Challenges and problems with data availability and quality during LCCA calculations in the early ship design phases

Panagiotis Evangelou, Christos Papaleonidas, Dimitrios V. Lyridis, Nicholas Tsouvalis & Pantelis Anaxagorou
National Technical University of Athens (NTUA), Athens, Greece

ABSTRACT: This paper identifies the challenges and problems linked with data availability and quality, necessary for **Life Cycle Cost Analysis (LCCA)** calculations via a concise literature review and expert input. Naval architects, shipbuilders and ship-owners constantly need to improve their capability to produce better ship concepts, adopt innovative ship designs and reduce costs of design and production, taking into consideration the increasing requirements for **LCCA**. However, the necessary data is either limited or cannot be obtained cheaply when the priority is to conduct reliable calculations in the limited time available. This paper will provide an overview of the aforementioned data sources, a general assessment of the quality of data available, and will propose solutions or ways to overcome or circumvent data limitations to the various problems described, so that a reasonably realistic implementation of a life cycle approach can be achieved.

1 INTRODUCTION

During the early design stages, LCCA calculations enable the evaluation of various alternative designs, estimating all costs created through the ship's life cycle phases (design, construction, operation, scrapping) and its' environmental impact. LCCA methodologies require availability of up-to-date data in order to provide safe estimations of lice cycle costs and the environmental footprint of a ship's life from its construction to its dismantling (Magerholm & Sørgård 1999).

Existing LCCA methodologies, like CMLCA and ReCiPe, use or have created extended databases with numerous of information about costs involved in the life of a ship and calculations for performing environmental assessment of the ship's life phases. CMLCA is a software tool developed by the Institute of Environmental Sciences of Leiden University, that supports the calculation of (CMLCA website May 2017):

- life cycle assessment (LCA), including social life cycle assessment (SLCA) and life cycle sustainability assessment (LCSA)
- input-output analysis (IOA), including environmental input-output analysis (EIOA)
- life cycle costing (LCC) and eco-efficiency analysis (E/E)
- hybrid LCA, combining LCA and EIOA

ReCiPe is a life cycle impact assessment method created by RIVM, CML, PRé Consultants and Radboud Universiteit Nijmegen. ReCiPe comprises harmonised category indicators at the midpoint and the endpoint level (RIVM website May 2017).

The availability of adequate data and the quality of these data has been on the center of the work conducted for the Ship Lifecycle Software Solutions (SHIPLYS) project. One of the goals of the project is the development of databases with updating facility to meet the requirements of the developed rapid virtual prototyping and life cycle tools (SHIPLYS Grant Agreement 2016).

2 SHIPLYS PROJECT

SHIPLYS is a three-year research project that started in September 2016. The main objective of the 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) for the respective ship as well as an environmental assessment, risk assessment and end-of-life considerations (SHIPLYS Grant Agreement 2016).

Project data availability and quality assessment will be conducted, in order to develop databases to be used in the implementation of the developed tools.

3 PRELIMINARY SHIP DESIGN

Ship design procedures aim to the creation of a product that fulfils the requirements of the ship owner and the expectations of the shipping market. Ship design may be considered decomposed into four main phases (Papanikolaou 2014):

a. Concept design—Feasibility study
b. Preliminary design
c. Contract design
d. Detailed design

The first two phases of the ship design (a and b), which are also known as basic design, are often merged into the more general definition of preliminary ship design (Papanikolaou 2014).

Preliminary ship design presents the main characteristics of the designed vessel, taking into consideration regulations and restrictions. Furthermore, it provides estimations of the general arrangement of the ship, profile and decks, machinery list, transport capacity, efficiency etc. and it enables uniform approaches.

In the early ship design phase are also introduced innovative design concepts, energy efficiency and environmental impact estimations.

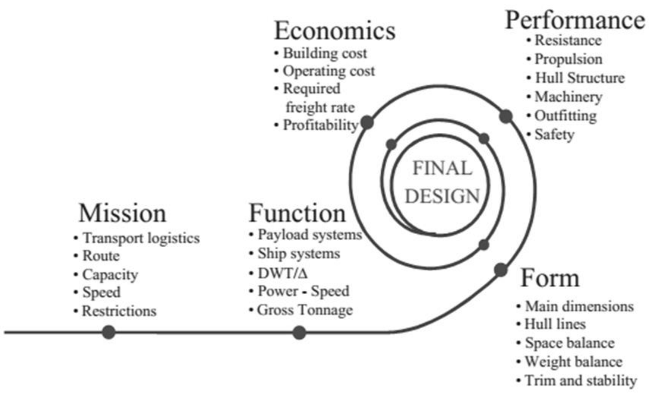

Figure 1. Ship design procedure (Papanikolaou 2014)

The main objectives of the preliminary ship design are presented in detail below (Papanikolaou 2014):

– Selection of main ship dimensions
– Development of the ship's hull form (wetted and above-water parts)
– Specification of main machinery and propulsion system type and size (powering)
– Estimation of auxiliary machinery type and powering
– Design of general arrangement of main and auxiliary spaces (cargo spaces, machinery spaces and accommodation)
– Specification of cargo-handling equipment
– Design of main structural elements for longitudinal and transverse strength
– Control of floatability, stability, trim and freeboard (stability and load line regulations)
– Tonnage measurement (gross register tons)

These elements must comply with various national or international rules and regulations and also take into account shipyard's construction restrictions. The environmental dimension in ship design should satisfy the following main issues (Shama 2005):

– IMO and other international conventions
– Statutory requirements
– Classification society requirements
– National and international safety requirements
– Performance requirements
– Rational use of materials
– Minimization of energy consumption
– Ensuring cleaner production
– Minimization of environmental impacts
– Minimization of solid waste
– Minimization of demolition problems

Preliminary ship design estimations and selection of specifications require technical knowledge and access to technical data which can often be limited. Usually, naval architects and shipyards use empirical methods and data of existing ships and successful designs (Papanikolaou 2014).

Modern preliminary ship design procedures have endorsed additional tools to provide a more detailed analysis of the elements that affect the ship's life. One of these tools is Life Cycle Cost Analysis.

4 LIFE CYCLE COST ANALYSIS

Life Cycle Cost Analysis [LCCA, also known as LCC (Life Cycle Costing)] is a method for estimating the total costs of a system or product, produced over a defined life time (Kaufman 1970).
Estimations cover the entire life of the product, from its design to its end-of-life. Regarding the maritime industry, and specifically the life of a ship, four phases are distinguished: design, construction, operation/maintenance and scrapping issues (Shama 2005).

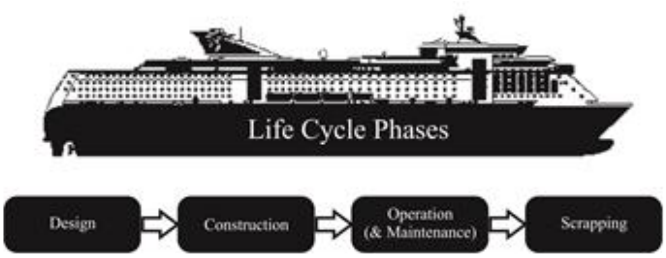

Figure 2. Life cycle phases of a ship

The design phase includes all the costs created from the preparation of a concept ship design to the presentation of a detailed design following the contract signature with the client/ship-owner. Construction phase contains all the procedures undertaken by a shipyard for the materialisation of the ship designs. It includes all costs created in the shipyard until the finalisation of the project and its delivery to the ship-owner. Operational costs of a ship include crew salaries, maintenance expenses, procurement, lubricants, administration expenses and dry docking costs (Lyridis & Zacharioudakis 2012). Depending on the specifics of a voyage, fuel costs, tugging, port and canal costs must be calculated. Finally, end-of-life decisions and its costs are also included in the estimation of the ship's LCCA.

All phases of the life cycle of a product, from the extraction and processing of the resources, production and further processing, distribution and transport, use and consumption to recycling and disposal, have to be assessed with regard to all relevant material and energy flows (Finkbeiner et al. 2010).

LCCA models have been developed in an attempt to improve design procedures of a product, reduce costs for design changes and production, and consequently reduce time to market. By taking into consideration the life cycle implications of their decisions at the early design stage, designers can significantly reduce life cycle cost of a product.

The term life cycle costing is used for the total cost of ownership assessments as well as external or social cost assessments (Finkbeiner et al. 2010). In addition, environmental impact assessment has been introduced in the life cycle analysis as part of the Life Cycle Assessment (LCA) model. Nowadays, the environmental footprint (carbon footprinting, water Footprinting etc.) of a project or a product plays a key role in the decision of undertaking a project or continuing with the production of a new product.

Regardless what the approach for life cycle estimations would be, one thing in common for every methodology is the necessity for qualitative and up-to-date data in order to produce safe estimations of the LCCA model.

5 LCCA DATA REQUIREMENTS

For each phase of the ship's life (design, construction, operation and scrapping) numerous factors are used for the estimation of LCCA. These factors require availability of qualitative and updated data in order to perform a more accurate life cycle evaluation.

The following factors have significant influence in LCCA outcomes and must be included in calculations for analysis (Dalton & Hancock 2015):

1. First Costs

(a) Capital cost of new equipment. Costs must include all components required for a complete and usable system to include distribution network costs.
(b) Labor for installation priced per location: If available, pricing may be based on data from recent projects at the installation of comparable scope and scale. Where such data does not exist, pricing will be based on the most accurate data available.

2. Operations Costs

(a) Energy and fuel used.
(b) Labor for operation priced per location: Pricing will be based on data from existing operation contracts of comparable scope and scale.

3. Maintenance Costs

(a) Required Maintenance: Hours must be based on manufacturer provided component and system maintenance requirements. Components and/or systems that are recommended to be replaced within the ship's life cycle must be accounted for in the LCCA.
(b) Labor Rates: Pricing must be based on data from existing Installation maintenance contracts. Where such contracts do not exist, pricing must be based on available databases.
(c) Systems & Equipment Compatibility with Maintenance Staff.

4. End-of-Life Removal

(1) to include any surcharge for material recycling, reuse, and special disposal costs
(2) Salvage value at end of useful life
(3) Discount and escalation rates

Depending on the type of the vessel designed, specific procedures (e.g. retrofitting) and conditions of the shipyard involved, different cost categories will be included in LCCA estimations.

6 DATA AVAILABILITY

Different sources for acquiring relevant data can be used, in the effort of developing a database for LCCA calculations. The most indicative data sources are theoretical methods and modern statistical trends, tender documents in response to which early design and life cycle assessments are required, previous projects performing life cycle analysis, existing experience of the shipping industry members and expert engineering judgement.

6.1 *Theoretical methods/modern statistical trends*

A possible source of data is the usage of 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, as well as for the estimation of the freight rates and other shipping market parameters needed for the estimation of the revenues during the vessel lifetime.

The methodologies created as a source of improved set of data use probabilistic, empirical and knowledge-based techniques (Batini & Scannapieca 2006) to redefine available data. Indicatively, a number of developed methodologies and theoretical methods are presented below.

BAYESIAN STATISTICS

Bayesian approaches have been used widely for scientific reasons and statistical analysis. Bayesian inference is a process of learning from data (O'Hagan 2008). In a Bayesian approach, the prior information is explicit and is used to identify optimal designs.

Bayesian Modelling identifies the unknown parameters and the inference questions about these parameters that are to be answered, while it constructs the likelihood and the prior distribution to represent the available data and prior information. Using the Bayesian Analysis one can obtain the posterior distribution and derive to inferences (O'Hagan 2008).

The most common Bayesian method used for statistical analysis is known as Markov Chain Monte Carlo. This method is a technique that can perform complex computations in multi-parameter situations (O'Hagan 2008).

STOCHASTIC PROCESSES

A stochastic process is defined as a set of random variables $\{Xt\}t\in T$ [T be a subset of $(0, \infty)$]. Every stochastic process can be viewed as a function of two variables, t and ω. For each fixed t, $\omega \to Xt(\omega)$ is a random variable, as postulated in the definition. However, if we change our point of view and keep ω fixed, we see that the stochastic process is a function mapping ω to the real-valued function $t \to Xt(\omega)$. These functions are called the trajectories of the stochastic process X (Žitković 2010).

Stochastic processes are very important in mathematical theory and have various applications in science, engineering, economics, etc. They use several procedures and models to produce simulation results of various random data and variables. Their application in probability and mathematics also integrate Monte Carlo and Markov chain approaches.

NEURAL NETWORKS

Preliminary evaluations of operating costs for the designed vessels can be performed with the use of neural networks, based on parameters defined by the shipping industry and the global market.

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurones) working in unison to solve specific problems. An Artificial Neural Network is configured for a specific application, such as pattern recognition or data classification, through a learning process (Minin 2006).

Nowadays, there are several methodologies and/or software programs that can apply these theoretical and statistical methods, and produce reliable data that can be used in life cycle estimations. A specific methodology has been developed recently by NTUA for modelling shipping markets, called FORESIM (Zacharioudakis & Lyridis 2008). The application of this technique can provide useful information regarding future values of the tanker market in numerous states of OPEC oil production levels but has also the capability to investigate any other shipping market. Dynamic features are applied in freight estimation taking into account all Tanker market characteristics and potential excitations from non-systemic parameters as well as their contribution to freight level formulation and fluctuation. In this way we are able to measure the behaviour of future market as long as twelve months ahead with very encouraging results. The output information is therefore useful in all aspects of risk analysis and decision making in shipping markets.

6.2 *Tender documents*

As LCCA methodologies have become a necessity in the development of new products across different sectors of the industry, a significant number of papers and publications deal with life cycle assessments. Regarding the ship industry, one can obtain several information on LCCA methodologies used as part of the ship design process in tender documents that deal with data acquisition problems and methodologies which produce a safe set of data for each case scenario studied.

6.3 *Projects performing LCCA*

SHIPLYS partners have suggested a number of research projects -that they have contributed in or they have been benefited by their results- as part of which a life cycle tool has been developed and a relevant database has been constructed.

Some indicative projects performing lice cycle analysis are MOSAIC, RESPECT, MAINLINE, INTERMODESHIP, INNOTRACK and ECO-REFITEC (SHIPLYS Grant Agreement 2016). These EU funded projects can provide a significant source of relevant data to be used in LCCA estimations but they can also provide additional information on existing databases and methodologies for developing new.

6.4 *Existing Databases*

Generally, the existing databases already available in the market that can be used as an input to the LCCA models cannot be accessed freely. Usually, annual subscription is required in order to have access to the latest updates of the needed database. The cost for the subscription differs depending on the price policy of each company exploiting commercially the available database.

Some of the most well-known databases used by professionals and researchers for LCCA estimations are LLOYD'S FAIRPLAY, CLARKSONS and GABI. There are several other existing databases that could be of interest. At each case, the selected database should be evaluated based on the input it can provide and its cost of access, identifying the benefits from its use and the capability of updating with new data collected along the process.

6.5 *Experience/expert engineering judgement*

Naval architectures and engineers are traditionally equipped with the skills and knowledge of developing ships to meet the needs of the shipping market. Their experience and expert's judgement can also be used in the collection of life cycle information for the designed vessels at their preliminary stage, which can be used for life cycle cost estimations.

Furthermore, ship industry members can offer their expertise in the quality assessment of the selected data, in order to produce a safe life cycle assessment of a designed vessel.

7 DATA QUALITY

In addition to the availability of data for performing LCCA calculations, the quality of these data is essential to the ship design process. Usually, an initial quality assessment of the data reveals uncertainties or gaps and they can also identify refinement needs in order to produce the best possible database for life cycle estimations.

It is often challenging to a) identify and factor the influence of various types of data on the magnitude of critical ship design characteristics and b) to estimate the influence of these basic ship characteristics on the production and life cycle cost. Especially for maintenance related data, it is often perceived that one has to deal with censored data, highly inaccurate at times, producing misleading reliability calculations.

The basic steps for the assessment of a set of data for the most of the methodologies used are (Batini et al. 2009):

– data analysis, providing a complete understanding of data and related architectural and management rules
– Data quality requirements analysis, which surveys the opinion of data users and administrators to identify quality issues and set new quality targets
– Identification of critical areas, which selects the most relevant databases and data flows to be assessed quantitatively
– Process modelling, selection of a model for producing or updating data
– Measurement of quality.

As the life cycle models require larger and larger databases for producing reliable estimations of life cycle costs and environmental impact, big data concepts and tools are used to describe large and more complex data sets that cannot be processed by traditional applications/software. Cai & Zhu (2015) have developed a five dimensions data quality standard for data assessment, presented below in figure 3.

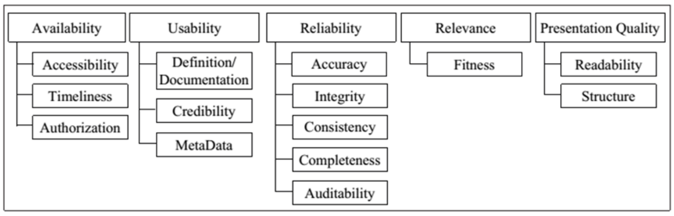

Figure 3. A universal, two-layer big data quality standard for assessment (Cai & Zhu 2015)

This methodology can be used as a general approach to data quality assessment even if no big data are used in the life cycle estimations.

Using the steps described above, a first quality assessment of the available data can be performed. If the assessment phase proves low quality of data, a methodology for improving their quality should be considered. The improvement phase is usually consisted by the following steps (Batini et al. 2009):

– Evaluation of costs, which estimates the direct and indirect costs of data quality
– Assignment of process responsibilities, which identifies the process owners and defines their responsibilities on data production and management activities
– Assignment of data responsibilities, which identifies the data owners and defines their data management responsibilities
– Identification of the causes of errors, which identifies the causes of quality problems
– Selection of strategies and techniques, which identifies all the data improvement strategies and corresponding techniques, that comply with contextual knowledge, quality objectives, and budget constraints
– Design of data improvement solutions, which selects the most effective and efficient strategy and related set of techniques and tools to improve data quality

- Process control, which defines check points in the data production processes, to monitor quality during process execution
- Process redesign, which defines the process improvement actions that can deliver corresponding data quality improvements
- improvement management, which defines new organizational rules for data quality
- Improvement monitoring, which establishes periodic monitoring activities that provide feedback on the results of the improvement process and enables its dynamic tuning.

The quality assessment of the data needed to proceed with the LCCA estimations, will demonstrate if there is a need for data refinement. Data refinement can be accomplished through the use of various methodologies, stochastic methods and statistical analysis that can improve the results of the LCCA.

8 CHALLENGES & PROBLEMS

While the development of an adequate LCCA tool is quite challenging, data collection as input to the LCCA model deals with a number of challenges and problems regarding the availability and the quality of the necessary data (Bidi & Ayob 2015).

8.1 *Cost of accessibility*

One of the main problems is the availability of relevant databases that can easily be accessed. As it has already been mentioned, these databases require a subscription for an amount of money in order to allow access to its data. Usually, this subscription should be renewed annually, in order to have access to new updated data. The cost for accessing life cycle databases maybe dissuasive for SMEs and small naval architecture offices, who would like to adopt LCCA estimations in their design processes, in an attempt to reduce constructional, operational and other costs. As a result, one of the other sources of data should be considered.

8.2 *Data availability/quality*

Existing databases may not be able to provide sufficient information for certain business and industrial sectors. As a result, data gaps in LCCA calculations regarding the shipping industry could occur, that will produce poor life cycle cost estimations.

Additionally, the quality of data sources is frequently very poor. Developed databases may not be updated with recent data who can improve LCCA estimations and preliminary ship design results. In this case, a statistical or theoretical methodology for data refinement and improvement should be considered, that could produce more realistic data for the process examined.

8.3 *Software integration*

A specific issue associated with the quality of data is the capability to integrate between tools and formats for different software or life cycle tools. Existing software tools for calculation of LCCA are based on the bottom-up approach, which makes it necessary to enter itemized data. On the one hand this requires a great deal of data entry while on the other hand the data is simply not available at the required level of detail in the initiation and early design phases (Hofer et al. 2011).

Generally, there are several uniform standards, software and data formats. When developing a new software for life cycle estimations, the availability of relevant data in certain formats should be taken into consideration. Using standard formats could improve the efficiency and effectiveness of software processes.

Furthermore, due to the large amount of data needed in order to perform life cycle estimations, data storage possibilities should be considered. Having an online database could offer advantages in terms of accessibility and updating facility, while create problems in performing fast estimations. On the other hand, local based databases are easier to use and offer copyright protection of sensitive information and available data.

8.4 *LCCA models*

The various methodologies developed for LCCA estimations, are not always fitted for all industrial and market sectors. Several models are adjusted towards specific parts of the production process and others do not cover certain parts of the product’s life cycle.

Regarding shipping industry, the methodology used to evaluate life cycle costs, should endorse all life stages of a ship (from design to scrapping) as well as take into consideration the environmental impact during the various stages of its life.

8.5 *Changing market/data currency*

The globalisation of the economy and the continuous changes taking place in the global shipping market, have as a result continuous changes in the set of data used in the LCCA estimations. Subsequently, LCCA calculations should constantly 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.

9 SOLUTIONS

LCCA estimations are usually performed early in the design process when only estimates of costs and savings are available, rather than certain amounts. Uncertainty in input values means that actual outcomes may differ from estimated outcomes. There are techniques for estimating the cost of choosing the "wrong" project alternative. Deterministic techniques, such as sensitivity analysis or breakeven analysis, are easily done without requiring additional resources or information. They produce a single-point estimate of how uncertain input data affect the analysis outcome. Probabilistic techniques, on the other hand, quantify risk exposure by deriving probabilities of achieving different values of economic worth from probability distributions for input values that are uncertain. However, they have greater informational and technical requirements than do deterministic techniques. Whether one or the other technique is chosen depends on factors such as the size of the project, its importance, and the resources available. Since sensitivity analysis and break-even analysis are two approaches that are simple to perform, they should be part of every LCCA (Fuller 2012).

In order to estimate the impact of the various types of data to the critical ship design characteristics, production and life cycle cost, a sensitivity analysis is usually qualified as the most indicative approach. Sensitivity analysis is a methodology used to quantitatively estimate how computed variables and indicators might be affected by the uncertainty related to low data quality (Mezzanzanica et al. 2012). It is used by a wide range of scientific and business sectors studying the uncertainty of outputs from mathematical models or systems using different sources of uncertain data.

Additionally, data refinement and improvement can be performed using various methodologies. These methodologies are distinguished in two main categories, namely data-driven and process-driven techniques. Data-driven techniques improve the quality of data by directly modifying the value of data. Process-driven strategies improve quality by redesigning the processes that create or modify data (Batini et al. 2009).

Furthermore, when low quality data exist and alternative (and more trusted) data sources are not available, data can be cleansed using business rules derived from domain knowledge. Business rules focus on fixing inconsistencies, but an inconsistency can be cleansed in different ways (i.e. the correction can be not deterministic) (Mezzanzanica et al. 2012).

10 CONCLUSIONS

Life Cycle Cost Analysis could be proven an important asset in creating advanced, cost effective and environmental friendly ship designs, with commitment in identifying and overcome challenges and problems along the way.

This paper summarises the difficulties obscured in the effort for performing safe life cycle estimations. The main challenges and problems opposed in this effort have been presented and analysed in respect to the shipping industry and the need to endorse additional tools in a more sufficient preliminary ship design procedure.

As part of the on-going SHIPLYS project, the opportunity for exploring preliminary ship design procedures has been presented. Additionally, Life Cycle Cost Analysis methodology and a number of life cycle approaches have been discussed, while the requirements for LCCA in the lifetime of a ship has been examined.

Furthermore, the study of this paper illustrates different sources for acquiring or producing data necessary for life cycle estimations and the environmental impact of the examined projects. Life cycle analysts could use any of these sources, depending on their access to primal data or relevant databases.

Finally, a number of methodologies for data quality assessment has been presented, in order to assess the available data and explore the need for data refinement/improvement to produce safe life cycle estimations.

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