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ShipSoft - Eco-efficiency tool for the Norwegian Maritime Industry

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Project Management
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ShipSoft

Eco-efficiency Design Tool for the Norwegian Maritime Industry

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Abstract

Background, Goal and Scope

The main target of the thesis is to contribute to the development of the software project ShipSoft and to reach to conclusions about integrating project management practices into ShipSoft. ShipSoft is an eco-efficiency tool that is to be dedicated to the Norwegian maritime industry. The contribution in this study includes identifying the needs of the industry, developing the related requirements, establishing the structure of the software and implementing case studies in order to demonstrate the tool.

Methods

Several methods have been utilized. The main methodology is derived from the Systems Engineering principles and Life-Cycle Assessment and Life-Cycle Costing techniques are used to estimate the full environmental and cost effects of ships and ship production. Unstructured interviews are made in order to gather information from the members of the industry.

Application

The developed frameworks are tested with a case study. Two ferries that are operating in the Norwegian maritime industry are compared according to their cost and environmental performances using the LCC module.

Discussion

LCC module proved to provide a consistent assessment of design alternatives as well as the effective comparisons among them. Further suggestions are made in order extend the scope of the project through applying the same structure for other modules.

Preface

This thesis is my final project at the Norwegian University of Science and Technology (NTNU), Department of Industrial Economics and Technology Management, in the discipline of Project Management. The thesis is written in collaboration with the ShipSoft Software Development Project.

The documents that were sent to the collaborating companies for the case study are attached. The information provided within the case study is confidential and should not be shared with third parties.

First and foremost, I wish to express my gratitude to my supervisor, Annik Magerholm Fet, for her guidance and feedback on the research. Her engagement to, and extensive knowledge of the topic has redeemed inspiration and motivation throughout the process.

Thanks also to Rolf Fiskerstrand and Per Asle Fiskerstrand from Fiskerstrand who have welcomed me to their shipyard and contributed to the study with their knowledge. Finally, the support from Dina Aspen, Ph.D. candidate at the Industrial Economics and Technology Department, has been very much helpful. Thanks her for all the support.

Contents

1. Introduction

Norway has been fishing and shipping nation for centuries. When the first profitable oil deposits were found on the Norwegian continental shelf, the country had not have any experience with oil. But, it had long experience and extensive expertise with building ships. It had not taken much time for the nation to develop the knowledge and technology needed to exploit the rich oil resources. Oil & gas became the leading industry in Norway and has made Norway into one of the world's richest countries.

Oil & gas industry also shaped and formed other support industries in the country. Ship building industry had started to design and build specialized offshore support, offshore construction, seismic and research vessels. Today Norwegian shipyards became the world leader in building complex vessels through systems integration that require the highest degree of customization. Shipbuilding industry in Norway can be classified as a typical "Engineer-to-Order" industry. Traditional supply chain management theories that has been developed and practiced until today are focused on high-volume manufacturing sectors. Engineer-to-Order manufacturing is, however, characterized by low-volumes, high degree of customization and project-based processes. Research addressing the design and management of supply chains in such industries is scarce. (Haartveit, Semini and Alfnes, 2011) However, the same degree of customization limits the potential of building ships with improved cost-efficiency and reduced production lead times. Norwegian shipyards remain to follow costly approaches and are threatened by the ship building industries of the developing countries.

Norwegian shipyards are well aware that the competition will become even stronger in the near future. However, they also know they cannot compete with low labor cost markets only on the price basis. They need to continue building on their core competences and at the same time they need to develop new competitive advantages. Norway has also been a leading nation in designing green ships and developing designs that could reduce the carbon footprints of ships. However, consideration of environmental factors in the design process has a price-increasing effect on ships. Shipowners want to know the possible economic and bureaucratic gains of having the environmental considerations embedded in their daily operations. In most cases the environmental or economic benefits of different design alternatives are not very straightforward. One needs to consider the full lifespan of a ship in order to perceive such benefits. Ship designers need smart tools that could provide information on life cycle environmental and cost performances of different design alternatives and that can make reliable comparisons among these alternatives.

Several software solutions that aim to provide environmental information of vessel construction and operation have been developed. (Aspen, 2011) Previous studies show that none of these existing software solutions are capable of integrating economical aspects into environmental assessments. However, in order to translate the results from environmental assessments into operational strategies, economic aspects must be integrated (Norris, 2001). A way of combining this data is to employ eco-efficiency indicators to measure both environmental and economic performances of vessels. Such indicators provide an opportunity to both manage and communicate eco-efficiency performances for companies in the maritime industry. In order to facilitate the use of such indicators, it's necessary to tailor indicators for the industries they are to be applied in and the purpose they are intended for (Steen et al., 2009).

1.1 Background

IGLO MP-2020 Project

IGLO MP-2020 (Innovation in Global Maritime Production, 2012) is a knowledge building project with collaboration between the Norwegian University of Science and Technology (NTNU), Marintek and industrial partners. The project was completed in 2012 and one of the most important research studies was the analysis on the existing marine design software with their corresponding LCA compatibility features. The scope of the work within this project was limited to Cargo Vessels (general cargo, tankers, dry – bulk, multi – purpose) and Fishing Vessels. Below is the list of different software that are widely used in the maritime industry and that were analysed in the IGLO project;

- AVEVA Marine / previously Tribon M3, used for conceptual design and analysis, detailed design and production
- FORAN, used mainly in the initial design and detailed engineering
- HyperWorks, used in conceptual design and detailed design
- Maxsurf, used in initial design and analysis
- NAPA, used in conceptual design to class drawings
- Nupas Cadmatic, used in initial design, detailed design, production and outfitting
- Rhino, used in initial design
- Ship Constructor, used in detailed design and production
- SmartMarine / IntelliShip, used in ship design, production and life cycle management of the ship

In this same research, it was concluded that due to the fragmented structure of the maritime industry, there are not any single actor within the industry which can possess all the required data for an LCA. (Garda, 2012) Customization of the design software tools was suggested with a shipyard material management system in order to achieve most reliable and accurate results.

1.2 ShipSoft Project

ShipSoft Project was initiated based on the needs for a reliable and effective eco-efficiency tool that is designed for the maritime industry. The Project is managed by the HMS Section of the Industrial Economics and Technology Management Department at NTNU. The ultimate aim was to design a tool that can make Life-Cycle Assessments (LCA) and Life-Cycle Costing (LCC) calculations. Through the use of such software, industry members will be able to see the full life-cycle effects of the different design or material choices very early in the project. Furthermore, ship designers and builders will be able to compare different alternatives and communicate this information to their customers and ship-owners. Finally, ShipSoft will enable the users to see the economical effects of having environmental considerations and also the other way around. With the current resource constraints the initial goal is to develop a pilot model that will represent the ideal complete system which can be tested with some case studies

1.3 Purpose and Objectives

In this master thesis study, the goal was to contribute to the development of the ShipSoft project and integrate the project management perspective into the final product of the pilot model of ShipSoft.

The contribution has covered the following areas;

- Identify the needs of the Norwegian maritime industry and determine how can ShipSoft cover these needs
- Develop the requirements specification and the scope of work for the pilot model
- Develop the structure of information gathering from the industry members
- Contribute to the development of LCA and LCC structures within ShipSoft
- Implement the case-studies and present to the collaborating industry members
- According to the feedback from the industry, redefine the scope and system boundaries
- Suggest future research areas on ShipSoft

- Propose the theoretical background for Integrating project management practices into ShipSoft

1.4 Method

The development of the ShipSoft project required a multidisciplinary approach that includes the scientific methods with regards to both economical and environmental considerations. Furthermore, scientific methods covered the full life-cycle of the ship. In order to identify the life-cycle phases of a ship and as well as the subsystems within a ship, Systems Engineering approach is utilized. To gather information on life-cycle phases and develop models that can make assessments, both qualitative and quantitative methods are used.

Qualitative methods are used to gather basic information from the maritime industry. In this respect, unstructured interviews are made with ship builders, ship-owners and consultancy companies. Meetings are made face to face and their depth will depend on the interviewees' knowledge and willingness to collaborate.

Quantitative methods are used to develop the cost and environmental assessment structures within ShipSoft. LCA and LCC methods have been the basis of all life-cycle estimations.

Demonstration of all theoretical work has been done through the implementation of some real-life cases. Case study implementations are also used to present the structure of the pilot model to outside parties and get their ideas in deciding the future development of the software according to the needs of the industry.

1.5 Scope and Limitations

The thesis aims to contribute to the ShipSoft and its scope is limited with the resource constraints that are pre determined with regard to the development of the pilot model. In the pilot model, although the life-cycle perspective has been the basis of the structure, not all subsystems of a ship have been implemented. However, life-cycle perspective still requires a macro-level focus which implies the need of collaboration with all different stakeholders that are involved in a ship's life-cycle. Therefore, assessments are not made on single phase level but they are evaluated in the full life-cycle perspective.

In the ShipSoft project the focus is on the environmental and economical dimensions in the ship's construction, operation and end-of-life treatment phases which leave out the business gains / losses that the ship may provide to its operators.

Finally, even though some of the findings from this thesis might be valid in other contexts besides from the maritime industry, this is not emphasized or further discussed. Moreover, the study focused on the maritime industry in Norway and the structure is developed mostly according to the needs of the Norwegian maritime industry members. In other words, ShipSoft is more practical when it is used for the assessment of specialized vessels rather than bulk or cargo carriers.

1.6 Industry Support

The industry support for the project has been crucial. A prototype of the system was modelled based on data from previous projects. The areas to be identified through the collaboration with industry members are;

- Relations between cost and environmental considerations
- What demands the prototype and future versions should cover
- Feedback on prototype development proposals
- Information regarding the design and construction processes
- What design alternatives to include in each step of the design process
- Information on the life-cycle effects of different design alternatives

1.7 Case Companies

The companies to collaborate for the development of ShipSoft are selected from the Norwegian maritime industry based on the following requirements;

- First and foremost, one company should be selected to collaborate from each one of the life-cycle phases of the ship. Furthermore, those companies should have supplier / customer relationships in their current business practices or at least should have delivered previous projects through their collaboration.

Apart from the first requirement, the company;

- Should have enough expertise and experience that can enable the company to provide historical information from the previous projects.
- Should be willing to collaborate with the project team and with other companies if it is needed.
- Should have focused on developing / operating vessels that are mainly used in the Norwegian maritime industry.

2 ShipSoft Concept and Theoretical Background

2.1 Definitions

This section presents definitions for some concepts that are the basis for the development of ShipSoft.

Life Cycle Assessment

Life Cycle Assessment (LCA) is a way of quantifying environmental impacts throughout the whole life-cycle of a product or service. The methodology behind LCA implies that all usage of relevant materials and energy or discharge of waste and emissions have a certain environmental impact related to it. By quantifying input and outputs flows of energy and material in the different processes included in the life cycle of the given object of study, a life-cycle inventory (LCI) is obtained. These flows may then be converted into environmental damage scores based on scientific models.

Life Cycle Costing

Life Cycle Costing is a method where a cost inventory in monetary units throughout a life cycle of a product system is compiled, i.e. acquisition costs, maintenance, operation and management cost, and costs of demolition and disposal.

In literature, there are three types of life-cycle costing that is widely accepted.

Conventional LCC: The assessment of all costs associated with the life cycle of a product that are directly covered by the main producer or user in the product life cycle. The assessment is focused on real, internal costs, sometimes even without the environmental perspective. The perspective is mostly that of 1 market actor, the manufacturer or the user or consumer.

Environmental LCC enhances conventional LCC by requiring, on the one hand, the inclusion of all life cycle stages and to-be-internalized costs in the decision-relevant future (hence, anticipated costs), and, on the other hand, separate not-monetized LCA results.

Societal LCC: The assessment of all costs associated with the life-cycle of a product that are covered by anyone in the society, whether today or in the long-term future. Societal LCC includes all of environmental LCC plus additional assessment of further external costs, usually in monetary terms. The perspective is the society overall.

The choice of LCC type depends what the user is willing to assess and achieve. Although the specific steps might vary according to the chose LCC type, the following steps might be relevant for carrying out consistent LCC assessments;

1. Goal and Scope Definition

   The goal and scope of LCC need to be defined before a study takes place. It is crucial to appropriately define the system boundary as well as the functional unit.

2. Information Gathering

   If all needed data is not available at the time of the study, then scenario development, forecasting or other estimation methods may have to be employed.

3. Interpretation and identification of hotspots

   A key outcome of an LCC, as well as of an LCA, is the identification of hotspots. These hotspots usually become evident as a result of the analysis, particularly if a sensitivity analysis is carried out.

4. Sensitivity Analysis and Discussion

   Connections between uncertain parameters used in LCC (e.g., project life, included life cycle costs and revenues, sales volume) and calculated outputs (e.g., net present value) should be revealed by a sensitivity analysis.

Eco-efficiency

Eco-efficiency as a quantity is often measured as the ratio of environmental to economic performance of a product, process or system. Increasing eco-efficiency implies improving the economic value or reducing the environmental effects of a product, process or system according to a base scenario. Eco-efficiency may be measured by the use of multiple techniques for estimating environmental and economic parameters. ShipSoft will apply LCA and LCC to best measure life cycle eco-efficiency.

The benefits that may arise from applying such techniques and tools in a maritime decision-making process are among others:

- Eco-efficient production: The tool will make it easier to identify the best economic and environmental options for vessel design and equipment, in addition to assess the construction phases isolated.
- Improve life cycle performances: Through increased knowledge on consequences of decisions made for construction, operation and EOL phases of vessels, actors can minimize resource use and waste production.
- Environmental and economic product development: The effects of various design solutions, systems and equipment selected for the vessels in addition to operational patterns and characteristics can be continuously evaluated.
- Increase competitiveness: Results from the assessments may be used as documentation to meet demands and prove best performances, which may give an advantage in procurement processes.
- Easier to measure and communicate compliance with laws and regulations: Laws and regulations that apply to actors in maritime value chains are getting more quantified, and the tool will enable an easy retrievement of data and facts to support compliance reports.

2.2 Requirements Specification

The first decisions regarding the boundaries and scope of the ShipSoft Project was made during the preliminary study done by Fet and Espen. (2012) In this study, sub-targets of the project were defined as;

i) Identify the needs and requirements for the tool from the industry
ii) Model a tool for environmental assessments of ships in a life-cycle perspective
iii) Discuss model implications
iv) Make suggestions for future work

In the same study, two conclusions were made regarding the needs and requirements of the industry from the ShipSoft model;

1. The tool must fit all actors in the industry

   This statement points out the importance of having a holistic perspective in structuring the ship model. According to this holistic perspective, the ship model should be divided into some subsystems, which eventually make it more practical to perform assessments both on the subsystems and the ship as a single unit, and these subsystems must fit the structure of the industry.

2. The tool ShipSoft should be easy to develop further to meet future demands and trends.

   In order to cope with the changing external conditions like international regulations and customer demands and to provide the allowance for the implementation of future applications, the model should have the sufficient flexibility and comprehensive perspective. In other words, ShipSoft must have a module oriented structure and there must be coherent interactions among different modules which sustains the holistic perspective of the model.

In addition to the above criteria that were concluded in the preliminary study, previous researches on the implementation of LCA tools in the design processes showed that the tools must; (1) be better integrated to the daily operations (2) allow for quick analysis, (3) based on readily available data and (4) not require administration skills that exceed that of a "non-practitioners". (O`Hare, 2010)

2.3 Development of ShipSoft Concept

A typical software development process consists of these three steps; (i) Planning, (ii) Implementation, Testing and Documenting and (iii) Deployment and Maintenance. In the scope of this project, the focus will be on the first two steps and suggestions for Deployment and Maintenance of ShipSoft will be addressed in the Suggested Future Research part.

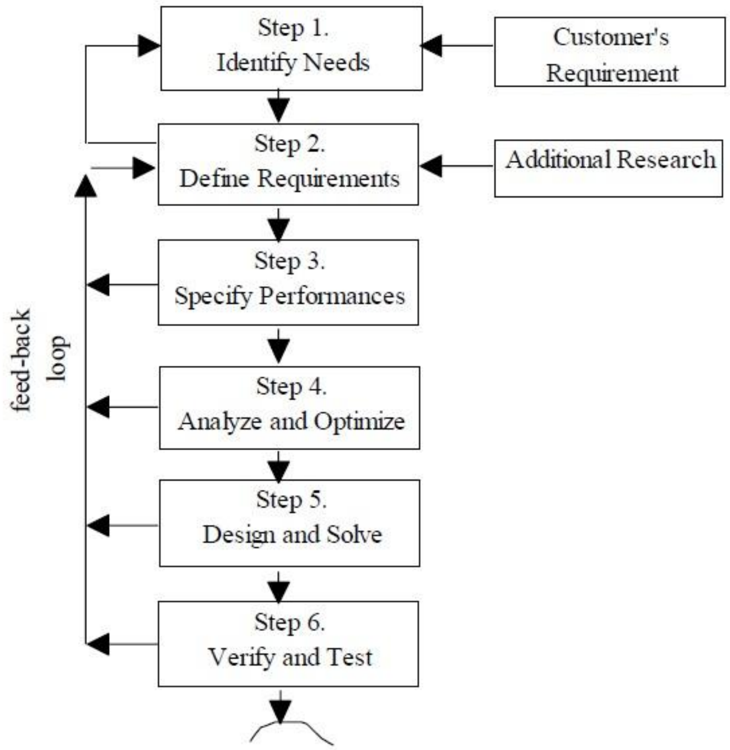
Planning Phase includes the activities related with requirements specification, determination of the scope of development and organization of all the activities successively.

- Developing a “Software Requirements Specification”: SRS provides reliable guidance in developing the software that will best meet the demands of the users. It should enlist all the requirements that will be needed in developing the ShipSoft. It should further include the complete descriptions of the behaviour of the system as well as the interactions the users will have with the system.
- Developing a “Scope Document”: It is important to have an agreement on “what is actually aimed to achieved” with all project members very early at the project. This document should clearly specify the project deliverables and describes any major objectives that include measurable success criteria for the project.

Actual coding takes place in the implementation phase. Software engineers should follow the requirements and plans developed in the Planning phase and design the software and user interfaces. After the implementation is finished, testing should be applied in order to pinpoint the defects and disconnections in the system. Documenting is the final and an important step as all the future steps and guidelines to how to use the system will be described in this section.

Preliminary study on the ShipSoft model suggests following the principles of Systems Engineering by Fet (1997) which was developed to be used as a guidance to make environmental impact analysis, evaluation and performance improvements in a holistic view for complicated systems.

Table 1: Systems Engineering Methodology



Identify Needs: Deliver information about the demands of the stakeholders in a coherent and consistent way

Define Requirements: Based on the stakeholder demands, find out corresponding requirements

Specify Performances: Follow up on the performance and benchmark / compare the information between alternatives.

Analyze and Optimize: The information / indicators/ categories should be analyzed for different systems and purposes.

Design and Solve: Generate an optimized set of performance indicators and information declarations in order to design and implement an effective solution

Verify and Test: Verify and validate the needs defined in step 1 (verification procedures, criteria etc.), and related testing procedures in accordance with international expectations and future standards.

SE methodology is based on the principles of feedback which ensures the continual improvements. Therefore, the model is illustrated with a cyclic design. This concept ensures the betterment of the process as new knowledge is gained in the later stages.

With regards to the application of SE principles in the development of ShipSoft, below steps are followed;

Identify Needs: the most important success criterion for the pilot model of ShipSoft is its ability to meet the needs of the Norwegian shipbuilding industry. And the primary prerequisite to that is to identify the clear needs of the industry. An important question in this phase is to determine "what is needed" (Fet, 1997). According to the unstructured interviews with Fiskerstrand BLRT and based on the review of previous research studies on Norwegian maritime industry, needs are identified.

- Environmental assessments should be supported by the cost analysis.
- Different design alternatives should be compared early in the design phase based on cost and economical performances.
- There should be a platform to communicate the life-cycle performances to the customers.

Define Requirements: The requirements specified in the Preliminary Report are coupled with the identified needs in order to specify performances.

- The tool must fit all actors in the industry
- The tool ShipSoft should be easy to develop further to meet future demands and trends.
- The calculations and assessments should be based on the life-cycle perspective.
- Environmental assessments should be coupled with cost assessments.
- User should be able to make comparisons among any design, material or product alternative. These comparisons should also be based on the life-cycle perspective.
- In order identify the sub-systems of a ship, the SFI Grouping System which is widely used in the Norwegian maritime industry should be used.

Specify Performances: Performance criteria should serve as test factors that could enable the assessment of the software's effectiveness. Some of the mostly used performance criteria in research projects, which might also be relevant for the case of ShipSoft are;

Feasibility

The time and means required to collect information to make assessments with ShipSoft can be evaluated as one performance criterion. Smart and user-friendly design of the user interface as well as direct and relevant questions to the user would increase the feasibility of the software.

Reliability

This criterion should be used to evaluate the consistency of the cost and environmental assessment structures. In order to be reliable, the tool should produce similar results when it is tested with same parameters over and over again.

Validity

This criterion is about whether a study measures or examines what it claims to measure or examine. For ShipSoft, this concept should definitely be tested especially on the life-cycle structures. It is extremely important to ensure that these structures do really measure and cover the full life-cycle of the ship.

Front – End Management of Projects

"The project's front-end phase is the stage when the project only exists conceptually, before the final decision of financing the project is made." (Samset, 2001) Commonly at the outset of the project, relevant information and knowledge about the project processes is at its lowest and thus uncertainty affecting the project is at its highest. Uncertainty gradually decreases as the project is planned and progressed. Starting the implementation of the project without sufficient consideration in the front-end phase might result in dedicating more resources in the execution phase in order to finish the project in time and within its planned budget. In most cases, such projects are exposed to time and cost overruns.

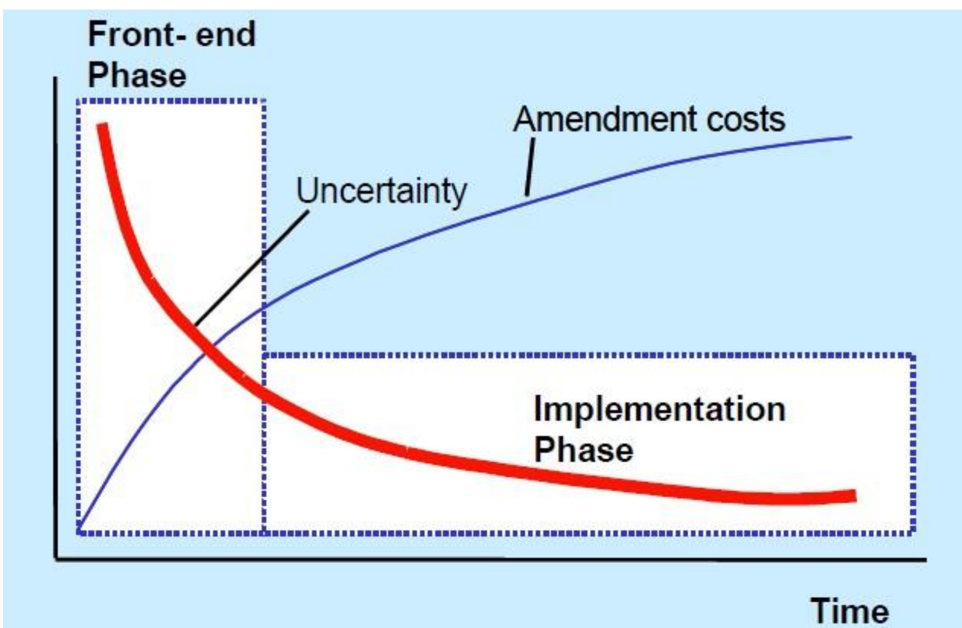


Figure 1: Front-end Management of Projects

In developing ShipSoft, one of the aims was to provide a software tool, to the maritime industry, that is a reliable guide in comparing different alternatives, gathering information about the future activities in the project, managing different risk elements and discovering the causal relationships within the project. With all these features, users will be able to get enough information in the front-end phase of their projects and hence they will be less reluctant in dedicating the right resources in the implementation phase.

Analyze and Optimize: Optimization is the process of finding the best alternative among a set of feasible solutions to maximize or minimize a certain objective function. In ShipSoft, the aim is to compare different alternatives according to their LCA and LCC performances and chose the alternative that exhibits the best environmental and economical performance. Because the assessments are made in the design phase and they cover the next 40 years period, there are certain assumptions that needed to be made. As more information becomes available in the life-cycle of the ship, the system should make analysis and update the assessments on different alternatives based on the new information. It is expected that as more information is available and hence the uncertainty decreases, the tool makes more consistent assessments. The ultimate aim should be to design the structure of the software in such a way that the variations among the early assessments and later assessments will be as low as possible.

Design and Solve: After different alternatives are assessed according to their environmental and economical performances, the user is able to choose the best alternative. System does not make any selections for the user as there might be reasons for the user to prioritize an alternative which is not an optimal solution.

Verify and Test: The most effective way to verify the results of ShipSoft is through presenting the differences among the performances of alternatives based on the life-cycle phases.

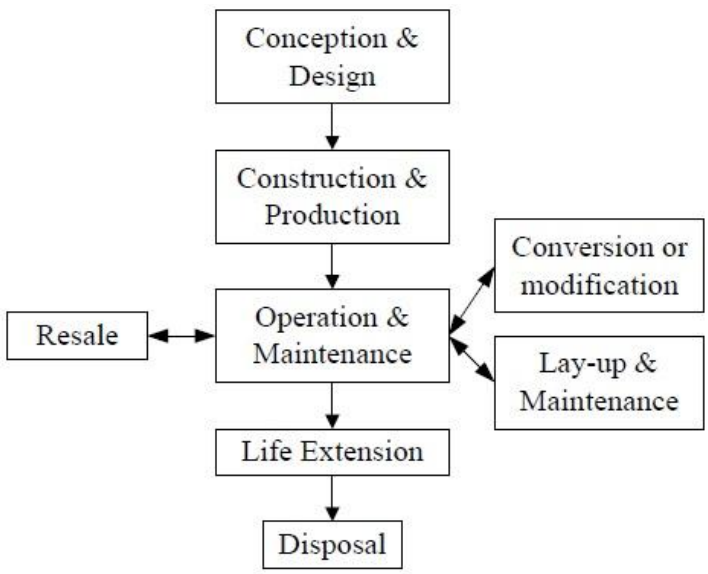
2.4 The System Life Cycle of a Ship

Prerequisite of making effective life-cycle assessments is to define what the life-cycle consists of in a consistent way.

Structural systems are usually perceived and designed to operate for a limited period of time. The concept of life-cycle provides the insight to understand and optimize the operational life of the ship. Although there are several different definitions on the “Life Cycle of a Ship”, main phases of this life cycle are defined in a common way. Fet (1997) describes the life cycle of a ship with four main phases; Project Planning / Design, Construction / Production, Operation / Maintenance, System retirement / Scrapping.

Ship Structure Committee (2000) defines the ship`s life cycle with five main stages; Conception & Design, Construction & Production, Operation & Maintenance, Life Extension and Disposal. In their framework, Ship Structure Committee distinguishes between the Service Life Cycle and Life Extension of a ship. "A service life cycle analysis starts from the current age of the existing ship and extends through the intended remaining service life, whereas a life extension analysis starts from the current age and continues through the intended extension of service life." (Ship Structure Committee, 2000)

Table 2: The Life Cycle of a Ship Structural System



In the structure of the ShipSoft Project, Life-Cycle method suggested by Fet (1997) will be followed. With regards to its compliance with the framework of the Ship Structure Committee (2000), Life-Extension phase will be regarded as a part of the main life-cycle of the ship.

2.5 Why Life-Cycle Thinking is important?

Life Cycle Thinking is becoming fundamental in environmental management decision making processes of businesses. Companies increasingly want to assess the environmental impacts associated with all the stages of their products or services. "Life Cycle Assessment takes into account the product's full life cycle: from the extraction of resources, production, consumption and recycling up to the disposal of remaining waste. Therefore it touches the environmental impacts associated with different sectors." (European Commission, 2010) In a life cycle analysis, all the short-term and long-term costs (financial, physical, service, environmental), benefits and risks involved in operating the structural system are assessed, evaluated and used for optimal decision making.

Life-cycle analysis in the maritime industry provides the holistic understanding of the long term economic and environmental effects of all the four main phases described in the above section. It also provides insight information on how these main phases are related to each other. All these information can be used for efficient design and efficient management of the system.

In businesses, the decision making processes that are guided by LCA must also eventually take the economic consequences of different alternatives into account. Although Life Cycle Costing (LCC) is regarded as a part of the LCA methodology and hence the two names are used interchangeably, there are fundamental differences between LCA and LCC. They are developed in order to present guidance for different kinds of problems. LCA, as explained in the earlier chapter, evaluates the environmental performances of different alternatives holistically throughout the life cycle. LCC, on the other hand, evaluates the cost-effectiveness of alternative business decisions estimating their future effects throughout the life cycle. In LCC, activities are regarded as a part of the life cycle as long as they cause direct costs or benefits to the decision maker during the economic life of the investment. LCC includes only the cost flows with the present value perspective. Therefore, timing of the activities is crucial where in LCA the flow timing can be neglected.

Norris (2001) pointed the lack of the focus on economic consequences of decision alternatives in LCA frameworks. "Neither the internal nor external economic aspects of decisions are within the scope of developed LCA methodology, nor are they properly addressed by existing LCA tools." (Norris, 2001) There are certain drawbacks associated with the separation of the economic perspective from the life cycle environmental assessment. Norris (2001) summarizes these certain limitations as follows;

1. It limits the influence and relevance of LCA for decision making. A company cannot afford to make product design decisions on strictly an LCA basis, without regard to economics, product performance, and so forth.

2. Separation of LCA and LCC leaves uncharacterized the important relationships and trade-offs between the economic and life-cycle environmental performance of alternative product design decision scenarios.

3. The LCA perspective and its results can have important economic relevance for companies, which may be missed when cost analyses neglect LCA's scope and findings.

In order for an LCA framework to be a reliable and effective decision making guidance tool for companies, it must have an embedded economic perspective. Therefore, it is crucial to "bridge the gap" between LCA frameworks and LCC. In ShipSoft project, the aim is to develop a software tool that integrates both LCA and LCC dimensions and aligns the user decisions in both perspectives.

3 Module Structures in ShipSoft

One of the important conclusions made in the ShipSoft Preliminary Report was to develop the software with a modular structure. Modules in ShipSoft will represent the separation of the concerns. The users may not be interested or even not be authorized to use specific functions of the program. Modular design will ensure that users can get or input information without having to deal with irrelevant and time-consuming functions. Moreover, more than one user will be able to work with the system at the same time. However, this does not mean the modules will perform completely discrete functions unlike typical modular designed software. In ShipSoft, it is extremely crucial to have the interactions and alignment of the modules through a reliable, efficient and user friendly interface.

3.1 LCA Module

LCA is applied to many different research projects in a wide scope. There are also different types of LCA studies that could be conducted in making research studies. One of the most important complexities of making LCA studies is related with which method to choose for a specific study. The decision will determine the quality of the study and achieving the aimed goals through the project. The most common division of LCA types is among the Attributional and Consequential studies. Attributional life cycle assessment focuses on describing the environmentally relevant physical flows to and from a product or process, while consequential assessment describes how relevant environmental flows will change in response to possible decisions. Both Attributional and Consequential LCA can be prospective (forward-looking) or retrospective (backward-looking).

Selection of LCA Type for the ShipSoft Project

Attributional LCA accounts all possible environmental impacts of a product, while consequential LCA aims to explore the environmental consequences of different alternatives. When the methodology is applied to the engine system comparison case study of ShipSoft, attributional LCA would help us to find out “What would be the overall environmental impact of marine transportation using the diesel / gas engine” where with consequential LCA, we would be more focused on “What would be the environmental consequences of using the gas engine instead of the diesel engine”, which is exactly what ShipSoft aims to achieve. Moreoever, the aim in ShipSoft is to provide the life-cycle information in the design phase which implies the importance of having the prospective perspective. With the chosen strategy, prospective – consequential LCA, the project will deliver the benefits associated with making early design assessments and comparing different alternatives according to their life-cycle performances.

In order to establish an LCA module for the full life cycle of a ship, it requires a deep understanding of the ship building processes, ship recycling processes, material processing in the building process and manufacturing processes of all parts / machines used in the ship.

For the LCA module of ShipSoft, the following criterion has been determined;

- It should provide to the users a comprehensive selection of environmental indicators that are relevant to the maritime industry
- It should provide enough flexibility to the users in modifying the scope of the projects and choosing the processes, materials and operations.
- In consideration of all the above points, the application to be developed in this project should be a practicable working prototype. In this stage, it should not be accepted for commercial applications.

In principle, LCA needs to be carried out for the full operational life cycle of the ship. If the ship is operated for n years, a basic formula to estimate the total environmental impact of a given indicator can be as follows;

$$E = C + n.A$$

where n represents the total number of years the ship is in operation, A represents the environmental impact in one single year and C is the summation of all the one-time environmental impacts in the building and end-of-life treatment phases. This formula assumes that the environmental impact of the indicator will be stable over the operational lifetime of the ship. In most cases, this is a weak assumption. The environmental impact of an indicator increases as the ship matures. For such indicators the formula can be modified in this way;

$$E = C + A. \frac{1-(1+x)^n}{1-(1+x)}$$

where x represents the increase in the environmental impact of the indicator in one year.

Functional Unit for the Operational Life

Ferries that are to be used in the scope of the case study have the same carrying capacity and have very similar technical specifications except the engine systems. They also operate on a different route which might be challenging for making a comparison among them. In order to ensure the consistency of such a comparison, it is important to define a functional unit which will be the basis of the comparison.

Both ferries have one ultimate function; transporting people and cars between two cities. Since at their maximum capacity, they carry the same amount of passengers and cars, the comparison should be made on the amount of environmental impact that they cause on 1 km. of distance. The life-cycle performance for the selected options will be evaluated in relation to primary energy use, global warming potential, acidification potential and eutrophication potential and also the flow indicators;

- Water (m^3)
- Energy consumption (MJ eq.)
- Bulk waste production (kg)
- Hazardous waste production (kg)

For all these categories, following methodology will be used;

LCA is carried out over the full life-cycle of the ship. Before developing the structure to make assessments, it is important to differentiate between two types of environmental impacts. There are environmental impacts that occur only once throughout the life-cycle of the ship where there are other impacts which happen continuously as long as the ship is in operation. Environmental impacts that occur during the construction, installation and dismantling operations can be classified as one-time impacts. All other impacts that happen during the operational life are continuous effects.

Fuel Consumption Levels

Fuel consumption rates of different engine systems will be assessed using the below form structure. Engine systems use different power level depending on the status of the vessel. All these different status will be considered.

Table 3: Fuel Consumption Levels

Fuel Consumption	SFI Subsystem 6						
	Unit	Steaming	Maneuvering	Docked	Maintenance	Total	40 years
Time	% of total time						
	days						
	hours						
Power	kW						
Power Consumption	kWh						
	MJ						
Fuel Consumption	kg / year						
	liter / year						
	cubic / year						

3.2 LCC Module

Developing the right structure for the LCC model is probably the most crucial step in having an effective tool. This should address important questions including; How are the costs modelled, How is the life cycle of the product / service structured, Which cost categories are employed, Whose costs are taken into account and How are costs aggregated.

The importance of an effective cost assessment and understanding the factors that drive cost can also be crucial when comparing design alternatives. Caprace and Rigo (2005) explain the possible gains of early cost assessment as follows;

1. Designers will be able to quickly perform trade off studies and therefore develop a better understanding of their designs affect cost
2. With an ability to perform reliable cost assessments at the preliminary level, the shipyards will be able to negotiate more favourable contract terms that could decrease costs.

In order to commercially succeed in the competitive ship building industry, companies need to compare different design alternatives by accurately assessing the costs associated with these alternatives and their implications for the production process. Although most of the cost assessments in the Norwegian ship building industry are based on extrapolations from previously-built ships, there are several methods that are also used. Some of the methods that have been used in earlier studies are;

- Top-down Cost Estimation

This method uses empirical relationships between product parameters and costs in estimating the cost of a new ship. This method is typically preferred when detailed design is not available and the ship cost is predicted with a macro approach according to the higher level specifications. It uses global parameters like ship type, size of the ship, weight of the hull and so on. Cost assessments on such parameters are done based on the evaluations and statistics from pervious projects. In other words, it assumes that the design of the ship will not differ significantly from the previous designs. There are obvious drawbacks with using this method. Firstly, improvements and technological changes in the production may not be reflected in the cost estimates. This also implies that, top-down approach can never be an effective method for design alternatives that includes innovations or certain improvements with the processes. Secondly, it is not a reliable technique in comparing different design alternatives. Finally, by using this method there is almost no chance to improve the efficiencies in the production process as all the parameters are estimated based on historical information. However, this method is preferred because of its practicality and ease of use especially at the early design phase when there is not much information available.

- Bottom-up Cost Estimation

In this approach, the idea is to break the project into the smaller products up to the most basic products and make detailed cost estimation for all the operations related with each single product. These estimated costs are then summed up with all preceding layers and an aggregated cost is obtained at the end. This cost reflects the total cost of the project. This method involves detailed engineering and analysis, thus it requires more effort to implement but the results it provides are also more accurate. Moreover, it captures the differences in design details and serves as a good tool to compare different alternatives. However, this method, so as the Top-down approach, do not consider the future costs associated with different design alternatives but only focuses on the capital costs of the alternatives.

- Activity Based Cost Estimation

Activity Based Costing (ABC) is a method that also works with the Bottom-up methodology. However, it better takes into account the costs related with the operations that require special engineering, special testing or operations that involve innovations. Such operations cause the most resource consumption in any project and ABC assigns the costs to the actual operations that they belong to. It is an effective method in identifying and determining the production overhead costs and allocating these costs to the activities in the design and manufacturing processes. The limitations of ABC are basically; it does not have any general cost criteria that can be used in selecting relevant cost drivers and it provides a linear costing system and may not be applied to projects with non-linear mechanisms. (Ziarati, 1989) As it is the case with other methods, ABC also does not provide a cost assessment in a life-cycle perspective. Because this last limitation, which prevents the consideration of uncertainty within projects life-cycle, weakens the effectiveness of the method, a new method (called ACU – Activity based Costing method with Uncertainty) This method was used by Fet, Embelmsvåg & Johannesen to assess the costs of a Platform Supply Vessel during operation. In this research it was mentioned that this method required more information input and more time to conduct compared to other methods because of the following features of ACU;

- based on ABC,
- handles uncertainty, and
- handles detailed design changes (Fet, Embelmsvåg & Johannesen, 1996)

ACU, although to some extent it can cover uncertainty and future predictions, can make the assessments only at one particular phase of the value chain. It lacks to consider the full value chain of a ship starting with the early design phase and up to the end of life treatments. Same weakness was determined in the study by Fet, Embelmsvåg & Johannesen and making a more comprehensive study on LCA and LCC that can take the total value chain was recommended with also comparing different design alternatives based on the life cycle data.

- Life-cycle approaches

The analysis of costing systems in the ship building companies has shown that the historical data has not been effectively used for future ship building projects costing.

There are important weaknesses related with using cost assessment methods that can only be built by using historical information from previous projects;

1. If there are errors in previous projects specifications, same errors are repeatedly transferred into the specifications of new projects.
2. Specifications in the previous projects might be developed in order to meet unique customer requirements and same requirements can be irrelevant for the new project.

3. Most importantly, such techniques tend to hinder the developments and innovations as all the data is gathered through from the operations that used the old techniques.

In ShipSoft, the aim is to improve upon the situation described above and at the same time expanding the scope of cost assessment from design and production to cover all value chain of the ship.

In order to improve the design of products and services, increase the efficiencies in terms of lead time and ownership costs and to have an improved environmental performance; life cycle engineering has emerged as an effective method to address these issues. As it is mentioned in almost any research study on product design, over 70 % - 80 % of the total life cycle cost of a product / service is committed and determined at the early design stages.

People are not anymore concerned only with the purchasing cost of a product / service but all the costs associated with the ownership of that product / service. For companies, reducing the costs associated with purchasing, production, logistics is not sufficient to keep their businesses competitive. In order to survive in their markets, manufacturers have to consider the full life-cycle costs of their products / services, which is known as LCC.

Challenges of Cost Assessment in Ship Industry

Although LCC is a promising future holistic costing methodology, its application in the maritime industry has been limited. Authors have described certain challenges associated with doing LCC assessments in the ship industry.

Firstly, in some cases there is a significant disconnection among the design stage and the actual time that the estimated cost should occur. In such cases, there is not any cost estimate that is available until the operation is sourced or even until it is finished. This is a typical problem especially in operations with some technological developments or unique operations that are to be planned for the first time. Cost estimates for such activities are very likely to be inaccurate.

Secondly, when historical information is used it is very unlikely for the cost estimates to be perfectly accurate. Even for the operations which are not subject to frequent changes related with technology or efficiency, the historical information used to estimate their costs may lag behind the point in time for decisions to be made, and the final cost estimate might have to be a very rough one. (Caprace & Rigo, 2011)

Thirdly, once the cost assessment has been made it is generally not updated as new or better information becomes available. New or better information has the potential to increase the quality of the estimate. However, especially if an integrated software application is not used within the organization, it becomes very difficult to update all the estimates as there is new information available.

Present Value Calculation Formulas for LCC

Present Value is a formula used in Finance that calculates the present day value of an amount that is to be received at a future date. The premise of the equation is that there is "time value of money". Time value of money is the concept that receiving something today is worth more than receiving the same item at a future date.

In order to make future cost assessments in the scope of ShipSoft, below present value calculation formulas will be needed. Following formulas are taken from Academic Resource Center publications of the Illinois Institute of Technology. (2012)

Formula 1 – Net Present Value of a Single Future Cost

$$PV = FV \frac{1}{(1+r)^n}$$

where FV = Future Value, PV = Present Value, r = discount rate, n = number of periods

Formula 2 – Net Present Value of an Ordinary Annuity

$$PV = C \frac{1-(1+r)^{-n}}{r}$$

where C = Annual Cost

Formula 3 – Net Present Value of Perpetuity (Periodic Payments)

$$PV = \frac{C}{i}$$

4 Case Study

4.1 Introduction to the Case Study

Case companies are chosen such that their collective operations will cover the ship's full life-cycle. For this purpose, the companies that were contacted to contribute to this case study are; Diesel Power AS; as the engine systems supplier, Multi Maritime AS; as the ship designer, Fiskerstrand BLRT; as ship builder, FosenNamsos Sjo AS and Tide Sjo AS; as the ship-owners and finally a ship recycling yard from Turkey.

Diesel Power AS is a Norwegian dealer that specialized on the design and manufacture of customer-specific power generation solutions for the shipping and off-shore market. Diesel Power is the chief representative of Mitsubishi Marine Solutions in Norway and offers both diesel engines and gas engines to the Norwegian maritime industry.

Fiskerstrand BLRT AS is a Norwegian shipyard specialized on manufacturing small to medium sized car and passenger vessels. Multi Maritime AS is a Norwegian ship designer and it is owned by Fiskerstrand. Fiskerstrand and Multi Maritime have developed and delivered many projects to the Norwegian maritime industry. Recently, they have started designing and manufacturing ferries that are powered with liquefied natural gas (LNG) fuel. One of their significant projects was the delivery of the World's largest LNG fueled sailing ferry "MF Boknafjord" in 2011.

FosenNamsos operates ferry and express boat routes along the central coast of Norway. The company aims to be one of the world's foremost users of gas-powered ferries and express boats. FosenNamsos has several vessels but in the scope of this project, our focus will be on "Selbjornsfjord" which has a Mitsubishi gas / electrical engine system.

Picture 1 Selbjornsfjord

Tide Sjo is another operator of transport systems on sea and land. The company operates 80 ferries / express boats which makes the company one of the largest sea transport operators within Norway. In the scope of this project, the focus will be on “Tidefjord”, a diesel / electrical engine ferry. The performance of this ferry will be compared with “Selbjornsfjord” of FosenNamsos.

Picture 2 Tidefjord

In this case study, the aim is to provide accurate and reliable life-cycle data on cost and environmental impacts of the new system (gas – electrical engine) compared to a conventional engine system (diesel – electrical engine). In order to have an accurate comparison among the two engine types, the ferries are chosen such that their engine system is supplied by the same company (which is Mitsubishi for the above two ferries). Furthermore, the two ferries have exactly the same capacity, 120 cars, and relatively similar speeds. Details of two vessels are as follows;

1. Selbjornsfjord Owner: FosenNamsos Sjo AS Engine System: Mitsubishi Gas / Electrical, Length: 109 meter, capacity 120 cars, Max. Speed: 15 knots
2. Tidefjord Owner: Tide Sjo AS (Norled AS) Engine System: Mitsubishi Diesel. / Electrical, Length: 113.50 meter, capacity 120 cars, max. Speed: 14 knots

Table below summarizes with which company to collaborate in each of the life-cycle phases.

Table 4: Industry Partners for the Case Study

Life-Cycle Phase	Type of Data	Environmental Data Source	Economic Data Source
Design	Engine System Design and Construction	Multi Maritime AS Engine System Supplier	Multi Maritime AS Engine System Supplier
Construction	Installation of Engine System at Shipyard	Fiskerstrand BLRT	Fiskerstrand BLRT
Operation	Operational Life Performance	FosenNamsos Sjo AS Tide Sjo AS	FosenNamsos Sjo AS Tide Sjo AS
	Maintenanace and Repair	FosenNamsos Sjo AS Tide Sjo AS Fiskerstrand BLRT	FosenNamsos Sjo AS Tide Sjo AS Fiskerstrand BLRT
End-Of-Life	Value after Ship Recycling	Ship Recycling Yards, Turkey	Ship Recycling Yards, Turkey

4.2 Data Collection from the Case Companies

Fiskerstrand was the first company, as being the shipyard (and the ultimate user of the ShipSoft), to contact in order to get their collaboration. After the preliminary meeting with Fiskerstrand, the concept of ShipSoft was better determined. In the meeting, Fiskerstrand was asked to suggest other companies that could represent the life-cycle phases for a possible case study. Then, each of these suggested companies are contacted and invited for collaboration.

In order to gather information for the case study, a data collection document is sent to all companies. Data collection documents were prepared to be company-specific, in other words rather than sending a standard document, a unique form is sent to each of the companies, depending on in which life-cycle phase they operate. The documents that were sent to companies are presented in the Appendix II.

The data requested from the collaborating companies were structured in such a way that, it does not require them to spend too much time on it or they would not have to make any kinds of computations. However and unfortunately, it was not possible to gather data from all companies. Companies that have not provided information had not mentioned the reasons of their nonparticipation. It might be either because they were reluctant to share the information that is confidential for them or because they did not want to spend any time on it although it was prepared to be as direct as possible.

4.3 Processing the Collected Data using the LCC Module Structure

Data collected from the collaborating parties needs to be processed in a life-cycle perspective. There are cost data which is assumed to happen at the present year and there are other cost data which are assumed to happen in the future years. Such future costs will be discounted to the present value. For the future costs, some are assumed to happen at a single time only where some others will happen every year or every five years throughout the operational life of the ship.

All of such different types of costs will be discounted to the current year through the use of different present value formulas. The formulas to use for present value calculations are described in part ...... (see page ....) According to these formulas;

- Capital and Installation Costs

  These costs are assumed to happen at the present day – at day 0. They are one-time costs that will not require any computation.

- Operation and Maintenance Costs

  Operation costs are assumed to happen every year throughout the 40 years operational life of the ship. Therefore, formula 2 will be used in order to compute their present value.

  For the maintenance costs, there are costs that happen every year, in a similar way to the operational costs, and the same formula 2 will be used to compute their present value.

  For maintenance costs that are assumed to happen every 5 years time, a different computation is required and this is given by the formula 3.

- End-of- Life Treatment Costs

  There will be certain gains and losses when a ship reaches to its end of operational life. All the costs or gains that will be realized are one-time future cost and they are represented with the formula 1.

4.4 Purpose and Audience

The goal of the comparison of two ferries based on their engine systems' performances, is to; (1) demonstrate which engine system performs better economically in the longer perspective, (2) how costs accumulate as the ship matures, (3) what is the break-even point for the innovative engine system.

The shipbuilder and ship-owners can use these results to make their investment decisions considering the life-cycle performances of different alternatives. Currently, they can only get data for the capital costs when they are to make their investment decisions. This case study will show that they have a new tool that can provide reliable information for all the costs that the ship-owner will eventually have to pay by owning the ship.

4.5 Collected Data for the Case Study

Data are collected from some of the companies that were mentioned in the preceding chapter. Unfortunately, it had not been possible to gather from all of the companies. For the lack of data for the full life-cycle of the ship, some previous studies were also used. These studies include; Life Cycle Cost Analysis study by the Glosten Associates and Next Ship – Lean Shipbuilding study of Steinar Kristoffersen. All data in below tables and computations are given is US dollars.

Capital Costs

Capital costs for main engines and gas storage and supply systems were determined as follows:

- Vendor supplied equipment costs were provided by Mitsubishi.
- Shipyard installation costs were estimated based on previous projects.

	Mitsubishi Diesel / Electrical	Mitsubishi Gas / Electrical
Total Capital Costs	4452110	7654000

Operational Costs

Fuel Consumption Costs

The consumption costs for the two engine types are calculated.

Table 5: Fuel Consumption Costs

Engine System	Status	Specific Fuel Gas (kJ/kWh)	Total Fuel Gas (Liter/hour)	Total Fuel Gas (Liter/year)	Specific Fuel Oil (g/kWh)	Total Fuel Oil (liter/hour)	Total Fuel Oil (liter/year)	Total Lube Oil (liter / hour)	Lube Oil (liter / year)
Mitsubishi Diesel / Electrical	Hauling	0	0	0	168	65,1	390600	0,651	3906
	Maneuvering	0	0	0	185	4,2	2100	0,042	21
	Docked/ Maintenance	0	0	0	185	4,1	4100	0,041	41
Mitsubishi Gas / Electrical	Hauling	6619	82,2	493200	0	0	0	0,822	4932
	Maneuvering	8432	86	43000	0	0	0	0,86	430
	Docked/ Maintenance	8564	86	86000	0	0	0		860

The prices of fuel are based on the fuel prices that is used by the recent research studies of Det Norske Veritas (DNV). (xx) Marine diesel oil (MDO) is assumed to be 870 USD / t and LNG is assumed to be 450 USD /t. Discount rate is assumed to be 3 %. According to these values, at the present year annual fuel consumption costs for the two engines are;

	Annual Fuel Consumption	40 - years Fuel Consumption
Mitsubishi Diesel / Electrical	350629,14	14025164
Mitsubishi Gas / Electrical	283442,16	11337680

Maintenance and Repair Costs

Maintenance costs are grouped in two categories;

Preventive Maintenance Costs; are the costs associated with the planned maintenance activities that aims to keep the system up and running all the time. Some of the preventive maintenance activities are carried out each year where some others are planned once in every three or five years time.

Corrective Maintenance or repairs refers to all activities that are carried out when there is a failure or a possibility for a failure in any part of the system. After the data is gathered for all these categories, below results were maintained.

	Mitsubishi Diesel / Electrical	Mitsubishi Gas / Electrical
Corrective Maintenance	211000	198000
Preventive Maintanance	320000	234000

End-of-Life Value

Below information is gathered from the ship recycling yards in Turkey. They represent the second hand economical values of the engine systems after 40 years of usage.

	Mitsubishi Diesel / Electrical	Mitsubishi Gas / Electrical
End-of-Life Value	780000	940000

4.6 Results and Discussion

Before implementing the case study, the motivation to compare different engine systems was the growing interest to the innovative engine solutions in the maritime industry. Although, there were many claims regarding the better operational performance of the LNG fuelled engines, it was also known that these engine systems required a higher level of capital investment. Through this case study, the intention was to find out how the total life cycle cost performance of the new engine system would be when compared to a conventional diesel / electrical engine system.

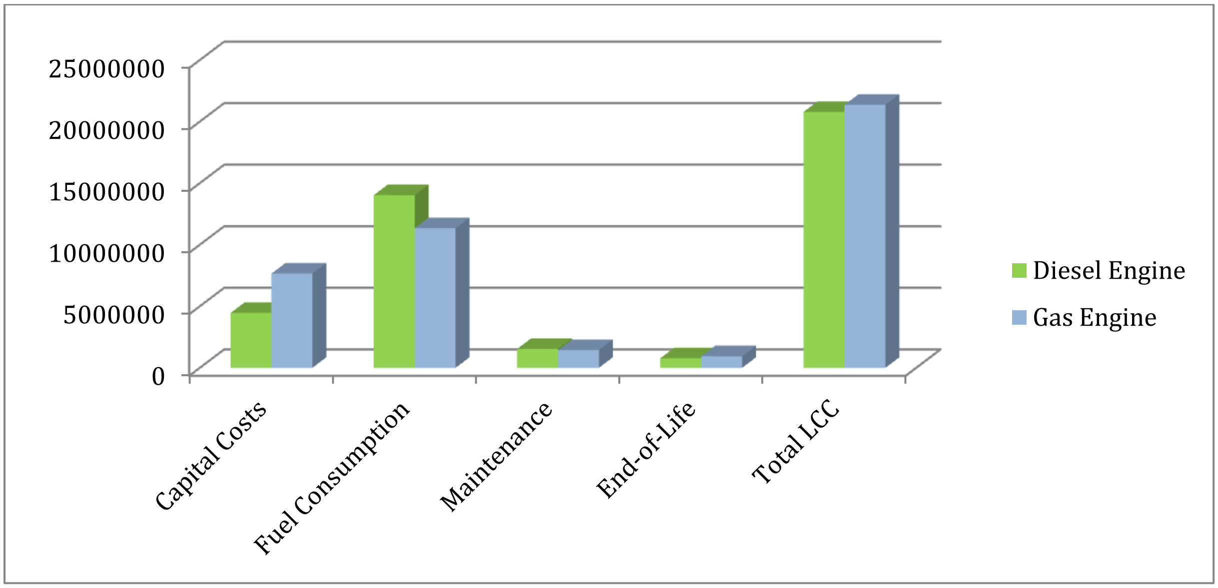


Figure 2: Comparison of Engine Systems

Results show that, gas / electrical engine required almost 70 % more capital investment. The installation costs and supplementary system costs were also higher for the gas engine system. However, in the operational life it had better fuel consumption performance and lower preventive and maintenance costs. In terms of the end-of-life value, gas / electrical engine system again had a higher value.

Combining all these information, it is found that diesel engine had a slightly better life cycle cost performance than that of the gas engine system. Better performance of the diesel system can be explained by the significant cost difference in the Capital Costs in other words in the Design & Construction phases.

4.7 Comments on the Case Study

In this case study, although the companies were contacted before sending the Data Request forms and their confirmation for participating the case was taken, not all companies provided the data. Especially, for the operational life phase, some adjustments needed because of the lack of data. Considering the small difference between the total life cycle cost amounts of the two engine systems, it is difficult to reach to a final decision and make any generalization about which engine system performs better. Still though, the case study has been a good demonstration to show how ShipSoft's LCC module will work.

4.8 Future Development Progresses in ShipSoft

Case study implemented in the scope of this master thesis has focused on the engine systems. Ships consist of many other systems and various subsystems in each of these systems. ShipSoft should include the structure for all the parts, materials, components that is used in a ship. Ship structures should be modelled and their algorithms in ShipSoft should be developed using the SFI Grouping system;

SFI Grouping System

There are several different group systems that are used world-wide in order to define the sub-structures of a ship. From a systems engineering point of view, these sub-structures are called sub systems and each sub-system consists of many components, parts and sections.

SFI Group System is the most used classification system for the maritime and offshore industry worldwide. It is an international standard which provides a highly functional subdivision of technical and financial ship or rig information. SFI was developed by the Ship Research Institute of Norway (SFI: Skipsteknisk Forskningsinstitutt) and it covers all aspects of the offshore shipping industry. More than 6000 SFI systems have been installed all over the world. SFI is being used by all the stakeholders of the maritime industry. SFI presents standardization on ship structures and provides significant benefits to the ship industry in the following areas; Communication, Co-operation, Cost Control, Cost Comparison, Quality Control, Computerisation, Development, Education and Training.

The system has a general structure with three main levels for data categorization. The main group is categorized on the first level and is denoted by a single digit number. These are presented in table 5, where a short description of the subsystems and functions are given. The ship is divided into 10 main groups, from 0-9, but only group 1-8 are in use. The second level shows the group and is denoted by two digits, while the third level shows sub-groups denoted by three digits.

Table 6: SFI group system description

Main Group	Description
1. Ship general	Details and costs that cannot be charged to any specific function onboard, such as general management, quality assurance etc.
2. Hull	Hull and superstructure, as well as material protection.

3. Equipment for cargo	Equipment, machinery, systems etc concerning the ship's cargo, such as hatches, cargo winches and loading/discharging systems
4. Ship equipment	Equipment and machinery that are specific for ships, e.g. equipment for navigation, maneuvering, communication and anchoring, as well as fishing equipment.
5. Equipment for crew and passengers	Equipment, machinery and systems that serve crew and passengers, such as equipment for lifesaving, catering and sanitary systems, furniture, etc.
6. Machinery main components	Primary components in the engine room, e.g. main and auxiliary engines, propeller plant, boilers and generators.
7. Systems for machinery main components	Systems that serve the machinery main components, e.g. fuel, and systems for lube oil, starting air, exhaust and automation.
8. Ship systems	Central ship systems such as ballage and bilge systems, fire fighting and wash down systems and electrical distribution systems.

ShipSoft should be structured according to the SFI Group System. The case study "Comparison of Different Engine Systems" is a part of the subsystem 6 – Machinery main components.

PART II

5 ShipSoft as Complete Shipyard Management Software

Second part of this thesis discusses and makes suggestions about how to make ShipSoft as complete management software for shipyards. However, suggestions that are made in this part will not be implemented in the scope of the ShipSoft project; they are only aimed to be the theoretical framework for an ideal shipyard management program.

There are many features that a shipyard management software should offer to its users. This study however, is focused only on issues that could improve the effectiveness of the LCA and LCC modules and also help to streamline all operations within the shipyard. Lean Thinking in shipbuilding industry has emerged as a growing field and it will be the main focus of this chapter.

5.1 The Lean principles

Lean is a comprehensive term that comprises of many different ideologies, techniques and practices. It is sometimes used to describe the practices of other techniques like Just-In-Time production principles (JIT), Total Quality Management (TQM), a widely scoped preventative maintenance program and human resource management.

Although it is difficult to make an exact common definition of Lean, as the definition might vary according to how it is adapted in an organization, there are certain characteristics that a Lean organization should possess;

- The use of overhead should be limited and the aim should be to reach a perfectly streamlined process among different departments and activities. All processes should be monitored.

- Instead of a reactive approach in the maintenance activities, the management should engage in a preventive approach through anticipating the problems and planning for them before they occur.

- Organization should have high transparency and less hierarchy. Employees from all departments should be engaged and aim to achieve one ultimate goal.

- All management units should continuously try to reduce the waste and redundant activities in manufacturing processes. Moreover, they should try to create efficiencies in the bottleneck activities.

Womack and Jones (2003) regarded the Lean Thinking as a cyclic route to seek perfection, centred around five principles;

1. Specify value
   Value should be defined by the end customer, in terms of product specification meeting the requirements of the end customer at a specific time and price.

2. Identify value stream
   Identify all the activities necessary to bring the product to the market, and eliminate activities that do not add value to the end product.

3. Create an uninterrupted flow

Make the value adding activities flow through the value stream to the end customer without obstacles such as delays and inventories.

4. Establish pull
   The reduced lead time from the first three principles should facilitate for only producing to a signal from a downstream customer.

5. Seek perfection
   The previous principles should allow for continuous improvement with the aim of maximizing value for customers while eliminating waste.

5.2 Lean Project Management in Shipbuilding Projects

Projects are temporary activities that are linked to multiple, enduring production systems from. In order to deliver a product or create efficiencies in a certain production environment, projects pull resources from various different production systems. Projects are costly activities and it is generally very difficult to anticipate the total life-cycle cost of a project during its planning phase. Lean Project Management aims to deliver the product or solve the given problem while trying to maximize its value and minimize all the costs associated with it.

There are fundamental differences between the conventional project management and lean project management. Although the names of the phases are same in both, their scope is totally different. For instance in lean project management, planning refers to setting specific goals for the production system. Operating consists of planning, controlling and correcting. (Kristoffersen, 2012)

Norwegian maritime cluster has important competitive advantages in the global ship building industry associated with the advantages of the unique region that they are operating in. Norwegian oil sector has been an important driving force for the Norwegian maritime industry since 1970s. Building the oil platforms and maintaining their operation required the development of specialized vessels, which is the major focus of the many Norwegian shipyards today. However, the dynamics of the global ship building industry has been changing in the last few years. “The competitive advantages of a region are never guaranteed to last, of course, and international capacity to deliver hulls and modules will potentially form the basis for stern competition in the future.” (Kristoffersen, 2012)

Norwegian shipyards have been facing a certain level of competition and this level is expected to increase in the near future. Some of the Norwegian shipyards have already started to engage their operations with international shipyards or they themselves invested in countries where labor costs are lower. Considering the demands of ship-owners and the dynamics of the competition, it is straightforward to understand that cost and lead times (speed of delivery) are the two major success factors for the Norwegian shipyards. This requires the integration of Lean Management in the daily operations of the companies.
Kristoffersen made a case study in a Norwegian shipyard where he analyzed the possible gains through the integration of Lean principles in the manufacturing processes of building specialized vessels. Firstly, he defined the major elements of Lean when they are applied to the shipbuilding;

- Precisely specifying the value of each specific product
- Identifying the so-called "value stream" for each product
- Make the value flow uninterrupted
- Let the customer initiate transaction (pull)
- The site itself is a resource.
- The production facilities have to be set up anew for each new build; indeed, the building project is in itself the production facilities.
- The production facilities as well as the teams and workers, are placed on the site and in relation to another.

In addition to these elements, he defined some further adaptations of Lean thinking that could increase the potential of applicability to the shipbuilding industry:

- Objectives need to be well and fully understood.
- Cross-functional teams may be concurrently active in the value stream.
- Design is likely to be shifted along the value stream, i.e., it is not all done up front
- Cycle–times are reduced
- Continuous improvement ought to be an integral part of the process

Considering these strategies and based on the principles of Lean thinking, Kristoffersen applied the Lean principles to the STX OSV shipyard in Norway. He obtained important results in terms of the applicability of Lean manufacturing to the shipbuilding projects;

1. Long-term philosophies do not govern short-term strategies

The tasks assigned to an assembly yard in Norway is not long-term strategically decided, but rather a judgment of capacity in the short-term, which is made by the board of the group rather than the director of the local yard. This does not seem to be part of a long-term philosophy.

2. Creating a continuous flow is hampered by the product-as-site nature of construction at the shipyard

The so-called Toyota-way calls for a continuous flow, which is the conceived non-interrupted and monotonously forward-driven nature of a process. It is problematic to implement in a setting that has some very large (and relatively few) critical process steps or machines in place, which is typically the case for shipbuilding with its cranes and docks. Typically, a situation was described to us in one of our meetings, which entailed the blockage of physical movement of one module by work on another. Finally, striving for continuous flow would also seem to try to reduce the change orders, since they by definition introduces back flows. Such back flows, on the other hand, are associated in shipbuilding with high-value work carrying better margins than work that proceeds according to plan, and hence it may be more difficult to eliminate, notwithstanding that there was not any indications given that the relationship between continuous flow and lucrative back flows had been explored in detail.

Also, there was a distinct cultural explication of the differences between yards in Norway and e.g., Romania, which in which the local yards were described as having more of an artisan (in contrast to industrial) history and hence, intuitive eye for shipbuilding, which made local workers understand intention better. This is a notional approach, which in addition travels poorly since distance and differences (cultural or otherwise)makes it more difficult to communicate. This part of our field work observation, regarding communication is not the only pertaining component. In addition is was recounted how the drawings were never finished, for various reasons, 3Ddrawings are poorly translated into 2D instructions, since the former is concluded in a more holistic way. The main point to notice here is not the explanations, but rather that the expectations, which thus reified the notion of a cultural difference, was that the steel yards in Romania needed precise drawings and instructions in order to do their work without waste of time and materials, whilst the Norwegian yards excelled exactly in managing well without those detailed drawings.

3. Using "pull" rather than push to avoid stocks and over production, may jeopardize supply security

The need to secure deliveries of very large and sometimes complex (or both) goods, which are not necessarily available from a production line with unlimited capacity (such as thrusters, streamers, lighting and subsea capacity),stocks are necessary in ship production.

4. Standardized tasks are needed for improvement and empowerment, but may be elusive

Given that the workplace is also the storage and part of the constructed mechanical structure; that it develops therefore throughout a process which is subject to variation due to the paradox of variation of parts if stock is eliminated vs. the lack of slack in space and suppliers production capacity, which may be strained, as well as the manpower-demand which is great overall, but not usually a static resource (people will be sick, take holidays and retire, require (re-)training or attend to their families during projects that go on for a year or more), tasks are less likely to be standardizable.

5. Bringing problems to the surface may reduce flexibility and trust

The initial response from subjects that we have talked to in the shipbuilding industry has throughout the project period been that “everything is under control”. This is understandable. Products are complex; construction is completely delegated and orders, as well as funding relies on trust. On the other hand, problems do, in fact arise, and hence it may be concluded that increased transparency reduces flexibility. Visualization (and documentation in general)must be seen in light of this.

6. Educate leaders and employees takes time and is part of a larger dynamics.

In our field work, STXOSV has provided an account, artefacts and demonstrations of a competence-oriented management style, in which people are constantly made aware of the core elements of lean shipbuilding. The interpretation of Lean (at the management side) varies from text book explication, however, and foremen and workers differ in the next instance even within what they have been taught. Evaluation of the learning outcome seems necessary.

Kristoffersen’s study provides a unique insight for understanding the dynamics of the Norwegian shipbuilding industry. Looking at the above points, it seems that shipbuilding industry has a completely different structure than other volume-focused mass production industries when it comes to the integration of Lean thinking. First of all, concepts suggested by Lean like; reduced lead times, pull strategies, reduced waste and idle times and all other methods that aim to increase the manufacturing efficiency is not applicable in the domain of ship building. In shipbuilding projects, considering the cost of the ship all other part – material costs can be negligible. The important thing is not the cost of parts or the wasted materials but it is keeping up with schedule. Once the schedule is disrupted, due to any minor issue, the whole project might end up with being a very unsuccessful one. However, there is probably no shipyard where all the orders and hence the schedules are fixed once they are placed. Changes in the customer specifications, supplier based incidents, problems related with financing are some of the reasons of the frequent variations in the manufacturing schedule of the shipyards. More importantly, because shipyards use common resources for many of their new building and repair projects, a minor change in one of the projects might have high influences in all the rest of the projects of the shipyard. Flexibility of the manufacturing processes for the variations is not a burden but actually an advantage of the Norwegian shipyards. Norwegian maritime industry is based on innovations and in order to stay innovative, shipyards have to afford a certain level of variation in their manufacturing processes. Therefore, even if the Lean principles are followed, this should not limit the flexibility potential of the shipbuilders.

One of the important principles of Lean thinking is the shared co-ordination mechanisms among the suppliers and the manufacturing site. This also leads to faster and more accurate transfer of the customer order information to the suppliers and hence decreases the supplier lead times. However, this technique has been physically practiced in the Norwegian shipyards since the first establishment of the modern shipyards. Most of the shipbuilding companies in Norway dedicate private plots to some of their key suppliers in their shipyard area. Suppliers and subcontractors, of course not all of them but only the key ones, use such spaces to store their own spares and equipment. This also enables to practice the “Genchi Genbutsu” (investiage personally) technique of the Lean thinking. This technique suggests that in order to truly understand a situation one needs to go to “gemba” or, the 'real place' - where work is done. In the current structure of the Norwegian shipyards, suppliers have their own staff in the yard all the time and they are able to continuously follow up the project and the manufacturing process in the shipyard. Even though the shipyard does not have any physical distance with most of their suppliers trough this structure, this is not supported by any software tool which limits the full potential of the co-ordination.

A core component of Lean Project Management methodology is “learning from failures” or “the evaluation”. Innovation based organizations tend to fail more with their projects than risk-averse organization. This implies that failure is a common practice of the Norwegian shipyards. Furthermore, it is an essential part of the profitability of the yard. Integrating the “learning from failure” concept into the daily operations of the shipyards would definitely provide significant benefits. In order to truly realize the concept, a typical shipyard should learn to accept failure as a real possibility in their innovation projects and even further they can plan for it by taking a portfolio approach where different projects balance each other’s risk profiles. This is also important to maintain the competitive advantages of the Norwegian maritime industry in the future. The key is to pursue innovation as a set of experiments that are designed to learn things and instrumenting each innovation project such that the planned learning is achieved at the end. Another key issue is the use of smart tools that can provide a reliable mechanism to store the experiences from the failed projects and their associated learning.

5.3 Lean Thinking and ShipSoft

This part will discuss how ShipSoft can be adapted to integrate Lean Thinking in the processes of a shipyard company. The suggestions for a possible adaptation will only be discussed but they are not going to be implemented because of the resource constraints of the project. Kristoffersen's study will be the basis for the discussion in this section as well. In the preceding section we discussed the six observations Kristoffersen's found based on the case study he made in STX OSV shipyard. The aim will be to address how this six points can be satisfied using the ShipSoft model.

Lean Thinking and all associated practices of it like Lean Project Management, Lean Manufacturing, Lean Design and so on, all starts with a change in the ideology of a company's top management and can only be sustained by the ongoing support of the management. Without such a support, no software tools would be effective in integrating the Lean into the company's organizational culture.

Firstly, ShipSoft should consider that the conventional Lean Project Management is not applicable to the Norwegian maritime industry because of the unique natural characteristics of the industry. Therefore, it should only focus on the techniques that can increase the efficiencies in the shipyards without suggesting any major changes in the current structure of the operations.

Secondly, it is also important to consider that Norwegian shipbuilders tend to follow their conventional way of "doing the things". They seem to be reluctant to implement the tight integration of the supply chains because they worry about the confidentiality of the communication. They are sensitive in sharing their inside information with third parties through any platform that can also provide an access to the core competences of their organization. This should also be considered and ShipSoft should provide limited access to the suppliers, subcontractors when they use the shipyard's databases.

Thirdly, the use of software tools in the Norwegian shipyards is very limited. Only designers and managers use such tools but it is very rare for the shipyard staff to be familiar with them. ShipSoft will require data input from technicians / workers that are working on the most physical tasks. They are both not familiar with computer tools and also do not have much time to spend trying to manage them. Therefore, all the modules of the tool should ask for very basic information which does not require any computation. Moreover, it should have a very simple interface, an interface that can be managed by non-practitioners.

5.4 Integration of Lean Project Management into ShipSoft

Norwegian maritime cluster in the Møre and Romsdal County is a unique maritime region in the world. In this region, one can find all the different stakeholders of the maritime industry; designers, ship builders, ship-owners and operators, equipment and parts suppliers, consultancy companies, engine manufacturers. This is also one of the main reasons why many ship-owners chose this region for maintenance and repair works of their vessels; they can easily find what they need in this region. The advantages of this area can be better utilized if common software is used by all the members of the industry. Japanese shipbuilding industry realized the benefits of the integration in the supply chain among shipyards and their suppliers of ship parts and also between the shipyards and the ship-owners. “In Japan, there was bigger cooperation for product development and technology that would benefit everyone, with government incentives, helping the growth of the local maritime sector.” (Moura & Botter, 2012) ShipSoft can be used by all industry members and innovation can be achieved as a result of the collective activities of these members. By using such a tool, shipbuilders can also unite their supply needs and would be able get more competitive prices than their competitors in other countries.

As it was mentioned earlier, cost of small parts / components are almost negligible when considering the cost of a ship for the shipyards. Based on this fact, shipyards are reluctant to decrease their stock level for such materials and parts. They prioritize the schedule over the cost of keeping extra intermediate stocks within their manufacturing process. However, a drawback associated with keeping intermediate stocks is not limited with the cost of keeping that extra stock. Shipyard’s physical area is its one of the most important resources. Shipyard’s profitability depends on its ability in how it utilizes its yard area. Keeping intermediate stocks occupies a considerable space. The pull methodology suggested by Lean Manufacturing offers a better way to streamline the different activities of the manufacturing process. In this method, a very few number of stock is kept and as soon as one unit is withdrawn from the stock, the preceding stations start manufacturing / processing a new unit. This method can be employed to minimize the number of intermediate stocks. In order to utilize the use of physical area, ShipSoft should offer a solution to the users.

In shipbuilding projects, most of the activities are carried out in parallel to each other. In order to obtain the best quality in production, decrease the manufacturing lead time and to lower the costs, it is essential to have more activities that run simultaneously. Having more parallel activities is constrained by the available physical area of the shipyard. For this reason, it is extremely crucial to plan the space accurately and efficiently and to eliminate all redundant moves and handlings in the process. Currently, Norwegian shipyards either use very basic and ad hoc tools or they make their own plans in order to allocate the space for the operations of different projects. Both of these methods are not only time consuming but also requires major updates when there is a little change in the schedule. With a separate module integrated to it, ShipSoft would support planners not only in generating efficient layouts, but also updating the existing plans with minimum effort when there is any change in the schedule. ShipSoft would aim to increase the utilization of the yard area and at the same time to maintain the production schedules. For the development of such a module, following activities are suggested;

- Firstly, there should be an automatic allocation of the activities depending on the type of the activity and the appropriate location of the activity inside the shipyard.

- Secondly, all wasted (not-occupied) spaces should be minimized.
  Although its integration into ShipSoft might be challenging, the most effective optimization would be through the use of a simulation program. The tool should find an optimal solution through considering several different alternatives that would be generated by the simulation program.

- Finally, the system should produce all the necessary documents including factory plans, daily production plans, schedules, list of not allocated activities.

Shipyards often prefer to do the planning themselves because they assign different priority levels to different projects. Some projects might have a very tight schedule and the user will probably like to prioritize the activities of such projects. Therefore, the system should also allow users to assign priority levels to projects so that this information is not disregarded in allocation decisions. Furthermore, a user interface can also be developed which could provide the user to re-arrange the automatically allocated activities on the yard area.

For the allocation algorithm, several options are present that could all be applied to the shipbuilding facilities. There are also algorithms that are specially designed and structured for the shipyards. One of these algorithms can be used to develop the structure of allocation algorithms in ShipSoft.

1. Long-term philosophies do not govern short-term strategies

Kristoffersen mentioned that the decisions are generally made by the top managers – board of directors – without any intervention of the local yard managers. This results in short-term strategies that are not aligned with the long-term goals of the organization. The use of a common software tool by the whole organization, that could include business unit managers, middle and top level managers, provides the unique chance of involving every member of the organization in decision-making processes. There would still be some restrictions regarding authorization of users for managing or viewing pages in the software. Through the use of such IT systems that involves people from all departments and all levels would lead to a more transparent organization where on the one hand the top managers can easily follow up the daily activities in the yard and on the other hand department staff can realize what other projects are being managed and what their direct contributions are to the long term strategies of their organization. To the extent that IT processes are strategically aligned, fast and cost effective, they would result in competitively important IT-enabled business advantages.

2. Creating a continuous flow is hampered by the product-as-site nature of construction at the shipyard

This is probably the major contradiction between the Lean Manufacturing and shipbuilding. Kristoffersen made very clear in his research that shipbuilding industry profits most from the back-flows (high value work – that occurs because of the change orders) where back-flows are regarded as evil in the Lean Thinking. As it was discussed earlier, with ShipSoft the intention is not to change any current structures of the industry as long as they are logically designed. Because back-flows are an important value added activity, ShipSoft will not define any new structures based on Lean Manufacturing.

3. Using “pull” rather than push to avoid stocks and over production, may jeopardize supply security

The third point is related with the intermediate and final stocks in the production process. The drawbacks of having intermediate stocks is discussed and criticized in this paper. Although their cost is negligible, the amount of space that they occupy can never be negligible considering the economic value of the physical space for the shipyard. Therefore, intermediate stocks should be minimized. In order to support this strategy, ShipSoft should employ the “pull” methodology of the Just-in-Time production strategy. Major components supplied by outside suppliers parties (suppliers / subcontractors that do not have their workshop inside the yard area) should be bought in advance in order not to cause any delays on the schedule.

4. Standardized tasks are needed for improvement and empowerment, but may be elusive

Norwegian shipbuilding industry is an Engineer-to-Order (one-of-a-kind production) industry. There are fundamental differences among the designs and specifications of different vessels. Ship-owners are interested to invest in new ships based on a unique need which requires a unique design. Ship is customized exactly according to the needs of the ship-owner. In this respect, it is very difficult and irrelevant to consider standardization of manufacturing processes in this industry. However, there are many parts which go through the same type of operations. ShipSoft can be structured such that when a new project is arrived to the shipyard and its information is feed into the system through the structure of SFI Grouping System, the system can aggregate some of the common components of the new project with the components of all other projects in the portfolio. Then, planning of the processes on these components can be made based on the aggregated number. Furthermore, this strategy would provide the shipyard negotiation power that is based on a higher amount of the aggregated demand.

5. Bringing problems to the surface may reduce flexibility and trust

There is no doubt that in any organization problems arise with the integration of an IT system. Flexibility gets diminished and trust is almost lost in some cases based on the transparency brought by the IT system. In ShipSoft, department managers will be the users and operators of their own projects and thereby they will still have some flexibility. Only difference will be that their decisions will be monitored by their senior level managers.

6. Educate leaders and employees takes time and is part of a larger dynamics.

Kristoffersen pointed the challenges related with the management of software training and difficulties with forming a central authority which can provide standardization on the training activities. This is a process that needs to be managed very professionally otherwise the software would never provide the expected full benefits. Companies can choose to get professional consultancy service if they do not have any prior experience in organizing software trainings.

5.5 Ship Repair and Maintenance Management

Ship repair can be described as a typical make-to-order operational system. The process of repairs, starting from taking the order up to the delivery of the vessel, is very complicated.

Ship yards, even the ones that are specialized on ship repair and maintenance, often make ad-hoc plans for the repair activities and hence use their resources inefficiently. In managing such complex operations requires the utilization of effective project planning and scheduling in all phases of the repair process including the management of human, material, facility and all reusable resource factors. What is even more challenging but also crucial is the alignment of all different resource factors such that they are used most efficiently in a collective manner. Without having such alignments among the resource factors cause workers or equipment to wait idle until the prerequisite activities are accomplished during the repair process.

Before the computers were used for planning and scheduling activities in shipyards, managers planned and scheduled their operations manually with using some basic charts. After the development and introduction of scheduling methods like Critical Path Method and Program Evaluation and Review Technique, shipyards started to apply such methods in their daily operations and experienced improved utilization of their resources. However, such methods have never been effective enough to guide the management of complex problems. In order to resolve the problems related with resource constraints more advanced techniques like branch and bound algorithm, zero-one programming and genetic algorithms have been introduced and used widely in the industry. But their effectiveness in addressing Resource Constrained Scheduling Problems has also been limited.

Effective management of resources is crucial and it is regarded as one of the most important success factors in almost any project, regardless of the size and complexity of the project. For a shipyard, the profitability and successful delivery of projects are very much dependent on the utilization of the shipyard's resources.

As it is the case in any typical operation in a shipyard, in repair and maintenance activities there are different stakeholders involved all aimed to achieve one ultimate goal. Some of these stakeholders are;

- The shipyard company
- The ship-owner / operating company
- Suppliers – Sub-contractors
- Classification societies

These different groups would come together either to plan and implement some maintenance activities that could prevent the breakdowns before they happen. This is called preventive maintenance and it does not only prevent the breakdowns but also many costs that could realize if such actions are not taken. In another case, the stakeholders might also be involved in projects to repair a ship which already had certain problems. This is called as corrective maintenance and it is needed when a certain equipment or component of the ship fails and this leads to (or might have the potential to lead to) a downtime in ship's operation. The cost of this maintenance is much higher than the cost of preventive maintenance.

There is a causal relationship between these two types of maintenance activities. Through preventive maintenance activities, the aim is to eliminate all the incidents which might cause a corrective maintenance. In other words, if there is not a proper and effective preventive maintenance management, then there will be more corrective maintenance activities that will be needed in soon time. In this case, overall repair and maintenance costs will increase and ship operator will lose a significant amount of time in the operational life of the ship.

Whether the maintenance activity is preventive or corrective, the partners that are involved in the process needs to exchange information while each has to do their own tasks in the proper way. However, the process is very complex just as the shipbuilding operations (Chryssolouris et al. 2001);

- One day operation loss has huge economical loss for the ship-owner. All the data about the ship repair / maintenance needs to be exchange quite quickly. At the same time, this should be done in a consistent way.

- It is not easy to anticipate the required maintenance activities at the very beginning of the process. Even identifying the required work takes important amount of time. The breakdown may be caused by or may have caused problems that are related with other parts or components of the ship.

- There are many parts that are involved in this process. Some will be repaired and some will be renewed. These parts are not supplied by one single company. There are different suppliers that will be involved in the process and all needs to follow the tight schedule and the shipyard is responsible for their follow-up.

Process starts when the shipyard receives a request from the ship-owner for the maintenance or repair activity. After the project is initiated, based on previous experiences and specific needs for the requested maintenance activity, shipyard starts planning the activities to carry out. Then, shipyard communicates with several internal and external suppliers and places orders for some parts and components. After the ship is in the yard for inspection, they gain more information about the required activities and shipyard orders more components from their suppliers and might request work from some of their sub-contractors. Throughout this process, a lot of communication takes place and the accuracy and speed of the communication is extremely binding for the successful delivery of the project.

5.6 ShipSoft – Maintenance & Repair Module

As per the future plans to design ShipSoft as a tool that could be used for all shipyard project management operations, the software should also be capable of handling the maintenance and repair operations. For the Norwegian shipyards, repairs are an important and high value business activity because of the unique maritime cluster in the country.

It is crucial to coordinate the operations to be performed as well as the utilization of resources within the organization. In most cases, this needs to be done with the suppliers or the sub-contractors. Synchronizing the resources with the sub-contractors

In ShipSoft's repair module structure, the shipyard should be specified as the main partner and the administrator of the system. The structure should be based on a hierarchical model where the shipyard is place at the top and all other external material and service suppliers are linked to the main partner. In repair activities, there will be various types of different tasks to perform and most of these tasks will have to take place in different departments within the shipyard. Therefore, shipyard should be partitioned according to Functional Units. Within each functional unit, there will again be different activities. A job shop should represent an activity within the functional units. Each job shop should have their own resources and these resources should be stored in the database. Each resource should be linked to an external or internal supplier. Resource term should also include a group of workers. Different Resources included in Job Shops should be parallel processors; they should be able to perform similar activities.

Customer request would be titled as "Orders" and in that case an Order should include the entire work activities that have to be done in order to fulfill the requirements of the customer. When an Order is received, the system should identify the Jobs within the Order and also the Tasks within each Job. Then, the Jobs should be directed to different Functional Unit and Tasks should be directed to Job Shop within the Functional Units. Figure below shows an example of such a system.

5.7 Contracts Management

Delivering a shipbuilding project consists of many different stages all of which needs to be well managed. In some cases, well designed, engineered and built ship projects might end up with being poorly executed projects due to the reasons related with the contracting strategy. An effective contracting strategy should consider the resource capabilities and availabilities of the shipyard as well as its suppliers and also the capabilities of the ship-owners.

ShipSoft should offer its users the possibility to manage their contracts through a reliable electronic system. Users then would be able to structure the contracts in a more consistent way, streamline all the procedures within the organization according to the contract strategy and increase their overall compliance. With an improved contract management companies would also capture more business opportunities, have improved relations with the suppliers and sub-contractors, have better mechanisms to anticipate unforeseen mechanisms and mitigate risk.

In addition to the standard contract structures that can be provided by any software, ShipSoft should focus on the following points;

- **Sharing the Schedule with the ship-owner**: ShipSoft will have a schedule management feature that can be updated at any time. Generally, ship-owners are interested to follow up with the manufacturing and delivery schedules of the shipbuilder. They are interested in this in order to compare the actual status of the project versus the scheduled delivery plan. The contract management module can produce updated manufacturing and delivery schedules to be presented to the ship-owner. Shipbuilder would probably be reluctant to share all internal procedures of their company so through this module they can design the schedules for the ship-owner by deciding what to include and what to exclude.
- **Changes in Specifications / Change Orders**: As it explained in this paper, changes in customer specifications or changes due to the supplier / manufacturing related incidents is a very common practice in the nature of the shipbuilding business. For Norwegian companies it is an important value generating activity therefore shipyards do not want to entirely avoid the change orders. However, with the lack of a software to support this process, the process becomes an extremely time-consuming and bureaucratic activity even for very small changes.

  A Change Order is a formal amendment to the contract, which might be due to the changes in any of the Contract Work Scope, the Contract Price, the Delivery Date or any other procedures that set forth in the contract documents. The Change Orders are very important considering their impact on the cost and the delivery schedule of the project. In a typical Change Order process, ship-owner makes their request for the change, shipbuilder presents a proposal for the amended cost and schedule, finally the ship-owner either accepts the proposal or the process results after some negotiations on the proposal. In ShipSoft's module, there can be standard Change Order form which should be filled by the ship-owner explaining all the details of the request. After shipyard received the request electronically, they can distribute the document to the related functional and managerial units. Functional units can update their own cost and time schedules and the Project Management Department should develop an aggregated plan after receiving to be presented as a proposal to the ship-owner. After the two parties agree on the proposal, updated plans should be send to all departments within the organization.

In some cases, the Change Order comes from the shipbuilder. This is generally related with an improvement change which occurs because of newly available information in the project. In such cases, the process should progress in the other way around by the initiation of the shipbuilder.

6 Resistance to the Integration of ShipSoft

It is natural and always the case that people are resistant in times of change. Resistance is generally due to anxiety and fear and also some part of it is due to the reluctance to the change of familiar practices that people are most confident with. In order to overcome this problem and achieve the successful implementation of ShipSoft, companies should engage their management in the integration process. Management should first try to understand the possible reasons of a potential resistance within their organization well before the software is implemented. Managers need to analyze the resistance according to several categories and then propose an action plan for each different type. Cameron et al. (2004) classifies the feelings that people might have during the change times; Learning Anxiety and Survival Anxiety. The former is related with the fear of connection the new thing that is being learned. Latter is related with the pressure to change. Learning Anxiety provides a resistance behavior where Survival Anxiety acts as the main driving force to adapt the new thing. Both of these feelings might be damaging and both needs to be well managed. The management can do several things. First of all, they should explain what kind of changes are expected to happen with the new integration and what will the organization's as well as the employee's benefits with this integration. Communicating the change and its expected results would give rationale to the employees for what will take place with the change in the organization. Then, they should listen to employees and try to understand their fear and anxiety. Next step would be to decide how to address the fear and anxiety. Most important part is related with the 6. point mentioned by Kristoffersen. Proper and effective training would prevent all the potential problems before they arise. Companies should get consultancy support in planning their training and educational activities.

7 Conclusion

In this thesis, the needs to develop an eco-efficiency tool for the Norwegian shipbuilders and designers have been identified, based on these needs; requirements for the software tool are determined and module structures of the software have been developed. Then, these are tested through the implementation of a case study.

Case study has shown that the tool can provide consistent results as well as reliable comparisons of different design alternatives early in the design phase of shipbuilding projects. The intention was to provide this information in the front-end phase of the projects which has not been achieved completely. In the front-end phase there is very few information available and there is a great possibility of variations in the available information. Therefore it is found that, ShipSoft would be most effective if it is used in the design phase. LCC module of the software proved to be a good indicator of the all future costs in ship's operational and end-of-life phases. However, the effectiveness of the tool depends on the user's ability to provide reliable information. As it was shown in the case study, results of different alternatives might be very close to each other and in such cases user might make wrong decisions if the quality of the input information is low.

In the second part of the thesis, the focus was on project management practices and how to integrate them into ShipSoft. Especially the Lean Engineering principles were discussed and some of the practices offered by Lean are found to be valuable integrations for ShipSoft. It was concluded that some of these practices will not only make the ShipSoft a complete shipyard management software but also will increase the consistency of the LCA and LCC modules through streamlining all the business operations of the shipyard.

This thesis also presented the future activities that are needed to accomplish the ShipSoft project. Structures to follow for the development of the LCA module have been given. Requirements for the rest of the developments have also been addressed. ShipSoft can be made a complete solution for all Norwegian shipyards if the suggestions given in Chapter II are also implemented.

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Appendix I – Software Requirements Specification

ShipSoft Pilot Project

Software Requirements Specification

24.03.2013

Volkan Tunarlı

Revision History

Date	Description	Author	Comments

Document Approval

The following Software Requirements Specification has been accepted and approved by the following:

Signature	Printed Name	Title	Date
	Annik Magerholm Fet	Project Manager	

1. Introduction

1.1 Background

Today Norwegian shipyards became the world leader in building complex vessels through systems integration that require the highest degree of customization. Shipbuilding industry in Norway can be classified as a typical “Engineer-to-Order” industry. Engineer-to-Order manufacturing is, however, characterized by low-volumes, high degree of customization and project-based processes. Research addressing the design and management of supply chains in such industries is scarce. (Haartveit, Semini and Alfnes, 2011)

Norwegian shipyards are facing fierce competition and they are well aware the competition will become even stronger in the near future. However, they also know they cannot compete with low labor cost markets on the price basis only. They need to continue building on their core competences and at the same time they need to develop new competitive advantages. Norway has also been a leading nation in designing green ships and developing designs that could reduce the carbon footprints of ships. However, consideration of environmental factors in the design process has a price-increasing effect on ships. Shipowners want to know the possible economic and bureaucratic gains of having the environmental considerations embedded in their daily operations. In most cases the environmental or economic benefits of different design alternatives are not very straightforward. One needs to consider the full lifespan of a ship in order to realize such benefits. Ship designers need smart tools that could provide information on life cycle environmental and cost performances of different design alternatives and that can make reliable comparisons among these alternatives.

Several software solutions that aim to provide environmental information of vessel construction and operation have been developed. (Dina Aspen) In the scope of the IGLO project relevant marine design software with their corresponding LCA compatibility features were analysed. The scope of the work within this project was limited to Cargo Vessels (general cargo, tankers, dry – bulk, multi – purpose) and Fishing Vessels. Below is the list of different software that are widely used in the maritime industry and that were analysed in the IGLO project;

- AVEVA Marine / previously Tribon M3, used for conceptual design and analysis, detailed design and production
- FORAN, used mainly in the initial design and detailed engineering
- HyperWorks, used in conceptual design and detailed design
- Maxsurf, used in initial design and analysis
- NAPA, used in conceptual design to class drawings
- Nupas Cadmatic, used in initial design, detailed design, production and outfitting
- Rhino, used in initial design
- Ship Constructor, used in detailed design and production

- SmartMarine / IntelliShip, used in ship design, production and life cycle management of the ship

In this same research, it was concluded that due to the fragmented structure of the maritime industry, there are not any single actor within the industry which can possess all the required data for an LCA. (I. Garda, IGLO – MP2020) Customization of the design software tools was suggested with a shipyard material management system in order to achieve most reliable and accurate results.

ShipSoft Project was initiated based on the emerging need of identifying the best economic and environmental options for vessel design and equipment. The main objective has been to develop a framework that serves as a basis for further development of LCA / LCC software for ships. (D.M. Aspen & A.M. Fet) The sub-targets of the project were defined as;

v) Identify the needs and requirements for the tool from the industry
vi) Model a tool for environmental assessments of ships in a life-cycle perspective
vii) Discuss model implications
viii) Make suggestions for future work

In the preliminary report by Aspen & Fet, two conclusions were made regarding the needs and requirements of the sector for the ship model;

3. The tool must fit all actors in the industry

   This statement points out the importance of having a holistic perspective in structuring the ship model. According to this holistic perspective, the ship model should be divided into some subsystems, which eventually make it more practical to perform assessments both on the subsystems and the ship as a single unit, and these subsystems must fit the structure of the industry.

4. The tool ShipSoft should be easy to develop further to meet future demands and trends.

In order to cope with the changing external conditions like international regulations and customer demands and to provide the allowance for the implementation of future applications, the model should have the sufficient flexibility and comprehensive perspective. In other words, ShipSoft must have a module oriented structure and there must be coherent interactions among different modules which sustains the holistic perspective of the model.

Previous researches on the implementation of LCA tools in the design processes showed that the tools must; (1) be better integrated to the daily operations (2) allow for quick analysis, (3) based on readily available data and (4) not require administration skills that exceed that of a “non-practitioners”. (O`Hare, 2010)

One of the important conclusions made in the ShipSoft Preliminary Report was to develop the software with a modular structure. Modules in ShipSoft will represent the separation of the concerns. The users may not be interested or even not be authorized to use specific functions of the program. Modular design will ensure that users can get or input information without having to deal with irrelevant and time-consuming functions. Moreover, more than one user will be able to work with the system at the same time. However, this does not mean the modules will perform completely discrete functions unlike a typical modular designed software. In ShipSoft, it is extremely crucial to have the interactions and alignment of the modules through a reliable, efficient and user friendly interface.

1.2 Purpose

The project's front-end phase is the stage when the project only exists conceptually, before the final decision of financing the project is made. (Samset, 2001) Commonly at the outset of the project, relevant information and knowledge about the project processes is at its lowest and thus uncertainty affecting the project is at its highest. Uncertainty gradually decreases as the project is planned and progressed. Starting the implementation of the project without sufficient consideration in the front-end phase might result in dedicating more resources in the execution phase in order to finish the project in time and within its planned budget. In most cases, such projects are exposed to time and cost overruns.

In developing ShipSoft, the aim will be to provide a software tool, to the maritime industry, that is a reliable guide in comparing different alternatives, gathering information about the future activities in the project, managing different risk elements and discovering the causal relationships within the project. With all these features, users will be able to get enough information in the front-end phase of their projects and hence they will be less reluctant in dedicating the right resources in the implementation phase. The goal is to provide information on;

- Life-cycle environmental impacts of different design and material alternatives
- Life-cycle cost assessments of different design alternatives
- Cost implications of environmental considerations as well as the environmental impacts associated with different cost decisions

early in the front-end phase of ship building projects.

The importance of an effective cost assessment and understanding the factors that drive cost can also be crucial when comparing design alternatives.

3. Designers will be able to quickly perform trade off studies and therefore develop a better understanding of their designs affect cost
4. With an ability to perform reliable cost assessments at the preliminary level, the shipyards will be able to negotiate more favourable contract terms that could decrease costs.

In the pilot project of ShipSoft, a model of the software will be developed in order to test and further develop the model with additional features.

1.3 Scope

The pilot project of ShipSoft is aimed to deliver a model that can be tested with all the modules inside it. The pilot model will be used to provide an idea about the system and its purpose to the industry and to get feedback from the industry in order to develop the project further. However, with its current scope, the commercial version of the software will not be developed.

Definitions, Acronyms, and Abbreviations

- IGLO: Innovation in Global Maritime Production Project – 2020
- LCA: Life Cycle Assessment
- LCC: Life Cycle Costing
- SFI: Grouping System for Ship Design / Construction
- EQMS: Enterprise Quality Management System

2. General Description

This document contains the guidelines and requirements for the development of the ShipSoft Project. It further contains detailed information about the different modules that should be included in the project and their possible interactions.

2.1 Product Perspective

The two main functions of ShipSoft is to allow ship designers to make cost and environmental impact assessments. With the use of these two individual modules as well as their combination, designers will be able to make their design choices based on the full environmental and cost impacts of different materials and design alternatives.

2.2 User Characteristics

The pilot model should provide the necessary tools to make environmental and economic assessments over the full life-cycle of ships. It should also provide the causal relations among the cost and environmental impact and assessments based on these relations. The software should have following features;

3. Specific Requirements

Criticality Scale: Very Low (1) – Low (2) – Medium (3) – High (4) – Very High (5)

1. Very Low: Items that can be eliminated should serious system constraints encountered.
2. Low: Items that are extra functionalities that may be evaluated for possible elimination.
3. Medium: Items that are strongly desired by the users of the system.
4. High: Items which are required in the system in order for lower criticalities to function.
5. Very High: Items that are mission critical and that the system cannot function without.

1. It should be possible to make individual cost estimations and environmental assessments

1. Description
   The system should allow making autonomous life-cycle assessments and cost estimations.
2. Criticality
   5
3. Technical issues
   Pre-condition: individual modules should be properly coded.
   Post-condition: the system shall properly display individual and dependent relations properly
   . on the user interface.
4. Risks
   The software may require information on both environmental and cost dimensions where the user is only interested in getting results for one of them.
5. Dependencies with other requirements
   Related with having modular structure

2. It should also be possible to see the cause-effect relations among cost and environmental impact.

1. Description
   The system should allow the users information about the cost effects of having environmental considerations in the design phase.
2. Criticality
   4
3. Technical issues
   Pre-condition: Interrelations among the modules should be properly coded.
   Post-condition: Same relations should be properly designed and displayed in the user interface.
4. Risks
   There might be difficulties in establishing the relations among environmental and cost factors.
5. Dependencies with other requirements
   Related with having modular structure

3. The software should have a modular structure and the modular structure should represent the separation of the concerns.

1. Description

   In order to have direct access and autonomous control of different factors, the system needs to have a modular structure.

2. Criticality

   5

3. Technical issues

   Pre-condition: individual modules should be properly coded.

   Post-condition: the system shall properly display individual and dependent relations properly . on the user interface.

4. Risks

   Information and causal relations might be lost while trying to make connections among the modules.

5. Dependencies with other requirements

   N/A

4. In each module, all the existing material and design options should be included and users should be able to make their own selections out of these options

1. Description

   Having such a tool should add value to the operations of users. Therefore, while modeling the modules no design or material alternatives should be lost.

2. Criticality

   4

3. Technical issues

   Pre-condition: Information should be gathered from the industry regarding all possible alternatives.

   Post-condition: all predetermined alternatives should be properly included in the interface

4. Risks

   There might be challenges with representing some of the alternatives in the software format.

5. Dependencies with other requirements

   Related with having information on life-cycle effects in the design phase.

5. Users should be able to see the life-cycle effects of each of their selections.

1. Description

   When selecting a certain design or material option from the software, users should be able to see the life-cycle consequences of their selections early in the design phase.

2. Criticality

   4

3. Technical issues

   Pre-condition: Life-cycle impacts of each design / material option should be developed.

   Post-condition: Life-cycle impacts should be linked to the options in the design phase.

4. Risks

Because the information will be gathered from the life-cycle, the accuracy will be weak.

5. Dependencies with other requirements

N/A

6. The pilot model should provide parameter – driven and user – definable reports

1. Description

There should be a report generation feature within the software.

2. Criticality

2

3. Technical issues

Pre-condition: Reporting system should be developed.

Post-condition: Reporting system should be integrated to the user interface properly.

4. Risks

N/A

5. Dependencies with other requirements

N/A

3.1 External Interface Requirements

3.1.1 User Interfaces

Visibility of system status. Users should always know where they are and what's going on.

Real world - system match. The system should mirror the real world of the user as much as possible. Use language, concepts, etc. that are familiar to the user. Order the processes/screens in a way that is meaningful and logical to the user.

Flexibility and efficiency of use. Accelerators (unseen by novice users) can speed up interaction for expert users. Allow users to customize frequent actions whenever possible.

Aesthetic and minimalist design. Visibility of rarely needed information should be avoided. The more information that appears on the screen, the less visible each unit of information becomes.

Effective error handling. Assist users to recognize, diagnose, and recover from errors.

The user should be able to set up a system by describing the sequence of operations involved in making, using, and disposing/recycling via a set of dialog sheets selected via the menu. Additional features should include pull-down menus, mouse support, and point and click activation of many of the features.

3.1.2 Hardware Interfaces

All components must be able to execute on a personal computer.

3.1.3 Software Interfaces

The LCA module should be developed with the GaBi software program. For the LCC, GaBi can be considered as well.

3.1.4 Communications Interfaces

Communication among the different modules of the software should be established. The developer and client modules must also communicate with the server over a TCP / IP connection.

3.2 Design Constraints

The ship model must be compatible with the industry structure. In this section, a ship model that meets this demand is proposed. The SFI Group System should be used as a foundation for the ship model.

3.3 Modules

LCA Module

It is evident that an identification of the actors in the industry, their incentives to use the tool and the current trends towards using quantified environmental data must be done in order to develop a tailored tool for the maritime industry.

In order to establish an LCA module for the full life cycle of a ship, it requires a deep understanding of the ship building processes, ship recycling processes, material processing in the building process and manufacturing processes of all parts / machines used in the ship.

For the LCA module of ShipSoft, the following criterion has been determined;

- It should provide to the users a comprehensive selection of environmental indicators that are relevant to the maritime industry
- It should provide enough flexibility to the users in modifying the scope of the projects and choosing the processes, materials and operations.
- In consideration of all the above points, the application to be developed in this project should be a practicable working prototype. In this stage, it should not be accepted for commercial applications.

In principle, LCA needs to be carried out for the full operational life cycle of the ship. If the ship is operated for n years, a basic formula to estimate the total environmental impact of a given indicator can be as follows;

$$E = C + n.A$$

where n represents the total number of years the ship is in operation, *A* represents the environmental impact of one single year and *C* is the summation of all the one-time environmental impacts in the building and end-of-life treatment phases. This formula assumes that the environmental impact of the indicator will be stable over the operational lifetime of the ship. In most cases, this is a weak assumption as the environmental impact of an indicator increases as the ship matures. For such indicators the formula can be modified in this way;

$$E = C + A.\, \frac{1-(1+x)^n}{1-(1+x)}$$

where x represents the increase in the environmental impact of the indicator in one year.

LCC module

A module that enables determination of life cycle costs along the same dimensions as the environmental performances may also be developed. This makes it possible to measure both eco-efficiency as well as tracking costs through ship or ship subsystem life cycle. This is an important parameter for many actors in the maritime industry. Especially for the shipowners, LCC can provide significantly important information when making their investment decisions. Certain ships might have relatively lower purchasing prices. However, operating them might be more expensive than the other alternatives that have higher initial purchasing price. LCC takes into account both the initial investment amount as well as the operational costs and presents a reliable benchmarking for the decision makers. In order to make this tool more attractive for the industry, it is crucial to combine the LCA tool with the LCC module.

Design module

ShipSoft should provide various alternatives for both assessing and comparing ships and subsystem through various life cycle stages. The motivation for using such a tool may quite often be to determine what design alternatives provide the most optimal results, both for ships and subsystems. This is a module that could be targeted towards design companies, ship owners and other actors involved in the design phase of a ship. Both environmental concerns and other parameters could be connected to various subsystems to create a foundation for decision making in this phase.

EQMS Module

A lot of the suppliers of subsystems in ship industry are certified according to ISO 14001, and ISO 9001 standards. These contain requirements for environmental and quality management systems. The tool can provide a module that enables companies to control their environmental aspects and quality management according to these standards. This can be done in several ways. Firstly, the already proposed structure enables tracking emission sources to various input factors.

By choosing other input factors, and the quantity of the various inputs, the tool could produce tables and graphs showing relative and absolute improvement. This control tool is based on the LCA data and the indicators already presented. Secondly, by developing an extension tailored the suppliers, various process alternatives can be weighted and relative performances according to the alternatives could be provided.

Carbon footprint module

Due to regulations and a global focus on environmental concerns related to climate change, ship industry actors have prioritized the control of CO2-emissions the last decade. Estimating Carbon Footprints is a simple approach to measure environmental effects from various design and operational alternatives. This module could build upon the ISO 14067 Carbon Footprints of Products. This module could become highly relevant if the integration of international shipping within the Kyoto Framework takes place. A similar tool, Carbon Management, is provided by PE international, where companies can monitor emissions and the market for carbon quotas, manage 29 allowances and communicate emissions to authorities and customers.

Water footprint module

Recently, the water footprint has also become a highly relevant parameter for measuring environmental performances. Such a module could estimate green, blue and grey water footprints.

Compliance module

How are subsystem suppliers and ship owners performing according to emissions and quotas on various substances? IMO has set strict regulations on SOx, NOx and CO2-emissions, and various regulative aims to control certain substances. By tracking these emissions in a life cycle perspective, companies can control and communicate their total emissions, and monitor and ensure they are complying with law.

End-of-Life Treatments Module

End-of-life treatments represent the final phase in a ships life cycle. Management of this phase is crucial both for the overall sustainability of the maritime industry and sustainability of the organizations in the industry.

In the maritime industry, both from the economic and environmental perspectives, the most desirable end-of-life treatment option for an old vessel is the recycling of the ship. Recirculation of the materials inside a vessel provides significant advantages to the environment as well as to the economy. From the environmental point of view; it reduces the use of natural resources in order to produce materials and provides sustainable solutions in getting rid of the old and highly hazardous vessels. From the shipowner`s point of view, it provides financial support to make investments for a new ship. In terms of the global and country specific economics it provides;

employment opportunities, support to local businesses and supply of good quality steel to steel manufacturing industries.

ShipSoft should provide information on the possible gains and losses associated with different end of life options. It should further link this information to the design stage and enable the designers to see what kind of end of life treatment effects a certain design alternative has and this information should then be used for benchmarking of the design alternatives and material options.

In this module one obvious weakness will be related with the lifetime of the ship. Since ships have very long lifetimes, estimating the present value of the ship's salvage value or the value of recyclable materials inside the ship will not be very accurate. Although it will not be very accurate, this information should still be get from similar ship projects whose operation are ended.

4. Change Management Process

During the course of the project, there might be changes about the scope and requirements. It will be possible to gather more information about the structure of the modules and depending on this new information project team members are authorized to make changes in the process. Other members should be informed about the structure of the change and its possible consequences.

Appendix II – Information Request Document

Information Request Document from the Industry Partners of ShipSoft Project

Purpose

This report is prepared in the scope of the ShipSoft project. It includes the structure for data collection from the industry partners of ShipSoft project in order to implement the LCC module of the pilot model. This is the first data collection document and aims to gather information only for the LCC purposes. A second document for the LCA module will also be prepared and send to the industry members.

Structure

Studies based on life-cycle thinking, requires gathering information from various different stakeholders which are involved at some point along the life-cycle of the product / service that is being studied. Ship's life-cycle is defined with four main phases; Project Planning / Design, Construction / Production, Operation / Maintenance, System retirement / Scrapping.

Therefore, this paper consists of 4 main sections, each aimed to be presented to one single stakeholder for each different phase. However, in making life-cycle studies, it is important to ensure that interactions among different phases are also covered. For this purpose, the companies to collaborate in this case study are chose such that, they already have the supplier – customer relationship with each other in their business activities.

Case Study

Engine Systems Comparison based on Life-Cycle Environmental and Economical Performance

The use of LNG fueled engine system in ships offers certain environmental benefits and operational cost savings. Because this is quite a new concept in the maritime industry, companies claim different saving rates for the environmental and cost factors. Scientific research on this concept has also been limited until now. Previous research has either focused on the environmental gains or on the cost savings but lacked to combine the two perspectives. With the pilot model of ShipSoft, a case study to compare conventional engine systems vs. LNG fueled engine systems will be implemented and the causal relations between the environmental considerations and cost factors will be revealed.

Case Companies

Case companies are chosen such that their collective operations will cover the ship's life-cycle. For this purpose, the companies to contribute to this case study are; Diesel Power AS; as the engine systems supplier, Multi Maritime AS; as the ship designer, Fiskerstrand BLRT; as ship builder, FosenNamsos Sjo AS and Tide Sjo AS; as the ship-owners and a ship recycling yard from Turkey.

Diesel Power AS is a Norwegian dealer that specialized on the design and manufacture of customer-specific power generation solutions for the shipping and off-shore market. Diesel Power is the chief representative of Mitsubishi Marine Solutions in Norway and offers both diesel engines as well as gas engines to the Norwegian maritime industry.

Fiskerstrand BLRT AS is a Norwegian shipyard specialized on manufacturing small to medium sized car and passenger vessels. Multi Maritime AS is a Norwegian ship designer and it is owned by Fiskerstrand. Fiskerstrand and Multi Maritime have developed and delivered many projects to the Norwegian maritime industry. Recently, they have started designing and manufacturing ferries that are powered with liquefied natural gas (LNG) fuel. One of the significant projects was the delivery of the World's largest LNG fueled sailing ferry "MF Boknafjord" in 2011.

FosenNamsos operates ferry and express boat routes along the central coast of Norway. The company aims to be one of the world's foremost users of gas-powered ferries and express boats. FosenNamsos has several vessels but in the scope of this project, our focus will be on "**Selbjornsfjord**" which has a Mitsubishi gas / electrical engine system.

Tide Sjo is another operator of transport systems on sea and land. The company operates 80 ferries / express boats which makes the company one of the largest sea transport operators within Norway. In the scope of this project, the focus will be on "**Tidefjord**", a diesel / electrical engine ferry. The performance of this ferry will be compared with "Selbjornsfjord" of FosenNamsos.

In this case study, the aim will be to provide accurate and reliable life-cycle data on cost and environmental impacts of the new system (gas – electrical engine) compared to a conventional engine system (diesel – electrical engine). In order to have an accurate comparison among the two engine types, the ferries are chosen such that their engine system is supplied by the same company (which is Mitsubishi for the above two ferries). Furthermore, the two ferries have exactly the same capacity, 120 cars, and relatively similar speeds. Details of two vessels are as follows;

1. **Selbjornsfjord** Owner: FosenNamsos Sjo AS Engine System: Mitsubishi Gas / Electrical, Length: 109 meter, capacity 120 cars, Max. Speed: 15 knots

2. **Tidefjord** Owner: Tide Sjo AS (Norled AS) Engine System: Mitsubishi Diesel. / Electrical, Length: 113.50 meter, capacity 120 cars, max. Speed: 14 knots

Table below summarizes with which company to collaborate in each of the life-cycle phases.

Life-Cycle Phase	Type of Data	Environmental Data Source	Economic Data Source
Design	Engine System Design and Construction	Multi Maritime AS Engine System Supplier	Multi Maritime AS Engine System Supplier
Construction	Installation of Engine System at Shipyard	Fiskerstrand BLRT	Fiskerstrand BLRT
Operation	Operational Life Performance	FosenNamsos Sjo AS Tide Sjo AS	FosenNamsos Sjo AS Tide Sjo AS
	Maintenanace and Repair	FosenNamsos Sjo AS Tide Sjo AS Fiskerstrand BLRT	FosenNamsos Sjo AS Tide Sjo AS Fiskerstrand BLRT
End-Of-Life	Value after Ship Recycling	Ship Recycling Yards, Turkey	Ship Recycling Yards, Turkey

Diesel Power AS / Mitsubishi

Engine System

This document is to be presented to Diesel Power AS in order to get information about the performances of engines systems that are to be compared with this case study.

Vessels use different speeds during their voyage. ShipSoft will provide three speed options where the users can set values for their low, average and high speed.

Case 1; Selbjornsfjord Owner: FosenNamsos Sjo AS Engine System: Mitsubishi Gas / Electrical, Length: 109 meter, capacity 120 cars, Max. Speed: 15 knots

Considering the three speed options that you want to use, please specify the engine power, the number of engines used, total power in terms of kW, hours per year and total power per year for each of the three options. Please also specify the same values when the ferry is maneuvering, when it is docked and when it is under maintenance.

Status		Engine Power	Number of Engines	Total Power (kW)	Hours / Year	Total Power / Year (kWh/year)
Travelling	Speed Option1					
	Speed Option2					
	Speed Option3					
Maneuvering						
Docked						
Maintenance						
Total						

Diesel Power AS / Mitsubishi

Engine System

This document is to be presented to Diesel Power AS in order to get information about the performances of engines systems that are to be compared with this case study.

Vessels use different speeds during their voyage. ShipSoft will provide three speed options where the users can set values for their low, average and high speed.

Case 2; Tidefjord Owner: Tide Sjo AS (Norled AS) Engine System: Mitsubishi Diesel. / Electrical, Length: 113.50 meter, capacity 120 cars, max. Speed: 14 knots

Considering the three speed options that you want to use, please specify the engine power, the number of engines used, total power in terms of kW, hours per year and total power per year for each of the three options. Please also specify the same values when the ferry is maneuvering, when it is docked and when it is under maintenance.

Status		Engine Power	Number of Engines	Total Power (kW)	Hours / Year	Total Power / Year (kWh/year)
Travelling	Speed Option1					
	Speed Option2					
	Speed Option3					
Maneuvering						
Docked						
Maintenance						
Total						

FISKERSTRAND BLRT

This document is to be presented to Fiskerstrand BLRT, in order to get cost information for the purchasing and installation costs of the engine systems.

Ferries Chosen for the Case Study;

1. **Selbjornsfjord** Owner: FosenNamsos Sjo AS Engine System: Mitsubishi Gas / Electrical, Length: 109 meter, capacity 120 cars, Max. Speed: 15 knots

2. **Tidefjord** Owner: Tide Sjo AS (Norled AS) Engine System: Mitsubishi Diesel. / Electrical, Length: 113.50 meter, capacity 120 cars, max. Speed: 14 knots

Note: Please specify the currency when entering monetary values.

Capital Costs of Engine Systems

	Gas / Electrical Engine System in "Selbjornsfjord"	Diesel / Electrical Engine System in "Selbjornsfjord"
Total Capital Purchasing Cost		

Installation Costs at the Shipyard

Shipyard installation costs refer to all cost that are incurred during the installation of the engine system at the shipyard. Installing a new engine system might require changes in some of the standard installation processes. All additional costs that occur because of such changes should be reflected in the cost data to be provided.

Hourly Wage of a Skilled Worker	Hourly Wage of a Unskilled Worker	Engine System	Total No. Skilled Worker Hours Required	Total No. Unskilled Worker Hours Required	Additional Installation Costs
		Installation of Selbjornsfjord's Gas Engine System			
		Installation of Tidefjord's Diesel Engine System			

FISKERSTRAND BLRT

Maintenance Activities in the Shipyard

In this document please provide information for the **"Selbjornsfjord"** ferry**.**

Please input information about the cost of routine maintenance activities on the engine.

Routine Maintenance Activities	
Time Frame	Cost of Routine Engine Maintenance

For all other preventive maintenance activities the two below tables should be used.

In this table, please specify the items / parts that need to be renewed every year as well as their approximate unit cost and labor hours required to change or integrate that part into the engine system.

Parts that require preventive maintenance every year				
Item Description	No. Of Parts	Approximate Unit Cost	Labor Hour Required for Replacement	Additional Costs

For the parts that undergo an overhaul activity every five years, the following table should be used.

Parts that require preventive maintenance every 5 years				
Item Description	No. Of Parts	Approximate Unit Cost	Labor Hour Required for Replacement	Additional Costs

FISKERSTRAND BLRT

Maintenance Activities in the Shipyard

In this document please provide information for the **"Tidefjord"** ferry**.**

Please input information about the cost of routine maintenance activities on the engine.

Routine Maintenance Activities	
Time Frame	Cost of Routine Engine Maintenance

For all other preventive maintenance activities the two below tables should be used.

In this table, please specify the items / parts that need to be renewed every year as well as their approximate unit cost and labor hours required to change or integrate that part into the engine system.

Parts that require preventive maintenance every year				
Item Description	No. Of Parts	Approximate Unit Cost	Labor Hour Required for Replacement	Additional Costs

For the parts that undergo an overhaul activity every five years, the following table should be used.

Parts that require preventive maintenance every 5 years				
Item Description	No. Of Parts	Approximate Unit Cost	Labor Hour Required for Replacement	Additional Costs

FosenNamsos Sjø AS

This document is to be presented to FosenNamsos Sjø AS, in order to get cost information related with the operational life of the gas / electrical engine system in the "Selbjornsfjord" ferry.

Fuel Consumption Costs – Operational Costs

Most significant environmental and economic gains of choosing an innovative engine type will be realized during the operational life of the ship. In this phase, precise analyzes and assessments are crucial in order to have a reliable life-cycle tool for the maritime industry. In this phase, cooperation with FosenNamsos, as being ship-owners and operators, is needed.

Representative Route and Annual Operation

In order to simplify the calculations but still ensure the reliability of the case, FosenNamsos is invited to define a representative operating route for "**Selbjornsfjord**" which will be assumed to be the basis of all calculations and comparisons for the total life-cycle of the vessel.

According to the defined route, please provide the fuel consumption rate on that route. There are three different engine status options which enable to specify different consumption rate while the ferry is (1) travelling, (2) maneuvering and (3) docked.

Considering the usual route that the ferry operates on, please specify the gas consumption rates for three status options. Also, specify the total gas consumption in terms of liters for each status option throughout the journey on the route. Finally, specify the total amount of time that the ferry is (1) travelling, (2) maneuvering and (3) docked during the journey on the defined route.

Please use the below table to input information.

Engine Type	Status	Specific Fuel Gas (kJ / kWh)	Total Fuel Gas per route (liters/route)	Total Number of Hours
Mitsubishi Gas Electrical	Travelling			
	Maneuvering			
	Docked			

Regarding the maintenance and repair activities, most of the information for the preventive maintenance activities will be gathered from Fiskerstrand. However, for corrective maintenance the following information is needed from FosenNamsos.

Please specify the types of engine breakdowns, their probability of occurrence, how many days it normally takes to repair the engine system and all costs that incurs because of this breakdown.

Case Description	Probability of Occurence	Exected Number of Days for Repair	Total Cost of Repair Activities	1 day operation loss cost for shipowner

Tide Sjø AS

This document is to be presented to Tide Sjø AS, in order to get cost information related with the operational life of the diesel / electrical engine system in the "Tidefjord" ferry.

Fuel Consumption Costs – Operational Costs

Most significant environmental and economic gains of choosing an innovative engine type will be realized during the operational life of the ship. In this phase, precise analyzes and assessments are crucial in order to have a reliable life-cycle tool for the maritime industry. In this phase, cooperation with Tide Sjø AS, as being ship-owners and operators, is needed.

Representative Route and Annual Operation

In order to simplify the calculations but still ensure the reliability of the case, Tide is invited to define a representative operating route for "**Tidefjord**" which will be assumed to be the basis of all calculations and comparisons for the total life-cycle of the vessel.

According to the defined route, please provide the fuel consumption rate on that route. There are three different engine status options which enable to specify different consumption rate while the ferry is (1) travelling, (2) maneuvering and (3) docked.

Considering the usual route that the ferry operates on, please specify the fuel consumption rates for three status options. Also, specify the total fuel consumption in terms of liters for each status option throughout the journey on the route. Finally, specify the total amount of time that the ferry is (1) travelling, (2) maneuvering and (3) docked during the journey on the defined route.

Please use the below table to input information.

Engine Type	Status	Specific Fuel Diesel (kJ / kWh)	Total Fuel Consumption per route (liters/route)	Total Number of Hours
Mitsubishi Diesel Electrical	Travelling			
	Maneuvering			
	Docked			

Regarding the maintenance and repair activities, most of the information for the preventive maintenance activities will be gathered from Fiskerstrand. However, for corrective maintenance the following information is needed from Tide.

Please specify the types of engine breakdowns, their probability of occurrence, how many days it normally takes to repair the engine system and all costs that incurs because of this breakdown.

Case Description	Probability of Occurence	Exected Number of Days for Repair	Total Cost of Repair Activities	1 day operation loss cost for shipowner

Ship Recycling Yards in Turkey

End of Life Value

This document is to be presented to Ship Recycling yard companies in Aliaga, Turkey in order to get information regarding the value of the engine systems when the ship reaches to its end of operational life.

After the ship has reached to its end of life, it will probably sold to a third party for the recycling purposes. Then, the engine will have a second hand or salvage value and this earning should also be taken into account with the present value perspective.

Engine System Brand	Engine System Description	Value After 40 years operation