	A1272	1		
Oil calorific value	Energy	MJ/kg oil	Real	Emissions of the ship at port	Specific value	Ship operating scenario	A1272	1		
LNG calorific value	Energy	MJ/kg LNG	Real	Emissions of the ship at port	Specific value	Ship operating scenario	A1272	1		
Calorific value of fuel	Energy	MJ/kg fuel		calorific value of a substance (fuel, oil, LNG) is the amount of heat released during the combustion of a specified amount of it. The energy value is a characteristic for each substance. It is measured in units of energy per unit of the substance	Specific value	http://www.kayelaby.npl.co.uk/chemistry/3_11/3_11_4.html	A1272	1		
Calorific value of oil	Energy	MJ/kg oil		calorific value of a substance (fuel, oil, LNG) is the amount of heat released during the combustion of a specified amount of it. The energy value is a characteristic for each substance. It is measured in units of	Specific value	http://www.kayelaby.npl.co.uk/chemistry/3_11/3_11_4.html	A1272	1		
Calorific value of LNG	Energy	MJ/kg LNG		calorific value of a substance (fuel, oil, LNG) is the amount of heat released during the combustion of a specified amount of it. The energy value is a characteristic for each substance. It is measured in units of	Specific value	http://unitrove.com/engineering/tools/gas/natural-gas-calorific-value	A1272	1		

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
Nox TIER 1,2,3	Mass	tons		The IMO emission standards are commonly referred to as Tier I, II & III standards. The Tier I standards were defined in the 1997 version of Marpol Annex VI, while the Tier II/III standards were introduced by Annex VI amendments adopted in 2008.	Specific value	http://www.imo.org/EN/Pages/Default.aspx	A1272	2		
A1273 Estimate of environmental impact of maintenance										
Maintenance emissions	Mass	tons,m3	Real	Emissions due to maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1273	1		
CO2 emission	Mass	g/kW/hour	Real	Emissions due to maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1273	1		
Nox emission	Mass	g/kW/hour	Real	Emissions due to maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1273	1		
CO emission	Mass	g/kW/hour	Real	Emissions due to maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1273	1		
HC emission	Mass	g/kW/hour	Real	Emissions due to maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1273	1		
Particulates	Mass	g/kW/hour	Real	Emissions due to maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1273	1		
S content in oil (%)	Percentag	%	Real	Pollution due to maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1273	1		
SO2 emission (g/kW/hour)	Mass	g/kW/hour	Real	Emissions due to maintenance	Specific value	Maintenance database (GaBi, CML, ECO-REFITEC, RECIPE etc.)	A1273	1		
A1274 Estimate of environmental impact of retrofitting										

Tier	Date	NOx Limit, g/kWh		
		n < 130	130 ? n < 2000	n ? 2000
Tier I	2000	17.0	$45 \cdot n^{-0.2}$	9.8
Tier II	2011	14.4	$44 \cdot n^{-0.23}$	7.7
Tier III	2016†	3.4	$9 \cdot n^{-0.2}$	1.96

† In NOx Emission Control Areas (Tier II standards apply outside ECAs).

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
Energy consumption for the installation of the equipment	Energy	kW	Real	It is the efficient use of energy, in this way optimizing the production processes and the use of energy using the same or less to produce more goods and services efficient.	Specific value	Shipyard's database	A1274	1		
Retrofitting Emissions	Mass	tons,m3	Real	the amount of emissions (CO2, S, etc..emitted into the atmosphere	Specific value	Shipyard's database	A1274	1		
Particulate reduction (%)	Percentag	%	Real	the amount of suspended particles emitted into the atmosphere and after retroffiting % reduction	Specific value	Shipyard's database	A1274	1		
SO2 reduction (%)	Percentag	%	Real	the amount of emissions (So2 emitted into the atmosphere and after retroffiting % reduction	Specific value	Shipyard's database	A1274	1		
Total change of SFOC	Percentag	%		Specific Fuel Oil Consumption is the consumtion of fuel oil per unit energy at output shaft. For retrofiting procedures the change in SFOC will be estimated.	Specific value	user defined: Specific Fuel Oil Consumption is the consumtion of fuel oil per unit energy at output shaft. For retrofiting procedures the change in SFOC will be estimated. $SFOC = \frac{\text{Mass of fuel consumed per hour}}{\text{Break power in that particular hour}}$	A1274	1		
Number of year of ship operation	Date	Time		The year in the life of a ship that retrofiting is selected	Specific value	user defined: The year in the life of a ship that retrofiting is selected	A1244, A1274	2		
A1275 Estimate of environmental impact of										
Average scrapping emissions	Mass	tons,m3	Real	Emissions due to scrapping	Specific value	GaBi database/shipyard's database	A1275	1		
CO2 emission	Mass	g/kW/hour	Real	Emissions due to scrapping	Specific value	GaBi database/shipyard's database	A1275	1		
Nox emission	Mass	g/kW/hour	Real	Emissions due to scrapping	Specific value	GaBi database/shipyard's database	A1275	1		
CO emission	Mass	g/kW/hour	Real	Emissions due to scrapping	Specific value	GaBi database/shipyard's database	A1275	1		

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
HC emission	Mass	g/kW/hour	Real	Emissions due to scrapping	Specific value	GaBi database/shipyard's database	A1275	1		
Particulates	Mass	g/kW/hour	Real	Emissions due to scrapping	Specific value	GaBi database/shipyard's database	A1275	1		
SO2 emission (g/kW/hour)	Mass	g/kW/hour	Real	Emissions due to scrapping	Specific value	GaBi database/shipyard's database	A1275	1		

A128 Estimation of risk

Activity	Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Input to (to which ISO activity node or tool this parameter is input	Level of confidence (scale 0 to 2, 0 meaning user estimation and 2 meaning fully validated data)	Time reference (when these costs were estimated/defined) DD/MM/YY	Geographical reference (where these costs were estimated/defined)
A1281 Identify hazard											
A1282 Assess risk											
A1283 Estimate risk control options											
A1284 Assess cost benefit											
A1285 Recommend and make decision											
	Risk Assessment										
	Cost of cargo loss										
	Cost of human life loss										
	Cost of accidental spills										
	Severity of structural degradation										
	Probability of structural degradation										
	Probability of components failure										

A129 Perform preliminary planning of production

Parameter	Physical quantity	Unit (of value of the parameter)	Type (parameter type)	Short description	Source type	Source or link to source (i.e. link to pdf, worksheets, tables, etc.)	Related to (to which ISO activity this parameter is related)	Flow designation (designation of the flow lines that connect the parameter to the activity node)	Level of confidence
A1291 Determine preliminary work breakdown structure and estimate material requirements									
Raw materials	Mass	kg	Real		Specific value		A1291		1
Block division	Non-Dimmesional	Character	Real		Specific value		A1291		1
Section division	Non Dimmensional	Character	Real		Specific value		A1291		1
A1292 Estimate production schedule									
A12921 Estimate production sequence start and end dates									
Start date production	Time	Date- Character	Real		Specific value		A12921		1
Finish date production	Time	Date- Character	Real		Specific value		A12921		1
A12922 Estimate delivery dates of raw material									
Delivery date raw of material	Time	Date- Character	Real		Specific value		A12922		1
Delivery dates of material for production	Time	Date- Character	Real		Specific value		A12923		1
A12922 Estimate delivery dates of master equipment and main outfitting components									
Delivery dates of main outfitting components	Time	Date- Character	Real		Specific value		A12923		1
A1293 Estimate capacity requirements									
Feasibility studies	Non Dimmensional	Character	Real		Specific value		A1293		1
Capacity requirements	Non Dimmensional	Character	Real		Specific value		A1293		1
Technology requirements	Non Dimmensional	Character	Real		Specific value		A1293		1
Subcontracting data	Non Dimmensional	Character	Real		Specific value		A1293		1