THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

Environmental Trade-offs in Ship Design

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Abstract

Ships interact with their surrounding environment throughout their lifecycle. During the operational phase of a ship, a range of impacts, such as emissions of acidifying exhaust gases and unpredictable introduction of invasive species via ballast water outlets, can and will be experienced.

This thesis aims at showing the possibilities of methods from the systems engineering discipline to achieve environmental improvements during the life cycles of ships. The methods are suited for implementation during the ship design phase.

Shipping is an international industry where national laws and regulations can affect the competitiveness of a national shipping industry in the global arena. Costly requirements with other than legal origins have similar effects on the competitive situation for individual shipowners. There is also a possibility for each ship-owner to register a ship under the flag of his/her choice. These circumstances are often mentioned as an answer to why ships have not followed the same development as has land-based transports regarding environmental improvement efforts.

The management of requirements is central to improve the performance of the ship. Requirements on environmental concern can be expected to be intensified in the future. The methods presented in this thesis suggest how these requirements can be dealt with by a ship design team in a trade study with performance parameters.

The methodological approach chosen has been based on systems thinking. The research has relied on iterations between findings from literature and interviews, and the framework in which new methods and theories have emerged. For example, a change of perspective concerning of the ship design process proved to facilitate the introduction of the environmental requirements posed on a ship's performance.

The two appended papers describe the methods used for trading performance parameters. In "Integrating Environmental Performance in a Logistic Approach to Short Sea Shipping – A Case Study", the total performance of a logistic system is considered in a comparison between five different transport concepts. In "Environmental Improvements in Ship Design by the use of Scoring Functions" the trade-off methods are further developed by the addition of scoring functions on environmental impact.

Keywords:
systems engineering; environment; transportation; scoring functions; trade-off analysis; performance parameters; ship design

Preface

A core area of research at the division of Marine Structural Engineering at the department of Shipping and Marine Technology (former department of Naval Architecture and Ocean Engineering) focuses possibilities of including systems engineering methods in ship design. This has been the context for my work at the department.

The VINNOVA sponsored project *"Systematic methodology for ship design"* has funded most of the work with this thesis. This project has provided the foundation for research on the integration of logistic and environmental preconditions with the traditional concepts of ship design.

"Intermodeship" is the second main sponsor of this thesis. *"Intermodeship"* is an EU-funded project that aims at producing an innovative ship design through the collaboration of several companies, universities and research institutes from Europe. A 'Design for Environment' approach was pronounced for the ship design process.

I would like to thank my supervisor Prof. Anders Ulfvarson for introducing me to the discipline of shipping and ship design, and for his well thought-through and motivating guidance throughout the research work that has resulted in this thesis.

I would also like to express my gratitude to my assistant supervisor Adjunct Prof. Herbert Nilsson who has given me great support and advice whenever I have asked for it.

Prof. Thomas Polesie at Göteborg University has an extraordinary ability to inspire me when he calls. I highly appreciate it.

I give a huge thank you to Ingar Malmgren, for being my supportive and encouraging room-mate since I started. I really have enjoyed working with you. Special thanks also to Sofia for being such a good friend and to the rest of my friends and colleagues at the department, who make this a nice place to spend your working hours.

Finally, with love to my family, which shortly is about to grow substantially, and to my closest friends for always keeping me happy.

List of appended papers

This thesis is based on the work contained in the following papers;

PAPER A *Integrating Environmental Performance in a Logistic Approach to Short Sea Shipping – A Case Study*
Ingar Nilsson, Hulda Winnes, Anders Ulfvarson
Proceedings of the ENSUS 2002 Conference
Newcastle, UK, December 2002

PAPER B *Environmental Improvements in Ship Design by the use of Scoring Functions*
Hulda Winnes
Submitted in January 2005 for publication in the Journal of Engineering for the Maritime Environment

Distribution of work in paper A:

The study was planned collaboratively by all authors. Ingar Nilsson and Hulda Winnes performed the method development, data collection, data analysis, and paper writing. Anders Ulfvarson designed the ship concepts and contributed with comments and feedback.

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Introduction

The transport market in Europe is increasing and with it environmental problems arise and increase. Congestion on the road network is mentioned as an example and as a motive to increase the use of inland waterways and intermodal transport solutions (EUROPEAN-COMMISSION 2001; 2002). The waterborne transports are discussed as a possible solution to these problems, but the industry has not faced the same requirements on environmental excellence as have other transport modes and they are in this sense not yet comparable.

The economy of scales of ships is beneficial for the environment but may have other implications as part of a logistic service. A ship seldom constitutes the only active transport mode in a transport chain and it is likely that the larger the volume of the ship, the more difficulties it will experience to reach ports close to the end customers. Complementary truck transport is almost always required. Larger ship volumes also require more goods than do smaller ships, trains or trucks to reach satisfactorily high fill rates (Nilsson, Winnes and Ulfvarson 2002).

The work presented in this thesis represents the result of research and studies on the possibilities of strengthening the role of environmental aspects in the design phase of ships. The introductory chapter presents the background, aim end scope of the work. The following chapter gives an overview of the methodological foundation for the work. After that, a lengthy chapter on the theoretical framework for the thesis is presented. The reason for the considerable extent of this chapter has its roots in the fact that it is a new topic within the department. This is followed by a description of the design of the research conducted and the course of action I chose in order to find answers to the research questions. Explicit results are then presented in chapter five and the final chapters include a discussion of the research and its results and summaries of two appended papers.

1.1 Background with problem description

When environmental issues in shipping industry are discussed, there is a consensus that the industry is not following the pace of development of the land transport sector. The main reason often stated is the global character of the industry, which means that environmental laws from the Swedish government adversely effect the competitive situation of Swedish shipowners on the global market. Any shipowner also has the possibility to flag a ship to registries with their origin in any chosen country. So-called open registries, characterized by not requiring citizenship of shipowners or operators, levying low taxes, allowing ships to be worked by non-nationals, and by seldom imposing demanding domestic or international regulations on registered ships, hold the majority of the world’s fleet. This has implications on the enforcement of, for example, environmental regulations, since it is possible to register under a flag that does not follow these regulations. However, the situation is changing and several of the open registries are signing the international environmental and safety conventions (DeSombre 2000).

National efforts have, however, been made in Sweden with, for example, the environmental differentiation of fairway dues (Kågesson 1999), and on a regional level with, for example, the EU’s phase-out of single-hull tankers. On the international level, the International Maritime Organisation (IMO) regulations in the field are convened in *The International*

Convention for the Prevention of Pollution from Ships (MARPOL), these are, however, seldom as demanding as Swedish and EU regulations are on similar matters (IMO 1991).

This reasoning shows the kind of conditions posed on environmental innovations in ship design and has also put some constraint on the research work in this thesis. The methods developed to help designers make good environmental choices have had to consider limitations concerning time consumption for implementation in the design phase, as well as generality. Environmental performance improvements of ships are mainly driven in three ways; legally driven, customer-driven and those driven by economic incitements from governments. Improvements made by shipowners in order to profile themselves on the market as an environmentally friendly alternative are considered as customer-driven and includes aspects, such as competitive differentiation and profitability improvement. A customer is defined as anyone who has direct requirements on the system under study.

1.2 Aim and scope

The fundamental aim of this thesis is to develop methods for environmental improvements of ship life cycles. Systems engineering, an engineering discipline with a body of methods for the systematic stating and solving of problems, provides the foundation in which the theoretical approaches and methods for further use are to be found. The methods searched for are required to be useful in the early design phases of the ship life cycle and are to be suitable for implementation on a company level.

A ship life cycle can roughly be considered to include the phases of design, construction, building, operation and dismantling. This leaves an enormous area for research and the following paragraphs will narrow the scope of this work.

The life cycle of a ship is spread around the whole world. Since earlier studies have indicated that the operational part of the lifecycle is the main contributor to environmental degradation, see for example (Johnsen and Fet 1999; Johnsen 2000), this study has a focus on the actual transport work performed by the ship. The European transport network forms the context for these studies.

The established Life Cycle Assessment method is used as a source for ideas to develop methods suitable for ships and for use in ship design. Suggested methods are not developed to the extent that they are ready for implementation.

No time frame is pronounced, but it is reasonable to believe that the proposed methods can be used by environmentally profiled companies in a near future and on a more general basis in the coming 10 to 15 years.

1.3 Research questions

To start with, the logistic requirements on ship transportation will be studied, since they constitute the context in which environmental requirements should fit. The first question concerns the relation of environmental requirements and other logistic requirements:

- How can the environmental requirements that should be incorporated in ship design fit into the management of logistic requirements?

After this, the environmental effects associated with shipping will be studied more separately, but with the intention of being used in a wider design and engineering framework constructed from systems thinking:

- How are available environmental assessment models suited to transfer knowledge on environmental effects in the surroundings of a ship's route, and caused by the ship, to the ship design process?

- What possibilities does systems engineering offer to improve previous environmental assessment methods in the design process?

2 Methodology

This chapter aims at describing where my research has its methodological foundation. The word methodology is used in the sense of being “a body of methods used in a particular activity” rather than being the “science of methods”.

2.1 Scientific considerations

This thesis is based on ‘systems theory’ where a system is believed to be more than the sum of its interacting parts. Systems theoretical analyses require that properties of the system as a whole (that would not exist if the system parts were not allowed to interact) are pointed out and that system boundaries, functions and the parts and interactions that make up the system should be determined. The system’s relations to other systems should be identified and defined. The analyses normally also include control mechanisms and system changes over time (Wallén 1996; Arbnor and Bjerke 1997).

The main objective for a study with a systems approach is to determine relations between the different parts of the system (Arbnor and Bjerke 1997). In this thesis, an inductive approach where theories and hypotheses about the studied system are developed parallel to the execution of the study plan has been adopted. Taken further, this approach with constant feedback between empirical findings and theory is classified as an abductive approach (Dubois and Gadde 2002). The abductive approach is worth mentioning here since it emphasises the strength of case studies in theory development. It differs from inductive approaches mainly in that it allows the theoretical framework of the original study to change as new information becomes available (Dubois and Gadde 2002). This element of the abductive perspective is to some extent applied in this thesis.

Arbnor & Bjerke (1997) use the term ‘operative paradigm’ to describe how a methodological approach is connected to a specific study area. Their reasoning on methodological issues concerns business knowledge, but the concept of operative paradigm appears useful in the context of this thesis as well.

The operative paradigm is constituted by the elements of methodical procedures and methodics, see Figure 2-1, where methodical procedures refer to how to adapt techniques to a methodological approach and methodics refers to how this is applied in a study plan (Arbnor and Bjerke 1997). The methodical procedure is always a part of the methodics used.

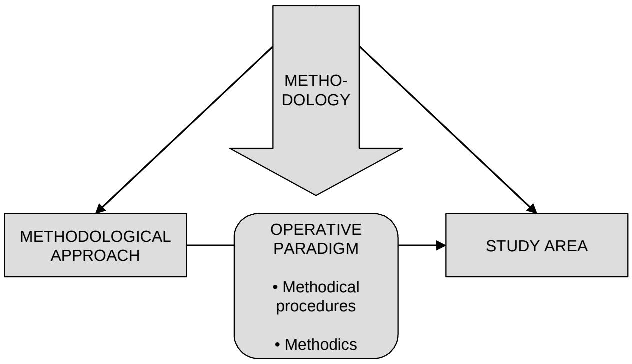

Figure 2-1. Description of how the methodological approach connects to the study area under the influence of methodology choices. The application on the study area of this thesis is discussed in chapter 4 (Arbnor and Bjerke 1997).

The techniques used in operative paradigm methodics rely heavily on the researcher's methodological approach. For systems theory, for example, the case study is frequently used, since these studies are able to treat whole systems with interacting units and can then be used to represent certain types of systems. It is also common to conduct personal interviews to gather information. Analytical experiments are not relevant as they are only performed to reproduce causal relations, whereas the systems approach focuses on synergistic effects and final relations. Validation techniques in the systems approach school relies on data collection from as many perspectives as possible and on acceptance from groups within the system under study, including the researcher (Arbnor and Bjerke 1997). The block arrow named "methodology" in Figure 2-1 shows how a body of methods only becomes useful when it is applied on a specific domain, based on a particular methodological approach.

The operative paradigm is comparable to the research design described in Yin (1994), defined as *an action plan for getting from here to there*, where *here* may be defined as the initial set of questions to be answered and *there* is some set of conclusions (answers) about these questions (Yin 1994). Bryman (2001) describes research design as the framework for the gathering and analysis of data and separates this from the actual techniques employed for the data gathering, such as inquiries.

3 Frame of reference

To integrate environmental impact, as well as other objectives, with traditional design parameters both challenges and requires the systems engineering approach to find a design solution. The techniques and methods in the systems engineering discipline need to be adjusted to include soft parameters such as environmental requirements; something which is possible but not customary (Beckerman 2000). There is an identified need of analysis and design of transport chains as a whole as well as for an interdisciplinary approach to these challenges (Thissen 1992). To include objectives of an uncommon nature in the engineering process of transport systems requires good comprehension of trade-off analyses. The values to be traded for each other differ in character and in improvement potential.

The above paragraph indicates the basis for the frame of reference for the research and study fields of this thesis. In this chapter, a few environmental assessment methods that previously have been used in ship design will be described. Subsequently, the ship design process will be dealt with conceptually. Finally, the systems engineering methods found appropriate for further use in the research will be added to the framework.

3.1 Environmental systems – models and methods

To assess environmental burdens associated with complex structures over time is not a new challenge. If a complete view of the environmental effects associated with a product is aimed for, and if the most cost-effective solutions to the identified environmental problems should be found, the environmental effects should be considered using a life cycle perspective. Largely, this can be dealt with by the now standardised Life Cycle Assessment (LCA) method. However, shortcomings of the standardised method have necessitated search for methods that are more suitable in the design phase of a ship. It has, for example, been considered important to be able to include an element of risk analysis when assessing environmental impact from ships. LCA and risk analysis will be briefly presented in the paragraphs 3.1.1 and 3.1.2.

3.1.1 LCA

LCA basically consists of the four steps goal and scope definition, inventory analysis, impact assessment and interpretation of results. The method makes it possible to analyse material- and energy flows of product life cycles.

The final step, apart from the continuous interpretation step, in LCA is the Life Cycle Impact Assessment (LCIA). LCIA includes the steps in LCA where the actual environmental impact is assessed through classification, characterisation and sometimes some additional steps, such as weighting and normalisation, see Figure 3-1. Some of the steps are mandatory and some are optional in the ISO standard (SIS 2002).

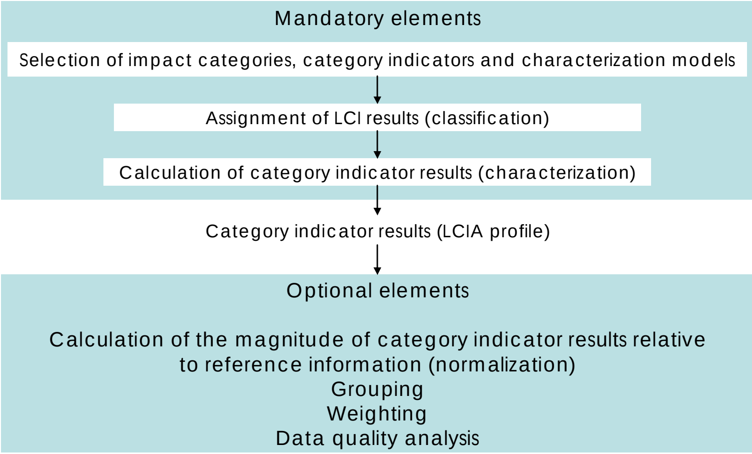

Figure 3-1. LCIA procedure according to ISO (SIS 2002)

The basis for the classification and characterisation are more or less scientifically calculated while the valuation or weighting step is built on preferences and always produces a subjective value. This is why there is a lot of discussion on which methods to use, and naturally also a lot of different methods to choose from.

Weighting is sometimes preceded by normalisation and grouping. Normalisation transforms an indicator result by dividing it by a selected reference value. This procedure estimates the relative effects of the product system in a defined area or a baseline scenario. Grouping involves a nominal sorting and/or a hierarchical ranking of the impact categories. The valuation or weighting is normally done with indices, which tell how harmful a certain compound or a certain category of environmental impact is in relation to another (SIS 2002).

3.1.2 Risk analysis

There is a strong element of risk-related environmental impact from ships. This is largely connected to the transportation of large volumes of oil in sensitive areas but the reasoning is also valid for the ballast water issue. Risk analysis tools have a longer history in the ship design industry than do LCAs, and are focused on local conditions and on single events. These methods use absolute measures without relating them to a functional unit and cannot in this form be integrated in LCAs (Assies 1998; Salter and Ford 2001).

Formal Safety Assessment (FSA) is a risk assessment methodology that has been adopted by the IMO in order to evaluate new regulations and to compare proposed changes with existing standards, but the method can also be used in the ship design process.

FSA consists of five steps (IMO):

1. Identification of hazards (a list of all relevant accident scenarios with potential causes and outcomes);
2. Assessment of risks (evaluation of risk factors);
3. Risk control options (devising regulatory measures to control and reduce the identified risks);
4. Cost benefit assessment (determining cost effectiveness of each risk control option); and

5. Recommendations for decision-making (information about the hazards, their associated risks and the cost effectiveness of alternative risk control options is provided).

What is interesting from an environmental perspective is the consequence analysis, included in step 2 and answering the question; “how bad and how likely?”

A fault tree, or similar structure, is produced to picture the chain of events and the associated probabilities. In FSA, like in other risk assessment tools, the damage is believed to occur occasionally over the ship lifecycle.

A Cost-Benefit Analysis is part of the FSA methodology. The cost benefit element of the FSA is an explicit place for conducting trade-off analyses, where negative sides of the system is assessed in relation to positive sides (IMO).

3.1.3 Environmental Performance Indicators

Environmental performance indicators (EPIs) are management tools employed to assess and report on environmental performance in an organisation (Fet 1997) . The indicators inform management on how well the organisation fulfils its objectives on environmental performance. Indicators are chosen to reduce the number of measurements that would have been needed to give an exact presentation of a situation, and thereby reduce the amount of work needed for environmental assessment (SIS 2002).

3.1.4 Study area - environmental concern in ship design

Consumption of fuel oil is one of the major costs of a shipping company and technical solutions to lower energy use and a subsequent reduction of the exhaust gas emissions often come about as a result of lowering company costs. However, problems concerning specific emissions, anti-fouling paints, ballast water, waste, decommissioning issues and oil spills, are seemingly only adding to company cost, at least in short term calculations. In the long term, benefits from good will performance might improve the same calculations. Several techniques to improve performance on the last mentioned issues exist, see for example (Sørgård, Mjelde, Sverud et al. 2001; TRESHIP Thematic Network 2002).

Environmental assessments of ships generally aim at stating the environmental impact from building, operation and scrapping, or/and to serve as a tool used in the design process. The studies can either focus on the ship as a product or as part of a transport chain. Common to several studies (Fet, Michelsen and Johnsen 2000; Hasegawa and Iqbal 2000; Johnsen 2000; Johnsen 2000; Iqbal and Hasegawa 2001) is that their focus is on the transportation of goods and not the ship as such. Depending on the aim and scope of the study, the level of detail on input data will differ.

Fet, Michelsen and Johnsen, (2000) concludes that product-oriented tools such as LCAs are the methods most extensively used for environmental evaluations in the ship industry. It is also stated that LCAs should be used together with Environmental Management Systems to provide shipping companies with a good basis for environmental work.

The environmental impact from operation generally acquires most evaluation efforts, since it was proved in early studies that this phase was more harmful than the building (Johnsen and Fet 1999; Johnsen 2000), and because data from scrapping is limited (Angelfoss, Johnsen, Fet et al. 1998). Lack of data on ship dismantling is a shortcoming for the LCAs, since the activity produces a lot of waste, of which a substantial amount is hazardous.

Professor Annik Magerholm Fet at NTNU has used systems engineering methods to show possibilities for the shipping industry to improve their environmental work. Fet shows how Environmental Performance Indicators (EPIs) can be used to analyse, evaluate and optimise improvements during the life cycle of the ship (Fet 1997).

3.2 Ship design model

A described design method can be useful for educational and ideological purposes. It can also be used in practical situations when people with different backgrounds and experiences work together.

The traditional way of illustrating the process, e.g. with the design spiral, is useful in an educational situation since it clearly shows which elements that need to be included in the ship design process and also the iterative nature of the process. However, new models that are more focused on functionality have been developed. These are applicable on a high systems level and useful in a discussing, innovative situation. A description of the two views will be described in the following paragraphs.

3.2.1 Traditional view

The traditional view of the design process can be represented by the design spiral as pictured in Figure 3-2.

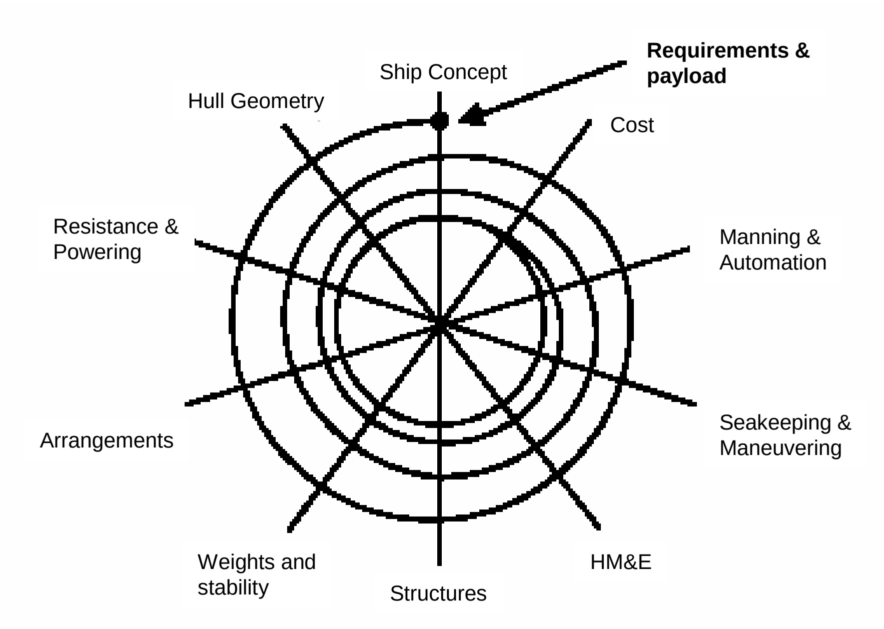

Figure 3-2. The design spiral.

The mission requirements that enter the spiral come from analysis of the transport need that the ship will satisfy – the mission analysis. This describes what type of goods is to be transported, how it is to be loaded onto the ship, which routes the ship will sail, how long it will be in service, etc. Based on these requirements the loop starts. The dimensions and layout of the ship are determined and powering needs are decided. The first loop represents conceptual design. The conceptual design phase consists mainly of technical feasibility studies to see if the mission requirements can be translated into reasonable technical parameters and still produce a seaworthy ship. Next come preliminary design loops where the ship characteristics are further refined and the main dimensions are determined and are no longer to be modified. After this, the contract design is developed, which, after further refinement and development of the preliminary design, is part of the shipbuilding contract. Finally, the detail design phase is reached. Detailed working plans are developed and the loops are no longer used – the centre of the spiral has been reached.

The criticism that has been raised against this traditional view is that ship design is a complex process that cannot be explained in a reductionist way, neglecting essential interactions between different parts of the ship. The spiral misses connections between design parameters that are needed in practical work. There is also a general shortage in the fact that the overall requirements on cost, etc., from the mission analysis are only briefly present. Generally, it can be said about spiral illustrations of design that these models cannot deal with optimal solutions, since they are not able to deal with comparative evaluations of different candidate solutions (Shell 2003).

Traditional descriptions still offer a reasonable picture of which parameters to include and their approximate order in the process, which is why they can well serve an educational purpose.

3.2.2 Holistic view

Adding all the missing connections between parameters makes any model hard to grasp and impractical to use, for example in teaching situations. However, attempts have been made to produce more functionality-focused models of the process. The concern lies in showing connections in the mission analysis and it also emphasizes the importance of the economics of the shipbuilding (Wijnolst 1995).

The transit from a design spiral to these models can be addressed as going from reductionist to holistic views of the system. Instead of reducing a system to its basic parts for analysis and decision, it is studied considering the multiple interactions between system elements (Beckerman 2000). Applying the holistic view on ship design means that the outcomes of the mission analysis will be more present in all stages of the design process.

The models are on a higher system level than the ones previously discussed and have high relevance in theoretical as well as in practical use.

The addition of innovative solutions to the design is also cared for by the holistic view of the design process (Wijnolst 1995). Innovations bring about changes in the system that need to be explained by the “missions” of subsystems. If a reductionist view is applied the effects of interfacing parts might be neglected and the innovations will fail to succeed.

3.2.3 Decision-making in ship design

The decision-making is an iterative process. Parameters become more and more inflexible as the process proceeds, allowing only minor detail changes in the final iterations. It is important to note that the decision-making process and the design process in general will not look the same from time to time. It differs from ship to ship, depending on the maturity of the requirements received by the design team and, obviously, on the time limits for the project.

Some mandatory requirements from the mission analysis set the first limits for the design. These requirements are related to cargo (e.g. the shape of the cargo space), and legal requirements concerning safety, etc. Decision points will be identified by their appearance in chronological order in chapter 5.1.

Integration of environmental aspects

Decisions influencing environmental performance are mainly identified as high-system level requirements and most of them originate in legal obligations. The conversion of these requirements into design parameters occurs at the same time as other legal and mandatory requirements. The trade-offs between less mandatory demands on environmental aspects and other parameters can be performed as soon as the interfaces between affected systems or subsystems have been made visible.

3.3 Systems engineering

Systems engineering has been used and described throughout the second half of the 20th century and maybe even before that. In the 1940s Bell Labs, the American telecommunications company introduced the term (Brill 1998). It was adopted by American governmental organisations such as NASA and the U.S. Department of Defense. The U.S. Air Force was the first to introduce systems engineering standards in the late 1960s. Also, private companies and academia have been involved in improving, describing and of course implementing systems engineering and later also systems engineering standards, for example, ISO 15288. Some main characteristics of the discipline can be followed all the way up until the present day. These are, for example, the fundamental aims for organising seemingly disordered and multifaceted systems, including aspects of a technical, economic and social character in the engineering practice and the use of interdisciplinary teams of workers in the design process (Brill 1998; Buede 2000).

Another vital aspect of the discipline has always been to transfer customers' requirements to technical design parameters and finally to a product. Systems engineering emphasises the importance of stating a problem correctly. An open mind concerning the solution to the stated problem is a prerequisite for successfully conducting the systems engineering process (Brill 1998; Buede 2000).

In later years, the systems engineering discipline has been recognised as a management technology dealing with the total system lifecycle (Sage and Rouse 1999). Systems engineering puts a great focus on describing the process of bringing a system into being. A challenge for systems engineering consists of the increasing complexity due to interaction between technologies today, and especially the development of information technology. The technologies are also rapidly changing, which requires adaptability in the systems (Thissen 1992; Beckerman 2000; Calvano and John 2004).

One of the great rationales for practising systems engineering is its focus on the initial phases of a project. During the early phases of a project, concept design and preliminary design, which are the relevant phases in this thesis, a major part of the costs for the whole project can be locked in, see Figure 3-3. During these early stages the knowledge of the system is still modest and a good knowledge of customer and stakeholder requirements are essential in order to make the right choices concerning materials, technologies used, etc.

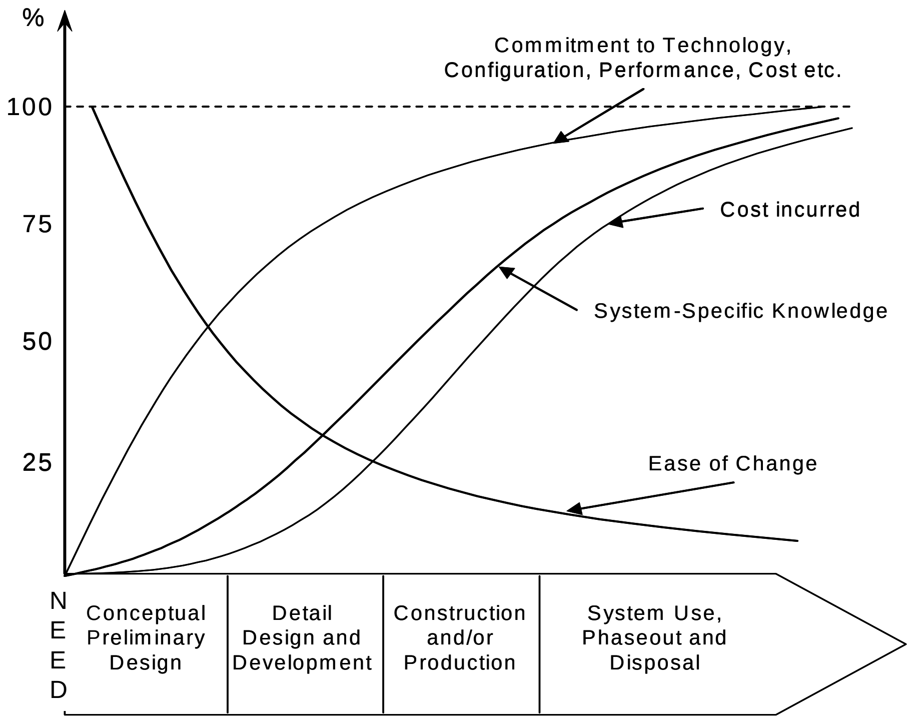

Figure 3-3. From Blanchard & Fabrycky (1998), on commitment, system-specific knowledge, and cost

3.3.1 Environmental aspects and systems engineering

Managing environmental concern in a ship design process might be approached from several angles. A system including environmental impacts has elements of a socio-technical system in the sense that the participation of groups of people significantly affects the architectures and designs of the engineering work. The level of acceptable quality in socio-technical systems is found by conducting trade-off analyses between technical, economic, social and political factors. One level of quality could, for example, refer to pollution level. Some factors specific to socio-technical systems need to be considered in order to design the system correctly. These are, according to Maier and Rechtin (2002):

- identification of client and user and the fact that these are probably not the same person/organisation. The client is defined as the person/organisation paying for the services provided by the systems architect/engineer and the user is the person/organisation using the services,
- answers to the four questions *who benefits? who pays? who provides?* and *who loses?*
- and finally to explore the interactions between the public and private sector.

This mapping of systems characteristics fits into the studies on environmental improvements in ship design, but needs complements from more explicit design methods.

Integrated design is a systems engineering term used on designs that consider disassembly and recycling in addition to assembly and usage. The proactive approaches of Design for Environment (DfE) and Design for Disassembly/ Recycling (DfD/DfR) are examples of other systems engineering approaches for dealing with environmental issues. Most eco-design, like for example DfR, deals with incremental changes to existing products. Few eco-design projects aim at finding new alternative solutions based on the function of existing products

(Baumann and Tillman 2004). All this is captured in the industrial ecology design concept Environmentally Conscious Design and Manufacturing (ECDM), a concept that deals with environmental quality in relation to more traditional quality parameters in design and manufacturing (Blanchard and Fabrycky 1998).

Attempts have been made to integrate environmental aspects to already established systems engineering assessment tools for products and processes. For example the concept evaluation tool quality function deployment (QFD), has been extended to include an environmental element, becoming Green-QFD (Zhang, Wang and Zhang 1999). Also, Failure Mode and Effects Analysis (FMEA) has been added an environmental element in practical work on Volvo, called E-FMEA. FMEA is a technique used to systematically identify and eliminate known or possible faults and disturbances of a system.

A few methods from the systems engineering discipline, essential for the research performed, are described in the paragraphs below.

3.3.2 Requirement analysis

This thesis does not primarily aim at clarifying what requirements are to be met by the ship project, but rather how to manage them. The requirements handled in this thesis are neither limited to a single ship design project nor even a single class of ships, but are of a more general character.

Requirement identification is essential in systems engineering work and originates in a need, an opportunity, a wish or a deficiency. Requirement has been defined as one of many statements that constrain or guide the design of the system in such a way that the system will be useful to one or more of its stakeholders (Buede 2000). To describe and treat requirements according to systems engineering principles include answering questions like “what is the improved ship to do?”, “How will it do this?” and “How can this be verified?”. The stakeholders posing these new requirements shall also be described.

The fulfilment of each essential requirement should be verified through test or demonstration. Figures of merit that are used in both of the appended papers can be regarded as showing how effectively a requirement is fulfilled. Quantitative verifiability of requirements is essential even for soft requirements and verification tests should exist for all requirements (Bahill and Dean 1999).

3.3.3 Objectives hierarchy

The objectives hierarchy is a value structure built on what the system’s stakeholders find valuable. The objectives hierarchy can serve as the basis for trade studies made throughout the project. Trade studies are made possible by adding value functions or scoring functions at the bottom layer of the hierarchy. The objectives hierarchy is usually set up for a specific working condition for the studied object, such as weather and other external conditions (Buede 2000). An example of a fundamental objectives hierarchy for an elevator system with scoring functions is shown in Figure 3-4.

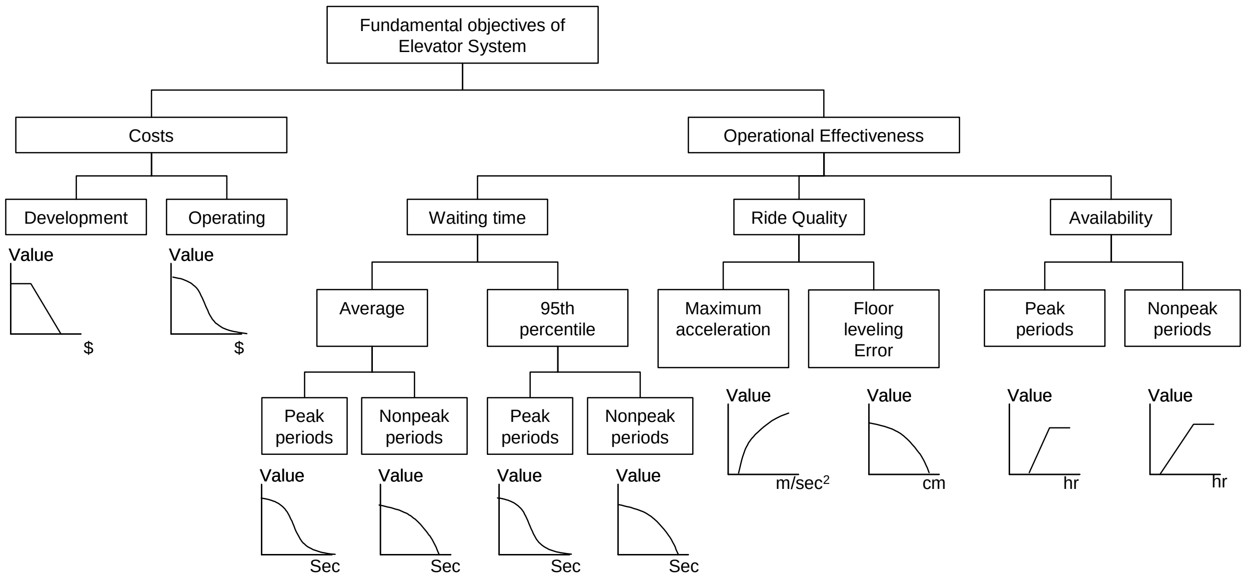

Figure 3-4. Example of a fundamental objectives hierarchy with scoring functions for an elevator (Buede 2000)

Trade-off analyses, or trade studies, are wide concepts and no exact definition will be presented here. A description given by Buede (2000) might, however, be useful:

> ”A trade study focuses on finding ways to improve the system's performance on some highly important objective while maintaining the system's capability in other objectives. Trade studies are focused on comparing a range of design options from the perspective of the objectives associated with the system's performance and cost. For example, aircraft manufacturers always do trade studies focused on the aircraft's weight, while maintaining the system's cost, safety, and so forth. Similarly, safety, reliability, and cost are among the many other objectives that are commonly the focus of a trade study”

Trade studies are carried out in the context of an investigation of alternatives in a product or process development.

In the objectives hierarchy, a specification of threshold levels in each objective should be produced. The lower threshold identifies the level below which the performance is so low that the whole project should be rejected. The higher threshold shows where further refinements on the parameter are unnecessary for satisfying stakeholder requirements.

In the process of decision-making a lot of different parameters should be weighed and evaluated in the light of others. The weighting of parameters of a different character and different measurable units can be done by defined systems engineering approaches. This is also true for parameters of a more “soft” character, as for example environmental issues that do not have a simple measurable or monetary value, which could be used in a comparison. The transfer of “soft” to “hard” values is, however, necessary for the analysis and quantifiable measures of effectiveness for each soft value need to be identified. Measures of Effectiveness (MoE) are solution-independent measures, indicators or “standards”, against which the performance of a solution can be assessed. These are deducted from stakeholders' requirements (Sproles 2000; Sproles 2001).

Scoring functions

The following paragraphs concern so-called utility functions or scoring functions. These functions are used for making MoEs of different character comparable by using the functions as a means of having them on a common scale (normally from 0 to1). This means that if environmental performance is on a high objectives level, to be traded against safety, cost, etc., you could find utility functions, for example, for NO_X release to air or noise. The parameters used should always be quantifiable, which involves the use of MoEs. The relevant measures are sometimes referred to as Figures of Merit (FoM), which are defined as the unique MoE for any particular candidate solution (Sproles 2000; Daniels, Werner and Bahill 2001). In Figure 3-5, below, g NO_X/kWh is the MoE and 11.5 is the FoM.

After the relevant utility functions are set up, a subjective weight is multiplied to each resulting score or utility (the score equals 0.7 in Figure 3-5). The weight should be derived from stakeholder requirements. It is also important that the scoring functions are set up in an appropriate manner that reflects the actual situation.

A general rule of utility functions is that a high score should always be better than a low score. In the context of an environmental study, this could for example mean that zero emissions of a hazardous substance are equal to one and the more emissions the lower the score, Figure 3-5. The shape of the function depends on the investigated parameter and the requirements posed on it. The value retrieved on the y-axis is comparable to values retrieved from corresponding functions for consequences of other detrimental environmental releases.

It is of the utmost importance to keep the functions related to stakeholder preferences (Buede 2000; Daniels, Werner and Bahill 2001).

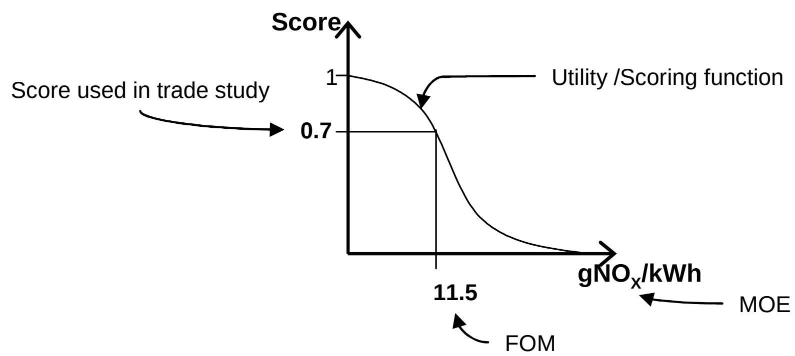

Figure 3-5. Example of a scoring function showing NO_x-emissions.

It should also be noted that different kinds of requirements should be treated differently with respect to the FoMs. For mandatory requirements it is important to keep the independence between the FoMs. This means that mandatory requirements should not be tradeable for each other, i.e. it should not be possible to compensate for one low FoM by raising the FoM of another requirement. For preference requirements, compensation is more important than independence and the FoMs should show compensation, so they can be traded for each other (Daniels, Werner and Bahill 2001).

Trade-off functions

Trade-off functions provide means of combining the scores retrieved from the scoring functions and their respective weight (Buede 2000). All scores from lower levels in the hierarchy will be combined to a single value at the top level, see Figure 3-4.

Trade-off functions are normally mathematical expressions, combining data by means of linear combinations, product combinations, exponential combinations etc, depending on the system examined. Different combining functions or trade-off functions produce different preferred alternatives.

When the procedure of assessing stakeholder requirements and weighting of the FoM scores is completed, each candidate solution will have comparable total scores. The possibilities for environmental aspects, as an example of a tradeable parameter, to impact the final result, lies in the weight which environmental aspects is given in the final weighting step where it is traded against cost etc.

4 Research design

The research design has been pictured in Figure 4-1, using terminology from Arbnor and Bjerke (1997) and with reference to Figure 2-1. The operative paradigm includes methodical procedures and methodics. The methodics – how methodical procedures have been applied in this study plan – will be described in the following paragraphs.

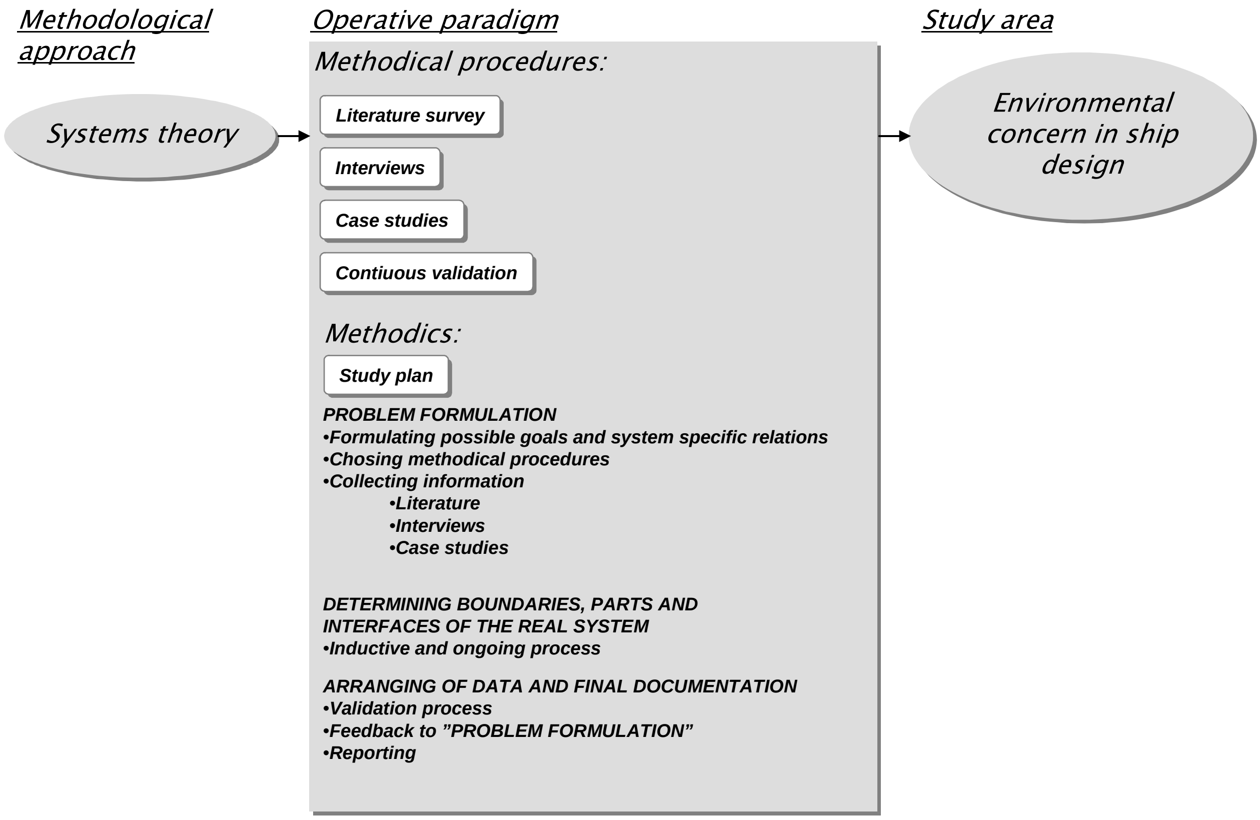

Figure 4-1. Using terminology from (Arbnor and Bjerke 1997) to show how the study area connects to the methodological approach via methodical procedures and methodics.

4.1 Defining the system

The methods taken from the systems engineering discipline have in a first study been applied on the logistic system and later on the ship, identified as a subsystem of the logistic system, see Figure 4-2. The system defined in a less strict engineering sense also embraces stakeholders, found in different contexts in society, and their requirements as well as the environment. Some reasoning about this follows in these paragraphs.

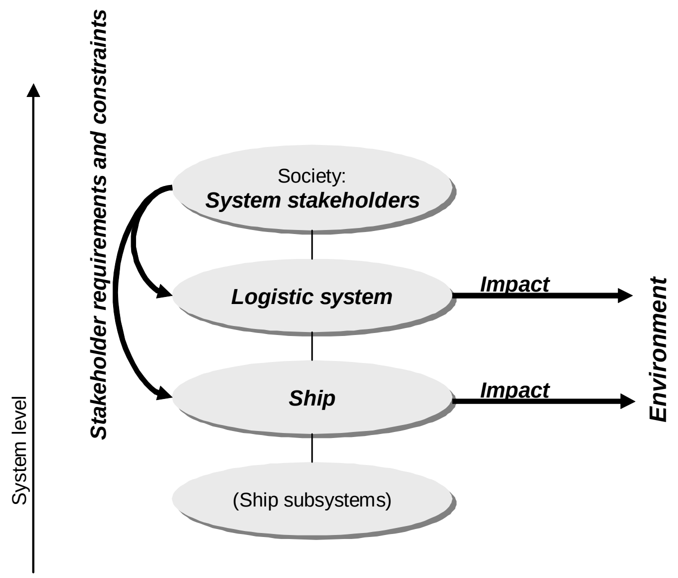

Figure 4-2. An overview of the systems under study. Factors included in the studies are printed in bold.

The logistic system qualifies as a system in that it possesses the properties of providing a utility to a customer that none of its inherent parts would be able to deliver on its own. This system consists of parts, such as an information system, transportation devices, cargo and infrastructure. Providing a logistic service also requires a certain level of quality in environmental performance. This system constitutes the base for the first study.

In the second study, the ship and the environment are part of the same system and the relation between them is studied for design method development. The ship still has a central position in the studied system and it is the system used when applying systems engineering methods. Interfaces with the other parts of the logistic system have not been considered in this study, but are kept in mind. These interfaces will provide the framework for the results from the study when implemented in practical work. The ship is in its own right a complex structure that interacts with the environment in several ways. These interactions constitute a main part of this study and are considered in a one-way perspective; the way in which the ship has an impact on its surroundings.

The ship is not considered inert to external impact. The influences considered come from several stakeholders, pictured in Figure 4-3. This is a general picture of actors and stakeholders in shipping and ship design activities including public opinion, consumers, governments, authorities, international organisations, cargo owner, insurance companies, classification societies, third part logistic providers and shipbrokers, who are posing and transferring environmental requirements. The only truly original environmental requirements come from the public opinion, with the aim to improve the environment they live in, and insurance companies whose intentions are based on a financial interest. The shipowner is central in Figure 4-3, and this is also the stakeholder that is considered as being the party who transfers requirements on environmental improvements to the ship. The shipowner company extends the experienced requirements to ship yards, operators and ports in order to obtain the desired level of environmental performance.

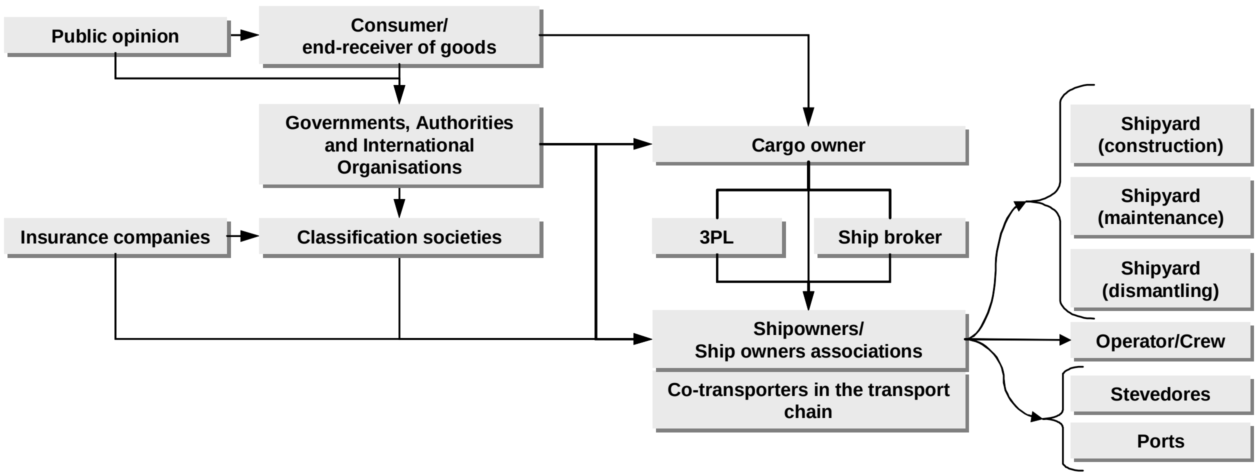

Figure 4-3. System stakeholders, the arrows indicate in which direction demands on environmental concern are placed.

Companies today experience several legal demands on improved environmental performance, which is also true for shipowners. It is possible that the methods suggested here can be modified and adapted to suit requirement-management on a society level, but this has not been the purpose when conducting these research studies. Instead, the focus has been to find methods for improvement in environmental performance during the ship life cycle that can be implemented during the design process and has thus been on a company level, see chapter 1.2.

Control mechanisms originate in the society level as indicated by the box “public opinion” in Figure 4-3. These are not analysed to a great extent and neither have changes over time been considered.

4.2 Literature review

An initial database search for published papers and reports was conducted using the following databases: Compendex, Academic Search Elite, Environmental Sciences and Pollution Management, Marine Technology Abstracts, MARNA, NTIS, Science Citation Index, Science Direct and TRIS. The search string was (system* engineering or system* architect*) and (ship design* or naval), with variations in truncations to suit the respective database. Hits varied from 5 to 224 and in total 19 hits were regarded as highly interesting. It proved to be too specific to search, for example, for (system* engineering or system* architect*) and (the environment or design for environment). Similar literature searches have subsequently been performed continuously throughout my research studies.

4.3 Interview series

A series of interviews with stakeholders in the shipbuilding industry was conducted as a state-of-the-art survey from December 2001 to February 2002 together with Ph.D. student Ingar Nilsson and in three cases with Professor Anders Ulfvarson. The interviews were of a semi-structured character and aimed at creating a state-of-the-art description of the industry and mapping its relations to systems engineering, logistics and environmental issues. Three shipowners, two consultant firms, two suppliers, one cargo owner, one port authority and the Swedish national maritime authority were interviewed (Interview series 1 2001 - 2002).

A shorter sequence of interviews with experienced ship designers was conducted in the start up with the work for paper B (Interview series 2 2003).

The questions were of an open-ended character, due to the aim of the survey. By not posing very limiting questions, the answers from different companies will be of a different kind. This should not be regarded as a disadvantage since the conversation is more open, which suits the purpose of the study (Mitchell and Jolley 1994).

4.4 Case studies

Two single case studies have been carried out. Yin lists five components in research design that are especially important for case studies (Yin 1994). These five components are the questions raised in the study; its propositions (if any); its unit(s) of analysis; the logic linking the data to the propositions; and the criteria for interpreting the findings. The case studies are presented below according to these five components and described in detail in the appended papers A and B.

4.4.1 First case study

The first case study was designed to answer the research question concerning how environmental requirements would fit into the process of handling the logistic requirements. The hypothesis followed was "*An increased use of short sea shipping can balance the European transport system and contribute to a better environmental situation. The competitiveness of short sea shipping is dependent upon improved logistic efficiency including high environmental performance.*"

The studied unit was a transport chain going from a defined area around Lake Vänern in Sweden to the industrial areas surrounding Duisburg in Germany. The aim was to identify and explore some characteristics of short sea shipping and to find general logistic weaknesses in the concept, but also to test if systematic use of so called Measures of Effectiveness could be applied to integrate environmental performance in an evaluation of a logistic service. Focus was set on inland waterway transportation to aid further development of the method in the department. Data for the used functions was collected from semi-quantitative interviews, while evaluation data was mainly chosen from literature.

4.4.2 Second case study

The second case study aimed at finding answers to how the surrounding environment is affected by a ship in operation and how improvements to this can be incorporated in the design. The first proposition is basically that as the ship enters populated areas the effect of health-hazardous emissions increases due to the change in combustion efficiency at reduced speed and due to higher population densities in these areas. The second proposition is that models and methods on environmental design in ships in use today need additional elements if they are to be able to handle specific geographical effects. Again, Measures of Effectiveness are used to model the situation and to suit the design process. The case studied for testing the theory is a ship in short sea traffic going from Gothenburg to Immingham. Data on reduced speed is collected from the ship's logged utilised percentage of maximum continuous rating (MCR), and data on the release of hazardous emissions are taken from literature sources.

4.5 Validation

Validation should show that the results from the research are credible and authentic.

The terminology on validation of research results originates from quantitative research (Bryman 2001), whereas this research is mostly qualitative. Some claim that societal situations can be explained as a reality by the researcher. Then the validation procedures from quantitative research are applicable. Others claim that several true representations of society exist and either reject the validation concept, or modify it to suit qualitative research (Bryman 2001). There is, as it seems, yet no consensus on the framework for validating qualitative research work.

The validation techniques in the systems approach school relies on data collection from as many perspectives as possible and on acceptance from groups within the system under study, including the researcher (Arbnor and Bjerke 1997). The validation of this work has therefore been continuous and has consisted in gathering information from several perspectives on the subject. As described above this has mainly consisted in literature studies and interviews with professionals within the industry.

The aim has also been to give the reader the ability to review the validity of the work by giving transparent and full descriptions on the discussed subjects. Paper A has been presented at two different conferences. At the first occasion it was presented for, and exposed for criticism by, an academic audience at the ENSUS 2002 conference held in Newcastle. The second occasion was at the VTI conference in Linköping, which reaches industry as well as academics. Paper B has not yet experienced the same validation process. The work has so far been supported by literature studies and contact with experienced ship designers and senior researchers. The paper has been submitted to the Journal of Engineering for the Maritime Environment where it will be considered for publication in an academic peer-review.

5 Results

To be able to answer the research questions appropriately, the view of the design process had to become more holistic. It needed to be visible how the mission of the ship project was present throughout the project.

Ending up with scoring functions on environmental performance was the result of identifying shortcomings of environmental assessment methods used today and looking for already developed tools used in the systems engineering discipline.

The environmental effects associated with shipping were studied separately but also in the context of the ship transport as a part of a logistic system. The environmental requirements from different stakeholders were investigated and treated on the same system level as other logistic performance parameters. This proved to function well in a comparison of the performance of transport concepts on a specific route. However, the environmental impact measured and used in the analysis was of low resolution and needed further refinement. This was accomplished by further extension of the evaluation method on logistic performance. More branches were added to the objectives hierarchy, see Figure 5-1, and a system level was reached where scoring functions were valuable.

In the following paragraphs I will extend this reasoning and show how the research questions were answered. Results relating to method development will be centred.

5.1 Important general findings from interviews

The interviews conducted at an early stage of this study, see chapter 4.3, showed that the environmental work carried out by the shipowner companies was still strongly related to legal obligations, but in a few cases the company had found a strategic advantage in profiling themselves as environmentally conscious. No explicit or standardised methods were followed to assess the environmental impact (Interview series 1 2001 - 2002).

The same interviews showed that systems engineering methods were commonly not applied in ship design or in the logistics around the ship (Interview series 1 2001 - 2002).

The second series of interviews, see chapter 4.3, were vital to identify decision points in ship design. These interviews made it possible to establish general time frames for the implementation of methods at different stages of the design phase.

The first design parameters to be frozen are normally weight, speed and volume. After that length, breadth and draught are determined, parameters that, naturally, are tightly coupled to the ship volume. Secondly, the lines of the ship are concluded. Thirdly, estimates of needed power and stability are made. The decisions on ship details are made in parallel and are not necessarily of great importance to the overall system. For any detail, a separate description of interfaces needs to be produced (Interview series 2 2003).

This led to the following conclusions on the integration of environmental aspects in ship design:

The relevant decision points to improve environmental performance during the operational phase are first found on the mission level in an explicit statement that extra concern about environmental issues shall be made. Secondly, on a lower system level, more defined decisions shall be made. Most of the decisions concerning installation of equipment and interfacing subsystems will be identified at this stage in the design process. This is still very early in the overall design process and any non-generic information that serves as decision material needs to be produced from the phase when the mission analysis is decided until the time when speed and power requirements are decided; a time window that is open in the range of a few weeks to a couple months.

5.2 Important general findings from literature

Earlier studies on environmental assessments and life cycle assessments in ship design are few and there is yet no consensus on which assessment method to use (Benvenuto and Figari 1997; Fet 1997; Angelfoss, Johnsen, Fet and Karlsen 1998; Fet 1998; Fet and Sörgård 1998; Hasegawa, Ishida, Hama et al. 1998; Hasegawa, Hamamoto and Iqbal 1999; Johnsen and Fet 1999; TEM 1999; Fet, Michelsen and Johnsen 2000; Hasegawa and Iqbal 2000; Johnsen 2000; Johnsen 2000; Iqbal and Hasegawa 2001; Ellingsen, Fet and Aanondsen 2002). Most studies also try to include an economic analysis and no recommendations have been made, in any of the studies, as to which framework or model that is best suited for ship LCIA. Risk issues, that earns a lot of attention in the general discussion and in design work, is normally not included in the assessments.

EPIs provide an alternative way to reduce the time required for analysis.

5.3 1st research question

The change to a holistic perspective (see chapter 3.2.2) on the design process helped answering the first research question - *How can the environmental requirements that should be incorporated in ship design fit into the management of logistic requirements?* - concerning the integration of environmental requirements in the requirements handling process. It was necessary to order the requirements on the system hierarchically, where environmental requirements were placed on an equal level with other logistic performance parameters, such as reliability and transport time, see Figure 5-1.

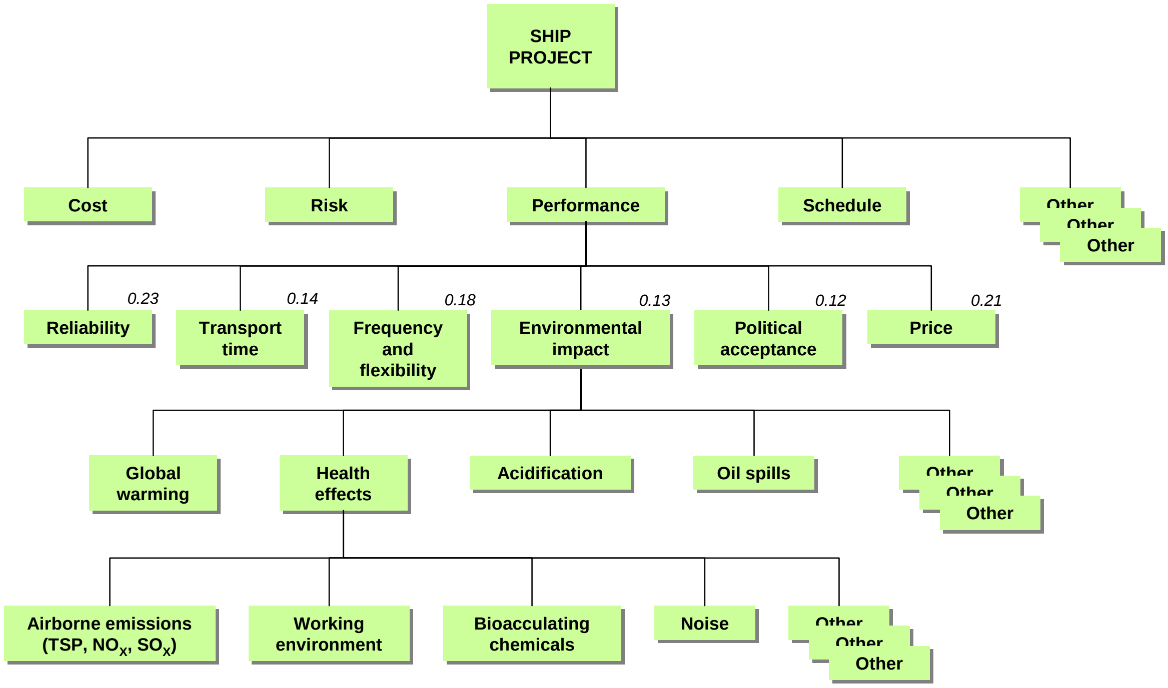

Figure 5-1. Objectives hierarchy in a ship project.

Conducting interviews with stakeholders in the business was the second factor that helped test and develop the method searched for. A test case was set up, comparing five different transport concepts on the same route, see chapter 4.4.1. Cargo owners from the Lake Vänern area gave their judgment on the importance of different logistic performance parameters. Ship owners and transport companies made the same assessment, but in the aspect of how they experience the values of their customers' requirements.

Measures of Effectiveness for each performance parameter were chosen and Figures of Merit for the different concepts were calculated see chapter 3.3.3. The quantitative values were then transformed according to a linear function delimited in the upper bound to the value of the best performing concept and in the lower bound to zero. This transformation scaled the FoMs to a range between 1 and 0, 1 being the highest score. These comparative numbers were then multiplied with the weighting factors derived from stakeholder requirements (these weightings are indicated above the upper right corner of each respective box in Figure 5-1). By this a total performance measure for each transport concept was obtained. A fuller description of the case study and its results are found in appended paper A (Nilsson, Winnes and Ulfvarson 2002).

5.4 2nd research question

The second research question - *How are available environmental assessment models suited to transfer knowledge on environmental effects in the surroundings of a ship's route, and caused by the ship, to the ship design process?* – was faced by two different approaches for managing ship-related environmental impact.

Actual effects on the environment are in Life Cycle Assessments related to a functional unit and in risk analyses kept absolute. Formal Safety Assessments uses Cost Benefit Analyses to relate cost to utility. For a single tool or method to transfer accurate information on environmental impact from a ship lifecycle to the ship's design phase it should consider both approaches; it should, like risk assessment methods, be able to consider damage in relation to specific spatial and temporal aspects and still manage to compare different solutions with respect to lifelong environmental impact, as is done in LCA. It was considered important to keep the life cycle thinking and the relation of the damage to the utility experienced. This was a central aspect when answering the third research question and even more so for the second question, which was considered to be satisfactorily answered and proving the need for further method development.

From systems engineering the concept of scoring functions, see chapter 3.3.3, had been found useful in paper A, and it was investigated if scoring functions could fit into, or already were used in methods applied in ship design to improve the ships environmental performance. No explicit uses of functions like these were found.

5.5 3rd research question

The third research question - *What possibilities does the use of systems engineering offer to improve previous environmental assessment methods in the design process?* - found parts of its answer in the development of the objectives structures, see Figure 5-1. Actual implementation schedule in the design process has not been dealt with extensively and the method produced has to be regarded as a first answer to how actual environmental effect in the surroundings of a ship's route, and caused by the ship, can be incorporated in a ship design process.

The holistic perspective of the design process, see chapter 3.2.2, is important to grasp in order to understand the basis for the appended papers as well as for the general purpose of bringing environmental innovations in ship design into being. The methods suggested in the appended papers can be placed in the design process only if it is regarded in this non-reductionist way. A picture of how the holistic approach can be applied on the ship design process is shown in Figure 5-2.

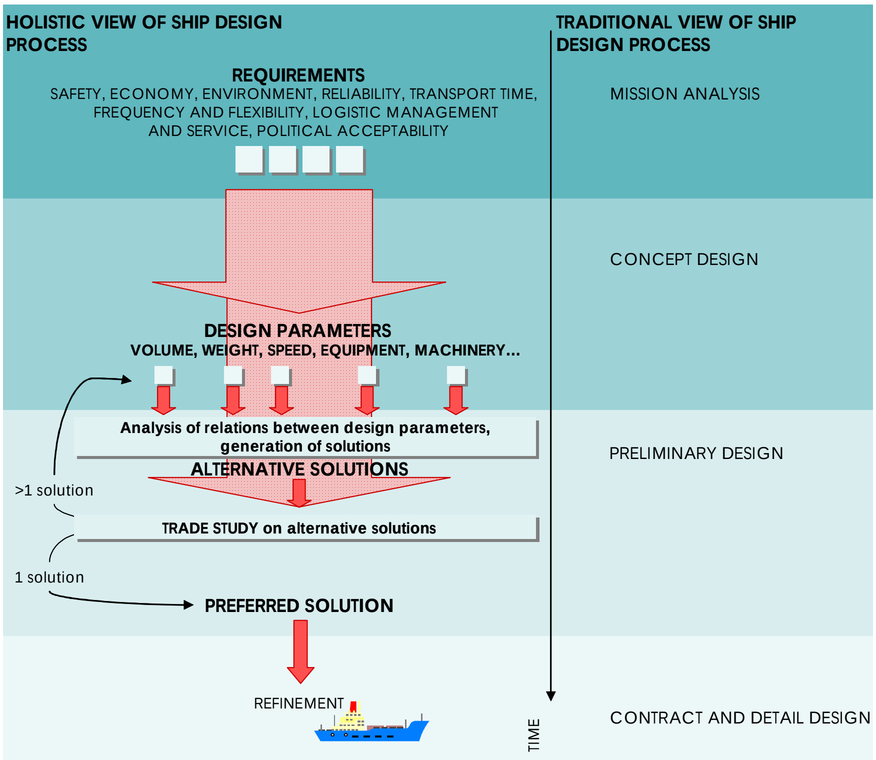

Figure 5-2. A model of the ship design process from a holistic perspective.

Figure 5-2 shows how several different requirements on the ship are identified in the initial design phase. These requirements must all be measurable and if they are not mandatory they should also be tradeable for each other. The requirements are then transferred into design parameters. The different characteristics of the requirements pose several constraints on the design parameters. If each design parameter is considered to have a certain "solution space", this space will be affected by several requirements. There are also a multitude of relations between the different parameters. This is managed in a following analysis, see Figure 5-2. Because of the complexity of the analysis, estimations and experience are needed to produce solutions that correspond to the originating requirements. The outcomes of the analysis are alternative solutions to the requested ship design. The generated solutions subsequently enter a trade study where the best solution with respect to the originating requirements will be the outcome. If several solutions are equal in total performance, iterations with refinement of design parameters are needed. The "solution space" for the ship design becomes more and more narrowed as more iterations are performed and finally only one solution remains, which after some last modifications will be developed to a final design.

On the right hand side in Figure 5-2 the stages described in traditional design are set out. The time scale shows time consumption of different stages in the ship design process. The correspondence between the phases in the two views is approximate.

The trade study requires some facts on how well each solution fulfils the stakeholder requirements. Paper B shows how scoring functions can be used as such facts for environmental impact (Winnes 2004). Standard scoring functions are taken from literature (Chapman, Bahill and Wymore 1992; Daniels, Werner and Bahill 2001), and applied on one case, see chapter 4.4.2, with particulate emissions from ships in urban areas. The scoring functions are in Figure 5-2 occurring as a part of the trade study on alternative solutions.

The varying sensitivity of different areas can be embraced by this method by the fact that the scoring function has the ability to change its shape considering the route of the ship. It will also be possible to include risk-related environmental issues. An environmental risk, the sum of consequence and probability, should be usable as a Measure of Effectiveness in a scoring function. The weight multiplied by the score from a risk scoring function, for example for large oil spills, is an indication of how the ship owner judges the risk. As it seems, a risk analysis will be necessary to produce reliable Figures of Merit.

6 Discussion

With the broad initial aim of developing methods for environmental improvements of ship life cycles, while employing a systems approach to the ship design process, several outcomes of this work were feasible.

If the ship shall be treated together with environment in a systems engineering fashion, some elements of socio-technical systems are applicable and useful in order to be successful.

To succeed economically the four questions *who benefits? who pays? who provides?* and *who loses?* need answers. The beneficiary of the ship system is the person or organisation receiving and/or sending goods on the ship. The cargo owner pays the transport invoice. The provider is the ship owner, and the losers, the ones who experiences that the downsides of the system is disproportionate to the good sides, are probably the people who lives in polluted areas but are not heavily depending on the ship transport.

Diverse interests within these groups and between the client and the user can be a difficult issue to solve for the design team. The imperatives between the public and the private sector often differ greatly. Companies do not have the same incentives to protect public goods, as do governments and international organisations. Economic regulations such as tradeable emission rights are sometimes found to be the solutions to situations like these.

The marketplace can regulate the use of most goods. This, however, does not apply for public goods, which gives the environmental valuation methods great importance in assessing environmental costs and benefits.

6.1 Designing complex systems

If the design considers environmental requirements, experienced environmental scientists or environmental engineers should be included in the design team. For environmental progress in the ship industry, the systems engineering concept of ‘technological readiness’ needs to be considered (Pahl and Beitz 1996). There are many environmental improvements that cannot be completed as practical innovations at a reasonable cost. This is due to the fact that environmental insight is a new aspect for industry and to the fact that ships constitute such complex systems that any new technical structure that is introduced affects several other ship sub-systems.

The complexity in decision making, with respect to environmental concern, including several design parameters can be demonstrated by a few examples. To start with, conclusions are drawn on the level of environmental performance that should be reached within the project. This will not leave a certain design space for each individual design parameter, but a design space for all the parameters together. Keeping CO_2 emissions within a predefined span could be achieved by adjusting speed, weight of the ship, load capacity or even hull shape. To maintain a certain level of particulate emission, the same issues need consideration but with the addition of better machinery and possibly also cleaning equipment. Decision on one parameter increases or decreases the solution span for the other affected parameters. It is also true that the different requirements will drag the solution span for each design parameter in different directions. This is the reason why the first analysis in Figure 5-2 will not allow exact solutions on each design parameter. Due to the complexity in the decision making situation this is completed only after several iterations, the number of iterations depending heavily on the experience of the design team.

6.2 Environmental assessment tools

There are general strengths and weaknesses of the LCA method and for ship life cycles some weaknesses are important to note. Conducting LCAs is a resource-consuming activity and since ships are not produced in serial production there are no prospects of using one study more than once. Several general software tools help overcome the heavy time burden for conducting LCAs. A specific LCA tool for ships has been developed by Mariterm, SSPA and TEM, focusing on energy balances in the ship, but capable of computing material flows as well (Jivén, Sjöbris, Nilsson et al. 2004). Tools like these are essential if the method is to be applicable in the design phase, especially for ships which are designed within very short time limits. An LCA could also be used as an accounting method of the environmental impacts caused by the product under study, which allows the study to take more time than if it is to be used in the design phase.

The weighting of environmental impact categories in LCIA is a delicate process that introduces a lot of uncertainty to the analysis. For global transportation the weighting models need to consider several different regional and local effects in addition to global effects. A lot of information is gathered in the analyses and to reduce complexity the LCA-methodology assumes linear relations between quantity and effect. Local variations are not possible to consider to any great extent, instead mean values are used. During its operational phase, a ship faces several environments of a highly different character. Loading and off-loading often takes place in populated areas, whereas most of the ship's lifetime is spent at sea. The consequences in port, where several people are exposed to the exhaust gases from the ship, are higher than the consequences from emissions at sea.

LCA and FSA rely on different value-bases. LCA has a strong environmental focus and weigh different kinds of environmental impacts against each other. This weighting phase of the LCA is particularly important if two alternative products are to be evaluated against one another from an environmental perspective. In practice, a second trade study, that is not part of the LCA, between environmental impact and other quality parameters and economy always follows (Bengtsson 2001). In FSA, the actual consequences in the environment are not specifically accounted for. Instead, the risk investigated is the risk of exposing the environment to something potentially damaging.

6.3 Further work

The first action to further refine and validate the methods will be to test the methods together with professionals from the industry. The second case study should be extended to include more routes and more ship types, which would prove whether universal scoring functions will actually improve the design process. Another extension of this study will be to follow the scores from the scoring functions to higher levels in the objectives hierarchy by the use of trade-off functions, briefly described in chapter 3.3.3.

As is argued in this thesis and in paper B, the risk element of environmental damage is a prominent feature in the ship's life cycle. Research on how the risk element and the continuous element of environmental damage should be coupled methodically and implemented, was started in paper B, but has several interesting aspects that have not been fully investigated in the brief discussion on methods in the paper. Additional insight into existing models and methods for risk assessment will refine the work with ship-specific environmental assessment tools.

This study has had a clear focus on developing methods for use in ship design. However, scoring functions could also be useful in, for example, environmental reporting and eco-efficiency calculations. An elaboration of this would be an interesting test of the generality of the methods.

7 Summaries of appended papers

The two appended papers can be related as shown in Figure 5-1 on the objectives hierarchy of a ship project; the trade studies performed can be placed in the same value structure or objectives hierarchy for the ship project. Paper A gives relevance to the paper B when considering environmental impact as a performance parameter when providing a logistic service. Paper B establishes a ground for setting up scoring functions on environmental performance. Through this, considerations to the specific prerequisites for ship-related environmental impact are made possible.

In the first study, the logistic performance of five different transport concepts are compared on a route from the Lake Vänern lake area in Sweden to the Duisburg area in Germany. The concepts investigated consist of one where only truck transport is used, one which employs a relatively large ship which is not suitable for transport on the Rhine, one ship with a draught that allows passage through the river part of the year, one smaller ship which reaches Duisburg all the year round and finally a rail-based concept. All hinterland transport is considered to go by truck and the transport is intermodal using containers. The comparison is made with respect to seven performance parameters; transport time, transport cost, frequency and flexibility, reliability, logistic management and service, environmental impact and political acceptability. The method used for evaluation uses weights derived from stakeholder requirements.

In a comparison between the transport concepts on the same route, the total weighted performance differs only slightly between the concepts although the performance for the individual parameters varies significantly. This shows that the concepts have very different characteristics but still attain the same level of service. It also indicates that environmental performance is tradeable with other performance parameters, such as reliability and frequency and flexibility. The first study also shows that the whole transport chain needs to be considered when assessing logistic services in order to avoid sub-optimisation of system performance. The concept using the largest ship shows an example of how sub-optimisation can damage the system performance. The ship is optimised according to economies of scale resulting in long hinterland truck transport with subsequent high cost and environmental impact.

The second study demonstrates the feasibility of the method of using scoring functions in ship design.

It shows that a trade study including environmental performance as a parameter should manage both the criteria of uncertainty and the criteria of environmental response to harmful incisions in the environment. Since environmental problems related to shipping are sometimes risk-related and sometimes continuous to their nature, a methodic change is required. The proposed method has a clear design focus and is taken from the systems engineering discipline to allow further trade-offs with performance parameters on higher hierarchical levels. Systems engineering methods can help integrate environmental aspects in the ship design process. They also provide options to consider geographical differences along the ship's route.

Employing standardized scoring functions eases the integration of environmental aspects in ship design. This requires a holistic view of the design process. The study also indicates that if the integration of environmental aspects into ship design is to be eased by the use of already standardized methods, the outcomes of these methods should be available at an early stage in the design process. This is achieved by providing scoring functions for the different scenarios and emissions of a ship's route.

Suitable trade-off methods certify that the system properties aimed for are prominent in the outcomes of the design process to the extent wished for by the design team. A holistic view of the design process helps in visualizing a process that keeps close contact with the mission of the ship.

7.1 Abstract of "Integrating environmental performance in a logistic approach to short sea shipping - A case study"

Transport by road is the most dominant mode of transportation in Europe today. An increased use of short sea shipping can balance the European transport system and contribute to a better environmental situation. The aim of this study is to identify and explore some characteristics of short sea shipping and to find general logistic weaknesses in the concept. By using a total logistic management approach, this study shows how short sea shipping is a competitive option with high environmental performance.

We present a comparative study between different modes of transportation. A fictitious case of transportation of cargo between the Lake Vänern area in Sweden and Duisburg in Germany is set up and evaluated. The intermodal network between these two regions includes road, rail and shipping. The logistic quality of the total transport chain is measured as a weighted sum of performance parameters such as transport time, transport cost, frequency and flexibility, reliability, logistic management and service, environmental impact and political acceptability.

The scope of the study is narrow, but by employing systems engineering techniques, interesting conclusions regarding a strengthened role of short sea shipping in a future European transport system has been made possible.

7.2 Abstract of "Environmental improvements in ship design by the use of scoring functions"

The introduction of environmental aspects in ship design requires a holistic view on the design process. This view allows trade-off analyses that are unfamiliar to the designer, as well as the integration of environmental knowledge.

Identification of decision-points is relevant to distinguish the possibilities of the mentioned integration and interviews with experienced ship designers have been conducted to support the mapping of the ship design process.

The aim has been to show a design method that is able to include geographical differences in sensitivity when it comes to environmental effects from a ship. It is clear that the effect is dependent on the sensitivity of the area and the amount of people living there.

This paper shows the usability of so-called scoring functions in a trade situation with environmental information. The method produced keeps a lot of information ready at an early stage in the design process and deals with the issue of changing environmental effects in the ship surroundings. Recommendations are given on the use of environmentally focused scoring functions in ship design.

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PAPER A

Integrating Environmental Performance in a Logistic Approach to Short Sea Shipping – A Case Study
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Integrating environmental performance in a logistic approach to short sea shipping – a case study

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Synopsis

Transport by road is the most dominant mode of transportation in Europe today. An increased use of short sea shipping can balance the European transport system and contribute to a better environmental situation. The aim of this study is to identify and explore some characteristics of short sea shipping and to find general logistic weaknesses in the concept. By using a total logistic management approach, this study shows how short sea shipping is a competitive option with high environmental performance.

We present a comparative study between different modes of transportation. A fictitious case of transportation of cargo between the Lake Vänern area in Sweden and Duisburg in Germany is set up and evaluated. The intermodal network between these two regions includes road, rail and shipping. The logistic quality of the total transport chain is measured as a weighted sum of performance parameters such as transport time, transport cost, frequency and flexibility, reliability, logistic management and service, environmental impact and political acceptability.

The scope of the study is narrow, but by employing systems engineering techniques, interesting conclusions regarding a strengthened role of short sea shipping in a future European transport system has been made possible.

Introduction

A precondition for this work consists in a greater importance of ships in the future European transport system. This assumption relies on the benefits of scales in shipping, their positive impact on congestion and their environmental benefits compared to road transport. The study is incorporating environmental aspects as a logistic parameter.

The logistic service is complex and consists of several parts, both physical and non-physical, which in the following will be referred to as performance parameters. For the outline of this study seven parameters were considered most important and were included in the analysis. Through interviews different system stakeholders were invited to give their opinion on the weight of each respective parameter as input to a trade-off analysis. In a case study, different transport concepts were then evaluated against the preferences stated by the stakeholders. The weaknesses and strengths of each concept are visible, and the concepts can after this analysis be refined for improved performance.

The models for evaluation of the transport system are taken from the systems engineering discipline. Difficulties arise when assessing and comparing qualitative performance parameters. The methods used are found in literature but have been slightly modified to suit the purpose and scope of this study.

Daniels, Werner et al., 2001 shows a useful method for trade-off analyses. Measures of Effectiveness (MoE) are quantifiable measures that help describe how stakeholders value important system characteristics. (Sproles 2000) They are solution independent and derived from stakeholder requirements. The absolute numbers of the MoEs (e.g. engine effect as expressed in kW) are denoted figures of merit (FoM) and are unique for each candidate solution. These are translated to normalised values, normally in the range 0-1. FoMs of different character can thereafter be evaluated against each other. The normalised value shall be multiplied by a normalised qualitative weight assigned by the system stakeholder on different performance parameters in the same product (e.g. acceleration vs. fuel consumption). The trade-off analysis then helps in designing the system according to the wishes of the customers. (Daniels, Werner and Bahill 2001) In this study the MoEs are referred to as logistic performance parameters.

The methodology is validated in a case study relying on an existing market need between Sweden to Germany.

Frame of reference

A model of the logistic network used is brought forward and explained. The performance parameters are introduced and defined and finally the hypothesis is presented.

Model of the logistic system

To put the system under study and the following discussion in its context we propose a model of the logistic situation encompassing it. Systems on different hierarchical levels pose constraints and offer possibilities for the transport solutions that we are suggesting. The infrastructure system consists of roads, railroads and rivers, canals, locks and ports. This system is assumed to be existent without change. The transport system includes the different modes of transportation and will apart from the shipping activities remain without changes. The transport market is therefore only marginally influenced by our system. Focus will instead be on the material flow systems, where the functional decisions concerning planning and design are made. (Rohani 2000) The political framework will not be seen as a dynamic factor.

The network in which goods and information flow, can be seen as an interconnected system of nodes and links, where the nodes are terminals and the links are transport relations. Most transport chains involve node handling; this is specifically true for transport by rail and ships where reloading activities in port or station are necessary. Intermodal connections are in this respect more complex than a direct truck relation. In the following definition, the difficulties that are connected with intermodal transport are pronounced;

> *Intermodal transportation can be thought of as a process for transporting freight and passengers by means of a system of interconnected networks, involving various combinations of modes of transportation, in which all of the components are seamlessly linked and efficiently combined. (Jones, C. Richard Cassady and Royce O. Bowden)*

The interfaces have to be carefully managed to provide a seamless chain and a high logistic efficiency.

Defining logistic performance

To make a comparison of different logistic services a balanced set of parameters reflecting different aspects of the total performance of that service has to be defined. In many comparative logistic studies, only one parameter is evaluated such as cost or transport time. (Beuthe, Jourquin, Geerts et al. 2001), (Hagman 1998) A one-dimensional analysis can comprehensively examine this particular aspect but does not reflect the complex assessment a cargo owner has to make to choose logistic arrangement.

The seven parameters chosen for this study are believed to give a representative picture of how quality aware companies assess and chose their transports. The parameters are logistic management and service, transport time, frequency and flexibility, reliability, price of transport, political acceptance and environmental impact. For the definition and selection of the parameters there are mainly two references that have been used as support; (Lumsden 1998), (Wijnolst, Hoeven van der, Kleijwegt et al. 1993).

The characteristics of each performance parameter will be described and a suitable figure of merit will be suggested.

Logistic management and service

Logistic management and service is defined as the ability to conduct and communicate a smooth service integrating transport, information and administration.

This parameter embraces many of the non-material elements of the transport assignment. The more complex a task is the more essential is the management and service facilitating it. In an intermodal arrangement with many interfaces this dimension increases in importance. The development of overall services is enhanced by the growing use of information technology and EDI between the interacting parties.

This dimension is to a greater extent depending on organizational policy and computerization than on the rough outlines of the transport solution. Therefore, no FoM was established and the parameter was excluded from the trade-off analysis.

Transport time

Transport time is defined as the time for transport from warehouse/factory to arrival at buyer’s facility. Other examples of definitions can be found in literature, Korpela and Tuominen uses the total order lead time as time measure. (Korpela and Tuominen 1996)

The FoM for transport time will be the time from source to sink, including both links and nodes, expressed in hours.

Frequency and flexibility

The definition used states frequency as the number of departures per unit time and flexibility as the ability to adjust to changes in incoming flow and size, composition etc.

Both rail and ship uses economies of scale to bear the high investments costs. This generally has a negative impact on frequency, or has to be compensated by large goods flows to keep the frequency at a satisfactory level. A low frequency increases the average time in the nodes due to long waiting hours for departure.

The connection between frequency and flexibility is based on the ability to adjust frequency to changes in incoming flow, size and composition.

No absolute measure of frequency has been defined. Instead a comparative figure based on the largest shipment size is used, assuming that the other concepts will have a frequency inversely proportional to the decrease in shipment size. The FoM for frequency and flexibility will thus be a measure of load capacity.

Reliability

Reliability in the sense of a logistic parameter is defined as the ability to provide the goods undamaged and in accordance with the agreed time schedule.

Reliability is a dimension that has increased in importance during the last two decades as a consequence of the just in time concept and the low stock levels in lean production. (Lumsden 1998)

The FoM have been taken from a statistical study of quality requirements that affect shippers' freight choices in the Nordic countries. Intermodal solutions were compared to single modal solutions. (Ludvigsen 1999)

Price

Price is traditionally considered the most important decision parameter when choosing transport arrangement, but has during the last 15 years diminished in favor for other qualities such as reliability and frequency (Lumsden 1998). One reason could be the increasing interest in monetary assessment of intangible costs of other factors such as reliability and environmental impact. For many types of goods this is still the conclusive factor especially bulk products and raw materials (EUROPEAN-COMMISSION 1996).

The financial context of the transportation modes differs in several aspects. Basically the ship and the rail alternative have high investment costs and low cost per kilometre travelled, while for the truck it is the opposite way. The infrastructural costs differ between the modes in the sense that the shipping sector carries its own costs to a greater extent than do the rail- and truck sectors. These costs also differ notably between countries.

When intermodal transport solutions include either transport by rail or by ship, reloading terminals is a must. The total cost consists of three principal cost types for intermodal solutions;

- "Distribution costs" - they are the costs associated with transport of goods to and from the terminals of departure and arrival respectively
- Handling costs in the "nodes".
- Cost for transport in the main transport leg.

For the direct transport with truck neither handling costs between transport legs nor distribution costs are relevant.

To be competitive with the truck and rail transport, the total costs of the shipping alternative have to be less than the price paid for the equivalent service on road or rail, and still contain profit margin for the ship owner. Reduction in costs are accomplished by high fill rates in the main leg, efficient handling equipment in nodes and the scope is set by the possible reach of the distribution leg.

In this study ship design is focused. Therefore the FoM of the price parameter differ between the transport modes in this study. For the land transports the FoM is the assessed price while for shipping it is the calculated costs.

Political acceptance

When a customer is to establish a new logistic arrangement an important decision factor is the future political direction e.g. if new dues and taxes are to expect or if the infrastructure is likely to be affected. This dimension can be summarized as political acceptance, expressing the compliance between the cargo owner's decision and the political will and approaching acts.

In this study the external costs of the transport has been chosen to serve as a figure of merit for political acceptance. These are the costs that are imposed on the society by the different transport sectors and the cost figures used are taken from a study by INFRAS/IWW that were used in the EU white paper on European transport policy (EUROPEAN-

COMMISSION 2001). These figures include external costs from congestion, accidents and environmental impact.

Environmental impact

Environmental impact is defined as a change in the state or prospects for a natural, social or technical system. This impact will then contribute to a change in an observable variable, such as the number of species present in a habitat or the yearly increase of growing stock or cancer mortality per 1000 habitants. These changes can be denoted environmental effects.

Environmental impact from the transport sector has been identified and discussed in several earlier assessment studies and not at least Life Cycle Inventories (LCI) and Life Cycle Assessments (LCA). (Blinge, Arnäs, Bäckström et al. 1997; Magerholm Fet, Michelsen and Johnsen 2000) It has often been shown that the consumption and combustion of fuel and the subsequent emissions are clearly dominant as contributor to environmental degradation.

In a future European transport system, environmental issues will be more in focus according to several reports from the European commission (EUROPEAN-COMMISSION 2001; EUROPEAN-COMMISSION 2002). The value of environmental assets is a delicate issue. We have chosen an evaluation method commonly used in life cycle assessments to address values to damages to ecosystems, human health and resources. The method is called Eco-indicator-99, the resulting one-dimensional value from the weighting procedure is used as FoM (Bengtsson 2000). Only emissions from fuel combustion are regarded in the weighting.

Interconnections between parameters

Several interconnections exist between the parameters. An example is how short lead time can have negative influence on cost, environment and sometimes even reliability as the time margins shrinks. On the other hand it may promote flexibility, if the planning horizon also can be shortened. The relation between environmental impact and political acceptance is another example of this.

In this study no thorough analysis on this matter has been conducted. The issue of defining an aggregated measure has been addressed in a. o. (Korpela and Tuominen 1996), (Ludvigsen 1999) and (Wijnolst 1993).

Hypothesis

An increased use of short sea shipping can balance the European transport system and contribute to a better environmental situation. The competitiveness of short sea shipping is dependent upon improved logistic efficiency including high environmental performance.

Case

The case study consists of a comparison between short sea shipping transport and transport by road and rail. The transport departs from the area surrounding the lake Vänern in Sweden for Duisburg and the Ruhr area in Germany. The Väner area is an important supplier of grain and forest products. The three counties surrounding Lake Vänern accounts for 22% of the Swedish GNP. The Ruhr area is one of Europe’s most densely populated and industrialized areas. The federal state Nord Rhein Westfahlen accounts for more than a fifth of the German GNP.

This route is chosen because it pronounces interesting ship design problems. The channel from Vänern to Gothenburg contains seven locks allowing the maximum dimension of length 88.0m and beam 13.2m. The passage between Gothenburg and Rotterdam goes in open water and the river Rhine has a very fluctuating water level with a median level of 4.25m. This implies that a ship built for this trip will be restrained in all dimensions but still operate safely in open water.

Altogether five different transport concepts were evaluated.

Logistic concepts

The first concept is the one most straightforward; direct truck from source to sink. The truck used is a Euro 1 long haul truck carrying a 20.4ton container. EC3 (Environmental Class 3) diesel is used. These presumptions are based on information from Schenker BTL (Schenker-BTL).

The second concept is an intermodal truck-ship-truck transport. A Euro 1 truck carrying 20.4 ton performs the short distance truck legs. In Sweden the fuel is EC1 diesel and in Europe EC3. A ship with main dimensions to fit the locks in Trollhätte channel performs the main leg. The draught, 5.85m, only rarely allows passage through Rhine, therefore the goods is unloaded in Rotterdam and further transported by truck.

The third concept is substantially the same as the foregoing, with the exception that the ship is modified for shallow water. The draught, 3.6m, is a compromise between load capacity and navigability in Rhine and statistically permits passage to Duisburg 237 days per year. The remaining part of the year it will have to unload in Rotterdam and continue with truck from there to the end destination. The distribution from the port of Duisburg is conducted with Euro 1 truck.

The fourth concept is a further modification of the ship. The draught is 2.55m, allowing passage in Rhine on average 353 days a year. It is assumed to be operating the route on a regular basis all through the year. A Euro 1 truck carrying 20.4 ton performs the short distance truck legs.

The fifth concept consists of intermodal rail and truck transport. It is assumed that rail is used between Karlstad and Duisburg passing through Denmark. A Euro 1 truck carrying 20.4 ton performs the short distance truck legs.

Cargo

In the study containerised goods have been in focus. The container has an intermodal interface and can be handled with standardised equipment.

The goods flow is assumed to be sufficient to operate three ships on the route allowing departures every second day. The optimal frequency for the main leg was set to one daily departure.

The return flow is not considered in this study. Due to trade unbalances an overcapacity in the return flow can be assumed and will affect the over all efficiency of the system.

Evaluation method

First an evaluation base is established; cargo owners from the Väner area gave their judgment on the performance parameters listed above. Ship owners and transport companies made the same assessment, but in the aspect of how they experience the values of their customers’ requirements. In total, representatives from six companies took part in the study. The parameters were assigned a value from one to ten, ten being the highest score. The resulting weights were then normalised.

The FoMs for the different concepts were calculated as described under *defining logistic performance*. The quantitative values were then transformed according to a linear function delimited in the upper bound to the value of the best performing concept and in the lower bound to zero. This transformation scaled the FoMs to a range between 1 and 0, 1 being the highest score.

These comparative numbers are then multiplied with the weighting factors and a total performance measure for each concept is obtained.

Results

The weightings assigned to the logistic parameters by the system stakeholders are presented in Table I. Due to the number of participators in the survey the values are not statistically supported but can be seen as a rough indicator of the customers' requirements.

WEIGHT / PARAMETERS	*Transporter A*	*Transporter B*	*Transporter C*	*Customer 1*	*Customer 2*	*Customer 3*	*Average*	***Normalised weight***
Transport time	1	5	8	10	1	10	5,8	**0,14**
Frequency and flexibility	6	6	10	10	2	10	7,3	**0,18**
Reliability	10	9	9	10	9	9	9,3	**0,23**
Price	8	10	8	7	10	8	8,5	**0,21**
Political acceptance	3	-	10	0	3	8	4,8	**0,12**
Environmental impact	4	4	9	0	7	9	5,5	**0,13**
								1,00

Table I Stakeholders' judgments on performance parameters and the resulting normalised weight

The normalised weights were transferred into the concept evaluation matrix Table II.

MODE / PARAMETERS	*Truck*	*Ship 5,8*	*Ship 3,6*	*Ship 2,5*	*Rail*	*Normalizied weight*
Transport time	1,00	0,42	0,39	0,37	0,31	0,14
Frequency and flexibility	1,00	0,43	0,57	0,86	1,00	0,18
Reliability	1,00	0,93	0,93	0,93	0,93	0,23
Price	0,38	0,90	0,89	1,00	0,41	0,21
Political acceptance	0,32	0,72	0,89	1,00	0,91	0,12
Environmental impact	0,45	0,79	0,62	0,50	1,00	0,13
Total	**0,72**	**0,72**	**0,74**	**0,80**	**0,76**	

Table II Total concept evaluation according to the weighted figures of merit

According to the stakeholders' evaluations of the parameters, no dimension is distinctly most important.

The results show that the most suitable transport service for the route investigated is the intermodal ship concept using the smallest ship.

It is also clear that the difference in total performance is small among the different concepts. Individual parameters on the other hand show great variation between the concepts.

Discussion

The trends in Europe point towards more regulations on environmentally degrading activities and regulations to avoid road congestion. If these parameters would receive a higher importance score from customers, the balance between the transport modes will be shifted towards rail and shipping.

The results imply that truck transport is the least favourable of the transport modes. This is not in accordance with the transport situation today in Europe. This discrepancy can be attributed to the fact that the parameters political acceptance and environmental impact are not as highly valued in reality as was stated by the interviewees. An extension of the model to include capital costs for the goods would further promote concepts with a short transport time.

The same weighting factors are used regardless of goods type. Depending on goods value, the cargo owners have different priorities for the logistic service. To obtain a higher precision in an analysis like this, a variation between different customer groups might be required.

As far as possible computational models and input data established in the branch are used. For the qualitative performance parameters environmental impact, reliability, flexibility and political acceptance, the evaluation basis is subject to preferences and needs further support among expertise and stakeholders to the system.

In a continuation the best performing concept should be further refined to identify additional opportunities to strengthen its competitive ability. Compared to truck transport the concepts employing rail and ships have environmental benefits. Shipping still has opportunities to efficiently improve its environmental performance

Concluding remarks

The total performance differs only slightly between the concepts but can vary significantly for each parameter. This shows that the concepts have very different characteristics but still attain the same level of service.

The results pronounce the value of systems thinking in logistic services. The effectiveness should be measured in several dimensions on the basis of the whole transport chain. The concept using the largest ship shows an example of how sub optimisation can damage the system performance. The ship is optimised according to economies of scale resulting in long hinterland truck transport with subsequent high cost and environmental impact.

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PAPER B

Environmental Improvements in Ship Design by the use of Scoring Functions
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Environmental Improvements in Ship Design by the use of Scoring Functions

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Abstract

The introduction of environmental aspects in ship design requires a holistic view on the design process. This view allows trade-off analyses that are unfamiliar to the designer, as well as the integration of environmental knowledge.

Identification of decision-points is relevant to distinguish the possibilities of the mentioned integration and interviews with experienced ship designers have been conducted to support the mapping of the ship design process.

The aim has been to show a design method that is able to include geographical differences in sensitivity when it comes to environmental effects from a ship. It is clear that the effect is dependent on the sensitivity of the area and the amount of people living there.

This paper shows the usability of so-called scoring functions in a trade situation with environmental information. The method produced keeps a lot of information ready at an early stage in the design process and deals with the issue of changing environmental effects in the ship surroundings. Recommendations are given on the use of environmentally focused scoring functions in ship design.

Keywords: Ship design, Environmental aspects, Scoring functions, Systems engineering

1. Introduction

The shipping industry causes a lot of environmental damage, but is a vital part in the global transport network. Most of the shipping industry's effects on the environment relate to the transport work carried out and the combustion of fossil fuels, but there are also environmental impacts that relate to the building of the ship, the scrapping and individual activities in the ship's life cycle. The greatest power to influence the environmental life cycle performance of the ship lies in the design phase. This relies on the fact that in this phase a designer is able to successfully trade environmental performance against other performance parameters and cost **[1]**.

The design engineer is in a process of constant decision-making. Usually the decisions are based on experience and not necessarily on documented data of a specific situation or scenario. Trades between different parameters are constantly made. Engineers are believed to concentrate on things they are familiar with in the trade-off situation and several environmentally degrading activities and components are believed to introduce new knowledge to the engineers. This is the reason why the engineers' general technique of using experience-based information is not enough and why a systematic design framework is necessary.

Among ship designers it is common knowledge that the cost for introducing changes to initial design greatly increases as the process proceeds. Roughly, it can be said that if a change made in the conceptual design phase has cost 1, the cost will be 10 if it is made during construction and 100 if enforced during the actual production of the ship. The same goes for environmental costs and damages **[1-3]**.

A ship in operation releases different amounts and proportions of fuel combustion gases and particles in the air at different stages of its voyages. This depends on the amount and type of fuel used and the utilized effect of the engine, which is designed to be optimal during the main transport leg. When manoeuvring in harbour, ships have been recorded to release a proportionally large amount of CO, HC and particulate matter **[4-6]**. In other words, the dose is higher in the surroundings of the harbour. There is also a difference in response, since the harbour area is populated with people, breathing the polluted air. This scenario with an increase in both dose and response may also occur close to inland waterways.

This paper will make a first attempt at answering what is needed by a design tool that should deal with this situation. Life Cycle Assessment, which is gaining increased attention and acceptance in the ship building industry, seems unfit for this type of analysis.

The belief is that systematically aggregated functions on environmental information made available in the early design phase will help improve the ship's environmental performance according to changes in the ship-route surroundings. This means that systematic trade-off methods can help to introduce environmental knowledge in the otherwise largely experience based design process.

Interviews with experienced ship design-engineers have been conducted and will serve as the basis in the design reasoning. Literature on ship design has also been used **[7]**.Trade-off analysis methods are taken from systems engineering literature **[8, 9]**. The concept of scoring functions will be described and explained.

2. Ship design process

The traditional view of the ship design process, generally represented by the spiral model, is not appropriate for the purpose of this paper. The reason for this is a need for a stronger focus on the integration of requirements from the mission analysis throughout the design phase.

Earlier criticism that has been raised against this traditional view consists of the fact that ship design is a complex process that cannot be explained in a reductionist way. The spiral misses connectors between parameters that are needed in practical work. There is also a general shortage in the fact that the overall requirements on cost, etc., from the mission analysis are only briefly present. Generally it can be said about spiral illustrations of design that these models cannot deal with optimal solutions, since they are not able to deal with comparative evaluations of different candidate solutions **[10]**.

To add all the missing connections between parameters would make any model hard to grasp and impractical to use. However, attempts have been made to produce more functionality-focused models of the process. **[11]** The effort lies in showing connections in the mission analysis and emphasizes the importance of the economics of the shipbuilding.

The addition of innovative solutions to the design is cared for by this functionality-focused, "holistic" view of the design process. **[11]** Innovations bring about changes in the systems that need to be explained by the "missions" of subsystems. If a reductionist view is applied, the effects of interfacing parts might be neglected and the innovations will fail to succeed.

2.1 Integration of environmental aspects

Decisions influencing environmental performance are mainly objectives on high system levels. Most of them even originate in legal obligations. The conversion of these requirements into design parameters occurs at the same time as other legal and mandatory requirements and they should ideally pervade the whole decision-making process. In this essay, however, the focus lies on dealing with less mandatory demands **-** demands that arise from stakeholders' wills but that are not wanted at any price.

The relevant decision points are first found on the mission level in an explicit statement that extra concern about environmental issues will be taken. Secondly, more defined decisions concerning installation of equipment and interfacing subsystems will be identified. The decisions most relevant in this study relate to fuel combustion and the parameters speed and power are also judged as being vital. Decisions on speed occur early in the design process and any specific information that serves as a decision basis needs to be produced from when the mission is determined up until the time when speed and power requirements are decided. A time window that is open in the time range of weeks to a few months.

3. Applicable systems engineering methods

For environmental progress in the ship industry, the technological readiness of solutions needs to be considered. There are many environmental improvements that cannot be completed as practical innovations at a reasonable cost. This is due to the new aspects of the environmental insight of the industry and of the ships being such complex systems that any new technical structure that is introduced affects several other ship sub-systems.**[12]**

In the process of decision-making, several parameters should be weighed and evaluated in the light of others. The weighting of parameters of different character and different measurable units can be done by defined systems engineering approaches. This is also true of parameters of a more “soft” character, as for example environmental issues that do not have a simple measurable or monetary value, which could be used in a comparison. The transfer of “soft” values to “hard” values is necessary for the analysis and quantifiable measures of effectiveness for each soft value need to be identified. The term Measures of Effectiveness (MoE) is used in the sense of solution-independent measures, indicators or “standards”, against which the performance of a solution can be assessed. These should be deducted from stakeholders’ requirements. **[13, 14]**

The following paragraphs concern so-called utility functions or scoring functions. Scoring functions are used to transform requirement-based measurable parameters of different kinds to comparable values (in the range 0-1). The traded parameters should always be quantifiable. The relevant measures are referred to as Figures of Merit (FoM), which are defined as the unique MoEs for any particular candidate solution **[8, 13, 15]**.

After the relevant scoring functions are set up, a subjective weight is multiplied to each resulting score or utility. The possibilities for environmental aspects, as an example of a tradeable parameter, to impact the final result, lies in the weight which environmental aspects is given in the final weighting step where it is traded against other performance parameters. The parameters to be traded are, for example, environmental impact, frequency and reliability, see Figure 1 on the hierarchy of objectives of a ship project. The hierarchy much include objectives for which system stakeholders are willing to pay for an increased performance.

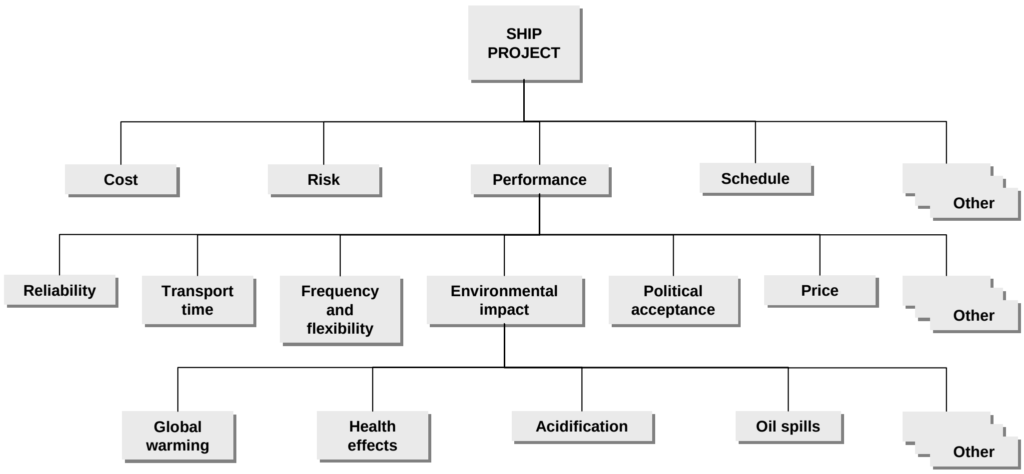

Figure 1. Objectives hierarchy on a fundamental level of a ship project. The environmental impact parameter is followed to one level lower than the other objectives.

Some standard scoring functions have been suggested **[8]** and the function presented here is deducted from one of these.

A general rule of utility functions is that more should always be better. In the context of an environmental study, this could mean that zero emissions, as an example, of a hazardous substance are equal to one and the more emissions the lower the score.

4. LCA and risk assessment in ship design

The following paragraphs aim at describing scoring functions of two different methods in a trade-off situation where several parameters will be analyzed.

In Life Cycle Assessments (LCA), which is becoming an increasingly popular approach to environmental management in the shipbuilding industry, see for example **[11, 16-22]**, the functions used assume a linear relationship between pollutant quantity and effect. The weighting of environmental impacts is in common LCA practice done by multiplying an impact (e.g. global warming) or its causes (e.g. CO_2 emission) with a calculated index based on economic terms, expert assessments, political goals or others. The linear function between quantity and consequence is shown in Figure 2 a), where the index depicts the slope of the line. The corresponding scoring functions can be represented as in Figure 2 a), with inverted values, Figure 2 b).

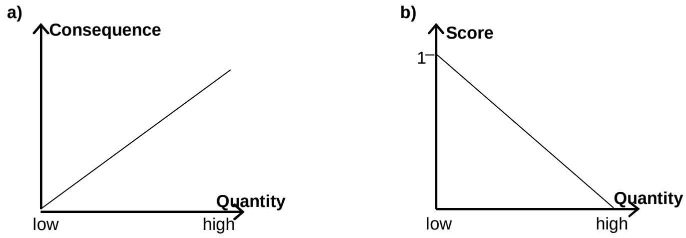

Figure 2. a) The relationship between quantity and consequence in LCA weighting practice b) The corresponding utility function

The shortage of this method when it comes to shipping is its insufficiency in accounting for geographical differences along a ship's route or damages caused by single hazardous events. Both issues are prominent aspects of environmental damage related to shipping. One way to deal with this is suggested in **[23]**, where a site factor is added to the results of a life cycle assessment on a transport chain. The results from this study are not highly affected by the extra step.

Risk assessment tools have a longer history in the ship design industry and are focused on local conditions and on single events. These methods use absolute measures without relating them to a functional unit. They do not apply any scoring functions and are not suited to include environmental consequences from the whole ship life-cycle or the transport work provided by it. This complicates comparison of objectives on higher levels in a final analysis.

The desired tool should, like risk assessment methods, be able to consider damage in relation to specific spatial and temporal aspects and still manage to compare different solutions with respect to environmental impact as is done in LCA.

5 Case testing

Emission calculations need to consider that certain emission species in the exhaust gas show a relative increase at lower engine effect utilisation due to incomplete combustion. This effect has been demonstrated for such gases as CO, HC and for particulate matter. **[4, 6, 24]** The emissions diffuse over vast areas, depending on winds and precipitation, and the specific characteristics of the emitted substances have a great influence on their lifetime in the atmosphere. Emission calculations also need to reflect that oil consumption per time unit decreases at lower speeds.

For the demonstration of the method the case will deal with emission of particulate matter, something that has earned a lot of attention lately because of its detrimental effects on human health.

Particulate matter comes in a range of sizes and is usually measured as PM10 (diameter less than 10µm) and as the finer fraction PM2.5 (diameter less than 2.5µm). Combustion particles are generally all found in the finest fraction. Smaller particles can stay in the atmosphere for a very long time and are also the most harmful to human health. **[25]** Particulate matter also has the characteristic of being most harmful while in the atmosphere as a contrast to, for example SO_2, which contributes to acidification after deposition.

A manoeuvering ship normally operates in the power range of 0-50% MCR. This is due to facts such as reduced speed while waiting for pilot assistance, increased speed with pilot assistance, passage through locks, and reduced speed for manoeuvering and berthing. The studied case is the round trip journey of a Ro-Ro ship between Gothenburg and Immingham. In Gothenburg the quay is situated in the outskirts of the city and speed restrictions do not affect the ship. In the North Sea, the speed is kept at approximately 20.5 knots depending on weather conditions. When entering Spurn – just outside the river Humber, which leads to the port of Immingham – waiting and idling is sometimes required depending on the traffic situation in the river. The water level is very fluctuating and when it is high, there are normally many ships leaving the ports upriver. The water level also affects the speed limits for the ship. There is also a passage through a lock, which requires idling for some 15 to 20 minutes, after which the ship needs about 20 minutes to manoeuvre before berthing. In total, the ship operates 1½ to 2 hours at reduced speed in the interval of 0-50 % of MCR.

A main engine of a modern RoRo-ship of 10500 dwt and a cargo capacity for 253 trailers, as in this case, consumes approximately 2000-3000 litres of fuel oil per hour during normal operations. While manoeuvering, oil consumption decreases per hour but shows a slightly erratic behaviour relative to the power output. The power output during manoeuvering used in the calculations is set to 20% MCR. The particle emissions during this time have been calculated from recent measurements on slow speed diesel engines, Table 1.

Table 1. Particulate emissions on a journey from Gothenburg to Immingham, emission figures from IVL [6]. TSP is Total Suspended Particles and includes all particulate matter less than 10 μm in diameter.

	Emission Particulates/kWh TSP		Appr. Time	Effect	Emission Particulates TSP	
Gothenburg fairway (20% MCR)	2,6	g/kWh	1 h	4067 kW	11	kg
At sea (80 % MCR)	1,3	g/kWh	23 h	16268 kW	486	kg
Immingham fairway (20% MCR)	2,6	g/kWh	2 h	4067 kW	21	kg

The ship going up the river to Immingham emits approximately 21 kg of total suspended particles (TSP), while it on a journey across the North Sea, from Gothenburg to Spurn, would release approximately 0.57 kg/km.

5.1 Application of the scoring function

The scoring functions are set up to be used by design teams who need to trade environmental performance with other performance and cost parameters. Standard scoring functions are present in SE literature **[8] [9]**and are applied here. The formulas used are presented in Figure 3 and are valid for MoEs where both a lower and an upper threshold exist and where the function is monotonically decreasing. The functions are universal in the sense that they are independent of route and ship. Only the emission level of the ship, giving the figure of merit, will differ between different ships and routes.

For $v < L$

$$Score = 0$$

For v higher than *L* but lower than *B*

$$Score = 1 - \frac{1}{1 + \left(\frac{B-L}{v-L}\right)^{2\cdot(-S)(B+v-2\cdot L)}}$$

For v higher than *B* but lower than *U*

$$Score = 1 - \frac{1}{1 + \left(\frac{B-(2\cdot B-U)}{v-(2\cdot B-U)}\right)^{2\cdot(-S)(B+v-2*(2\cdot B-U))}}$$

For $v > U$

$$Score = 1$$

B = Baseline value
L = Lower threshold value
v = value on x-axis (Figure of Merit)
U = Upper threshold value
S = Slope of the tangent to the curve at B

Figure 3. Standard scoring function with upper and lower threshold and where a higher FoM is worse.

For particulate matter the curve will assume different shapes depending on the population density of the area around the emission. The actual health effects seem to be proportional to the amount of particles emitted, no no-effect concentrations have been observed. **[25, 26]** Even though this fact implies a linear function, there will also be thresholds to the functions indicated by stakeholder demands and design constraints. These could, for example, be an upper limit for where cleaning equipment, such as a particulate filter, would have effect and a lower limit for where the release is not acceptable to the surrounding environment.

The quantity on the x-axis should presumably consider both exposure and the utility acquired. My suggestion is that the score is a function of exposure/tonkm. The exposure unit is calculated as μg/m^3 per emitted kg. For urban areas the following formula is suggested:

$$X = X_0 \cdot F_v \cdot \sqrt{P}$$

Where:

X = specific exposure
X_0=exposure factor, a constant calculated to the value 0.029 [μg/(m^{3}kg)]
F_v = the ventilation factor for the urban area
P = the size of the population

The formula is taken from **[26]** and has earlier been used for Swedish conditions. The ventilation factor for coastal towns are given the value 1, corresponding to climate conditions on the west coast and on the south east coast of Sweden. The specific exposure multiplied by kg emitted particles per transported tonkm will give the measure of effectiveness.

The lower threshold value below which the score is insensitive to changes in performance has been set to 0.0002eu/tonkm since this is where the baseline value would be, if a particulate filter cleaning 90% of the emitted particles, was installed. The upper threshold level has been set to 0.007eu/tonkm, as a measure of what could be acceptable to the people in the area. The slope should be at its steepest at the value that should serve as the wanted baseline- or design value. In this function, this value has been set to 0.002eu/tonkm, corresponding to 0.5 in score.

The fact that this function has been based on the studied case implies that it is not necessarily applicable on other ship types than Ro-Ro ships and that further studies are necessary to produce a more general design value as well as upper and lower threshold values. See Table 2 for the values on exposure unit/tonkm for Gothenburg, Immingham and Grimsby.

Table 2. Exposure unit per tonkm. Sailing up the river Humber, the ship passes the city of Grimsby. Time and emissions have been split in half between Immingham and Grimsby before calculating exposure units per tonkm.

	Population	Specific exposure [µg/(m^3*kg)]	tonkm	Exposure unit/tonkm [µg/(m^3*tonkm)]
Urban areas				
Immingham	**11000**	3,0	70000	0,0004
Grimsby	**90000**	8,7	70000	0,0012
Gothenburg	**481000**	20,1	70000	0,003

A scoring function based on the case presented above generated the curve shown in Figure 4.

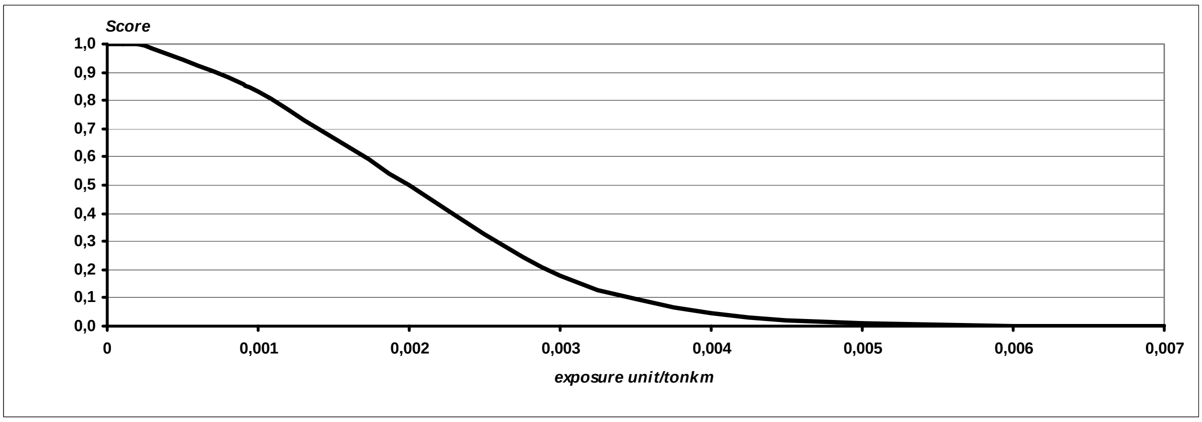

Figure 4. Scoring function with *B*=0.002, *L*=0.0002, *U*=0.007 and *S*=-380.

It is also obvious that the functional unit tonkm has a great impact on the result and some rough estimates on other types of ships suggest a change to "valuekm". Indicating the value of the transported goods might improve the generality of the function.

6. Discussion

Environmental aspects that are not legally regulated are seldom integrated in the ship design process. The concerned technologies are often new and imply additional costs to the shipowner. New technological solutions need to be traded for economic performance and long term economic effects of goodwill from good environmental performance are difficult to include in a forecast.

Simplification of the complex system of the environment and environmental effects are needed to be able to communicate any problems associated with it, which is the reason for aggregating a lot of information and data to a one dimensional value. This is the reason for using scoring functions explicitly or implicitly, as in the case of LCA, when dealing with environmental consequences.

For each situation where an environmental damage may occur, a specific scoring function should be set up. Depending on the characteristics of the emission, the functions will differ according to the sensitivity of area of release. Carbon dioxide, for example, will only need one function since its effects are found on a global level. To avoid additional time requirements during design it is necessary to identify a few but important cases where the reasoning on geographical differences is extra vital.

If the new knowledge is applied in the design process when the route has been decided, fast situation-related environmental assessments can be made. The information can be available in time for the choice of engine and related equipment and the choices can be motivated and documented with reference to the proposed functions.

The double nature of environmental problems is explicit in ship transport. The need to find a method that can deal with both sides, risk related and continuous impacts, is therefore vital to the ship industry for efficient progress in the field. The suggested methods can deal with these issues since the scoring functions are adjustable for different geographical areas.

The suggested method shows a way of integrating environmental aspects in ship design. The method emphasizes the need to have a scheme for conducting trade-off analyses based on appropriate scoring functions. Suitable trade-off methods certify that the system properties aimed for are prominent in the outcomes of the design process to the extent requested by the design team. A holistic view of the design process helps in visualizing a process that keeps close contact with the mission of the ship. This work could limit the information needed to perform a full LCA or the corresponding assessment tool before the crucial decisions are taken. It is thereby a more suitable tool for the rather short time-window in the ship design process that needs to be matched for these kinds of decisions.

The formula on exposure in urban areas used in the case study is developed for emissions from road vehicles in the city. The estimates on exposure due to the ship are therefore probably somewhat high and should be modified if external costs are to be calculated.

For environmental impacts with a clear geographical dependency on effect, this way of measuring environmental performance in relation to utility could also prove suitable for future use in eco-efficiency reporting.

7. Concluding remarks

The feasibility of the method of using scoring functions in ship design has been demonstrated.

Employing standardized scoring functions eases the integration of environmental aspects in ship design. This requires a holistic view of the design process

The use of scoring functions provides options for considering geographical differences along the ship's route - a prominent characteristic of ship-related environmental impact.

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