Ship life cycle assessment and management

Gesellschaft für Angewandten Umweltschutz und Sicherheit im Seeverkehr

Gesellschaft für angewandten Umweltschutz und Sicherheit im Seeverkehr mbH

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1 Introduction: Research, decision support and service

Being a relatively new methodology, the range of applications of the life cycle approach is still growing. The examples in section 4 represent different ways to use life cycle assessments. The examples range from comparisons of similar products to continuous LCA operations which support the companies' management. This set of examples with growing complexity also demonstrates the methodological development from a life cycle assessment to life cycle management.

Beginning with a fundamental consideration of a life cycle assessment of ships (Shama, 1995) the life cycle assessment approach was intended to provide information on the products' environmental impact throughout the products "life" from design phase until scrapping and discharge. This approach is illustrated in section 1.4.2.

Life cycle assessment is applied in very different fields of activity:

- Some are of general interest, providing orientation for a very big community of users in different maritime branches. This field might be called *research*.
- Some other activities deal with specified product requirements in rather singular cases with limited transferability. They provide *decision support*.
- Some have *enduring service* character. They are specified according to companies' management needs. Here we have *the ship life cycle management*.

Many more products and services are not based on life cycle assessment methodology but use the wording because the expression "life cycle" sells.

Life cycle assessment methodology has become an object of international standardisation. Even so, there are life cycle assessments beyond ISO standards.

Methodology, applications, ISO standardisation, products and services do not form a stringent line but rather a cloud.

This teaching module therefore aims to offer orientation on:

- Future challenges which might be better met with LCA
- Wording to prevent confusion
- Basics on the life cycle assessment methodology
- Application of LCA and resources needed for different LCA options
- Resources needed and general outlook, relevance of operational data policies

1.1 Environmental performance and reporting

The maritime industry – like other industrial branches – has been confronted with a rising demand for information about the management of its environment and the industry should therefore plan for the future when there will be an ever-increasing spotlight on environmental issues (Sharma 2006).

If a company intends to improve its environmental performance, there are different methods available to do so. The methods are process oriented, product oriented or management oriented.

- Process oriented tools enable an overview of material and energy flows in production processes. The focus is on opportunities for waste reduction or elimination of pollutants.

- Product oriented tools enable the identification of the environmental impact and improvement options in product systems.

- Management oriented tools are more comprehensive. The Environmental Management System (EMS), as an example of the management oriented tools, includes procedures for the understanding of environmental aspects, sets objects and targets, establishes programs to achieve those objectives and targets and reviews the performance against the latter.

The description above follows the outline of Magerholm Fet (2003), which is recommended for further reading.

Before the methodology and examples of application are presented, the basic assumptions of the LCA approach, the linkages with ISO standardisation, the future challenges for maritime business and the terminology are described.

1.2 Basic considerations and fields of application

The following figure demonstrates life cycle management in relation to ships:

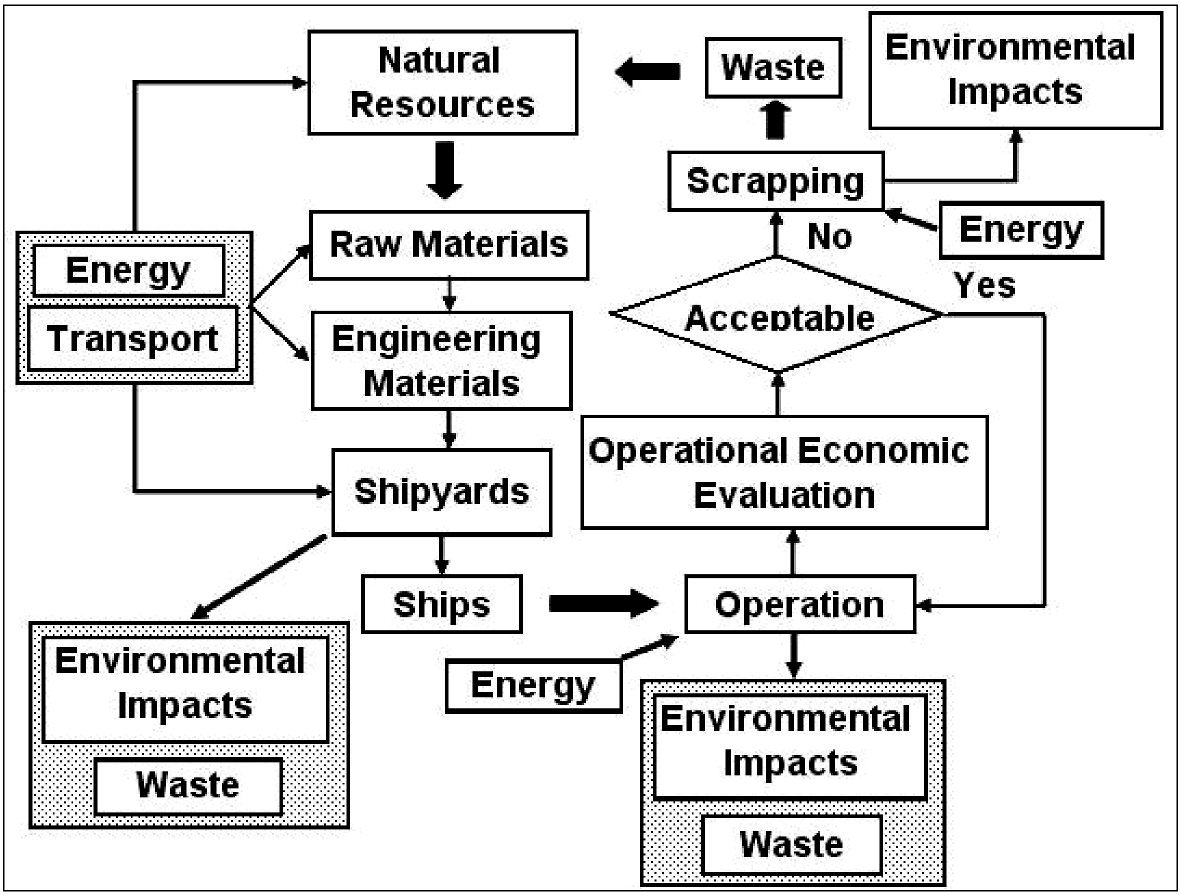

Figure 1: Ship life cycle (Shama , 2004)

This figure might appear confusing at first sight. What is important is that neither the ship nor the ship operation dominates the figure. Instead the energy input, the resulting wastes and environmental impacts related to ship building, ship operation and ship scrapping are emphasised. Impacts of accidents are left out.

The cycle is closed by adding some of the wastes which result from the break down of ships to the natural resources needed for ship building. Operation occurs as long as the operational economic evaluation reveals it is acceptable. This evaluation is not influenced by the acknowledgement of environmental impacts.

The following picture and the following table show that life cycle assessment (here called analysis) is expected to provide information for very different fields of activity.

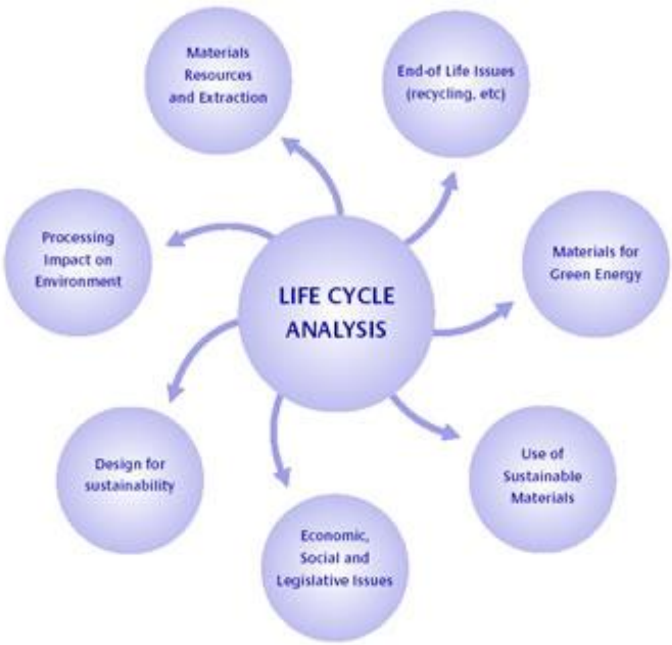

Figure 2: Fields of application of LCA, (Sharma, 2006)

With reference to maritime business, few of the actors between shipyard and insurance company or flag state administration can be excluded from the potential target groups of life cycle management tools to be presently developed.

- *Materials, resources and extraction* refer to the raw materials and energy used for ship building. An example of the application of LCA can be found in section 3.1.2 (ship hull material).
- *Processing impact on the environment* refers to ship building and fabrication of ship components. Examples of the LCA application can be found in section 3.1.1 or 3.1.3 (anti-foulings or fuel cells).
- *Design for sustainability* refers to the important phase of ship design when very important decisions for future energy efficiency are made. Section 3.1.4. refers to this field of application.
- *Economic, social and legislative issues* are manifold. This field refers for example to a ship's life cycle costs (example presented in section 3.1.4) as well as to repair planning (section 3.2.1) and ship life cycle guidance tools (section 3.2) in general.
- *The use of sustainable materials* refers to LCA for comparisons of hull materials and anti-foulings, (section 3.1.1).
- *Materials for green energy* refers to the use and comparison of different fuels, as illustrated by Bengtsson et al. (2011).[1]
- *End of life issues* refers to ship recycling and to the Inventory of Hazardous Materials, (IHM), described in section 3.3.

A more abstract view is presented below:

[1] Bengtsson, Selma/ Andersson, Karin/ Fridell, Erik (2011), A comparative life cycle assessment of marine fuels, liquefied natural gas and three other fossile fuels, in: Journal of Engineering for the Maritime Environment; manuscript.

Table 1: Options / purposes of LCA (Sharma, 2006)

Options / purposes of life cycle assessment
Improvement of the environmental aspects of a product and of the weak points in the product chain, where the changes are needed
Selection of relevant indicators of environmental performance
Product development for environmentally better products
Decision making in governmental organisations
Product comparisons and product selections
Development of specifications, regulations or purchase routines
Marketing

1.3 LCA methodology and the ISO 14 040 series

LCA methodology is the object of international standardisation. The first two standards in the ISO 14 040 series have already been published and the other two are under debate. The standards are:

* ISO 14 040 Life cycle assessment – Principles and framework

* ISO 14 041 Life cycle assessment – Goal and scope definition and inventory analysis

* ISO 14 042 Life cycle assessment – Life cycle impact assessment

* ISO 14 043 Life cycle assessment – Life cycle interpretation

As outlined above, LCA might contribute, with other methods and indicators for example, to an environmental management system such as ISO 14001 - 14004. The ship recycling industry deals with its own ISO standards (see section 3).

The International Organization for Standardization (ISO) and the other standardisation organisations, the European Committee for Standardisation or Comité Européen de Normalisation (CEN) recognise that "*every product has an impact on the environment during all phases of its life*" and therefore it has started a system, where each new product standard is attached with a temporary environmental annex. For this annex life cycle assessment is a central tool. [2]

As can be seen above, LCA can be divided into three basic steps: goal and scope definition, inventory analysis and impact assessment. Deviating from the list above, in the figure below the interpretation is not regarded as the final step but as a necessary procedure during the whole assessment.

This difference should not confuse but instead it proves that the methodology *needs* standardisation.

It might be good to ask the providers of the LCA about the internal order of operations in order to better understand the results.

[2] This is the ISO guide 68/2008, please check http://www.iso.org/iso/pressrelease.htm?refid=Ref1173

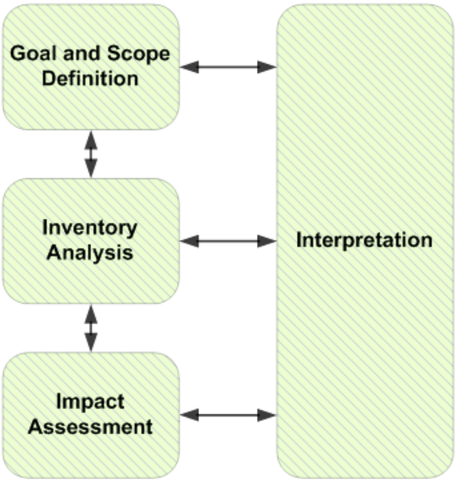

Figure 3: Illustration of life cycle assessment phases (Sharma , 2006).

For an insight into the processes and procedures, technical committees etc. please have a look on the website of the International Organization for Standardization.

For further reading Magerholm Fet (1998) is recommended.

1.4 Terminology

The range between rather abstract and very much more applied approaches to life cycle activities is very wide. The different approaches have to be clearly distinguished and therefore an insight into the terminology is important.

Life cycle management, life cycle guidance systems, eco efficiency analyses all depend on a life cycle assessment being carried out first.

As there is no legal obligation for ship life cycle assessments or related activities, agreed-upon definitions like those used in international conventions are missing. Therefore it is even more important to use precise wordings.

Environmental impact

- Possible adverse effects caused by a development, industrial, or infrastructural project or by the release of a substance in the environment. [3]

Life cycle

- Consecutive and interlinked stages of a product or service system, from the extraction of natural resources to the final disposal.[4]

[3] www.businessdictionary.com/definition/environmental-impact.html

[4] ISO 14040.2 Draft: Life Cycle Assessment - Principles and Guidelines

A ship's life cycle

- An approach to regard the ecological performance of the ship's main functional units[5] within defined system boundaries[6] during the ships life span.

Life cycle assessment (1) [7]

- Assessment of a product, used to identify, evaluate and minimise energy consumption and environmental impacts holistically, across the entire life of the product.
  - LCA conceptually: A process guiding the selection of options for design and improvement.
  - LCA qualitatively: An assessment of key environmental burdens or releases at the different stages of the life cycle of a product.
  - LCA methodologically: A quantitative inventory of environmental burdens or releases and considering alternatives to improve environmental performance.

Life cycle assessment (2)

- A systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle.[8]

Life cycle management system

- Among the newer concepts in LCA one finds "life cycle management" (LCM), which is an integrated approach to minimising environmental burdens throughout the life cycle of a product, system or service.[9]

Life cycle management system for the shipping industry

- A life cycle management system for the shipping industry is supposed to provide a documented whole life survey. It must represent the vessel and its current condition not only during regular operation, repairs and maintenances but also through constructional alterations. (Thoben et al. 2009)

[5] See chapter 2.1.1

[6] See chapter 2.1.2

[7] See Shama 1995, 2004.

[8] ISO 14040.2 Draft: Life Cycle Assessment - Principles and Guidelines

[9] See European Environment Agency (1997): Environmental Issues Series, No. 6

Life cycle data

- Product data: Information, knowledge and documents created and archived during the conception and design phase of a ship and ideally filed within a product data management system. This can be system related data sheets, specifications, manuals, calibrations, settings, manufacturer information etc. (Thoben et al. 2009).
- Operation data: The operating data is data collected on board the ship during its operation. Most of this data consist of real-time measurement data resulting from condition monitoring systems (Thoben et al. 2009).

Life cycle accountability

- The notion that a manufacturer is responsible not only for direct production impacts, but also for impacts associated with product inputs, use, transport, and disposal (Tellus Instiute).[10]

Cradle-to-grave

- An approach which includes the extraction of raw materials; the processing, manufacturing, and fabrication of the product; the transportation or distribution of the product to the consumer; the use of the product by the consumer; and the disposal or recovery of the product after its life (EPA 2010).[11]

Variation: Cradle-to-gate

- Cradle-to-gate refers to product life from resource extraction ('cradle') to the factory gate (EPA 2010).

Variation: Well-to-propeller[12]

- Approach to compare different fuels. The life cycle assessment is carried out from the crude oil extraction in the oil – or gas field to the ship propulsion aggregate.[13]

[10] Cited on www.gdrc.org/uem/lca/lca-define.html

[11] see: http://www.gdrc.org/uem/lca/lca-define.html acc. to "Defining Life Cycle Assessment (LCA)." US Environmental Protection Agency. 17 October 2010.

[12] Also existing: Well-to-wheel, if referring to road transport

[13] Bengtsson et al. (2011)

Just to avoid confusion with similar concepts, they have to be mentioned:

Eco efficiency analysis EEA

- Enables the comparison of the eco efficiency of products which provide customers with the same benefit. The point is to determine the relative environmental and economic impact of products
- Life cycle assessment is used to provide eco efficiency analysis results. EEA is covered by ISO 14040 and 14044.

Environmental impact assessment EIA [14]

According to Sharma (2009) the difference between environmental impact assessment and life cycle assessment is "*that EIA generally addresses more localized impacts and [uses] the most appropriate methods for the uniqueness of the site and significant impacts. The standard LCA methods, on the other hand, are virtually incapable of detailing most local impacts, but generally provide the most reliably complete quantification of net environmental impact from a regional or global perspective*". [15]

Please note:

With regard to the shipping industry many projects, such as enlargement of shipyards, river bed regulations and construction of terminals, are accompanied by environmental impact assessments,

When focussing on the environmental impact of ship operations or single ship aggregates and components the life cycle assessment approach is chosen because a ship operates in different environments.

2 Future challenges for maritime business

"Environmental impact of a product accumulates throughout its lifecycle, with transport representing a major contribution to the total environmental load of the product. Environmentally friendly means of transport have therefore become an important element of competition and a new challenge to the entire transport industry". (Magerholm Fet, 1999*)*

2.1 Defining maritime business

Describing the whole maritime business is a big task on its own – and a description of future challenges for the different branches such as shipping companies, shipyards, port operators, traders, insurances, consultancies, cannot be done in this teaching module.

In accordance with Smith (2000) it is presumed that *"marine transportation consists of a whole group of inter-related industries with commercial shipping at its centre".*

With regard to commercial shipping and ship building, examples of LCA applications are outlined in section 3.

Differences in the definition of shipping companies come from the fact that there are two different descriptions of the term shipping:

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[14] For an insight in the bunch of definitions of EIA please see http://www.gdrc.org/uem/eia/define.html

[15] see: http://saferenvironment.wordpress.com/2009/11/06/life-cycle-assessment-lca-a-tool-for-quantifying-sustainability-and-sound-methodology-for-describing-environmental-impacts

- Shipping: Complex international business involving international trade, multinational finance, insurance, investment, ship broking, management and cooperation of ships.[16]
- Shipping: Transportation – the commercial enterprise of moving goods and materials.[17]

Exercise:

Please think about these definitions and try to find a definition of shipping which best fits to your professional background or to the field of maritime business you want to enter.

……….

……….

……….

The future challenges for maritime business and in particular for shipping companies will be described according to the cradle-to-grave perspective of the life cycle assessment approach. Therefore the three phases 1) ship building, 2) ship operation and 3) ship scrapping are distinguished and described in the following sub-chapter.

Before dealing with future challenges, the fundamental considerations of the ecological impact of the three mentioned phases have first to be taken into account:

2.2 Ecological impacts from cradle-to-grave

The basic environmental considerations in a ship's life cycle and the life cycle assessment of ships were published in 1995 by M. A. Shama.[18] In line with this approach and examining an entire ship, a LCA for the Color Line Ro-Ro Passenger vessel "*Color Festival*" [19] was carried out in 1998 as a demonstration project. However, this is not a typical application and has never been repeated.

Ship building

In the shipyard various components and much energy is used to build ships, as illustrated below. More information on the environmental impacts of ship building can be found for instance in the OECD Council Working Party on Shipbuilding (2010).[20]

[16] Norwegian Ship Owner Association

[17] Taken from a free online dictionary: http://www.thefreedictionary.com/shipping

[18] Please note that two authors with very similar names play a certain role in the discussion about LCA: A. M. Shama is an Egyptian scientist from Alexandria and P.D. Sharma is an Indian scientist from Hyderabad.

[19] In 1999 a project, called "Lifecycle Evaluation of Ship Transportation: Development of Methodology and Testing" was completed by Magerholm Fet and Sørgård.

[20] http://www.oecd.org/dataoecd/22/10/46370308.pdf

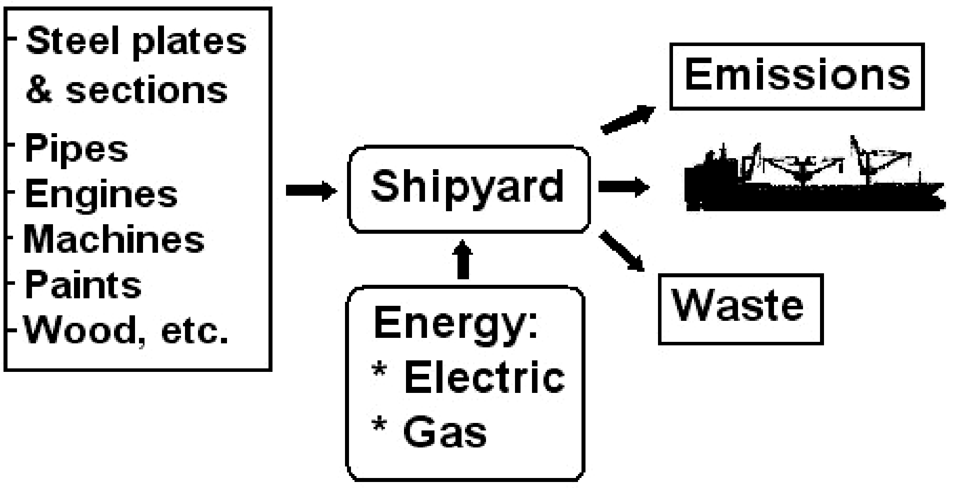

Figure 4: Input / output of a shipyard (Shama, 2004)

Ship operation

During ship operation a steady flow of consumption materials and fuels as well as maintenance works is needed. Ship operation may result in an accident. Both, casualties and daily operation cause pollution: accidental and operational pollution. For further reading is recommended: [21]

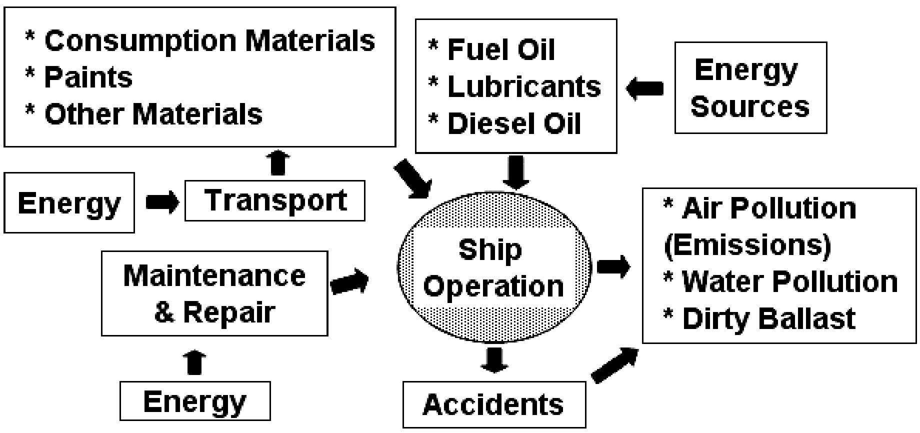

Figure 5: Energy and environment in ship operation acc. to Shama (2004)

Ship scrapping

Ship scrapping causes pollution of air and water as well as solid wastes and finally results in usable, repairable products which partly get recycled. Energy is used in the transportation of ships and their components as well as in the welding works and other steps of the ships' break down. Ship scrapping is the subject of the Hong Kong Convention (see section 3.3). Further reading about the environmental impacts of ship scrapping is recommended. [22]

[21] The NMU module elements "Consequences of (maritime) transport" and "Minimizing the negative effects of maritime transport"

[22] http://www.shipbreakingbd.info/Environment.html

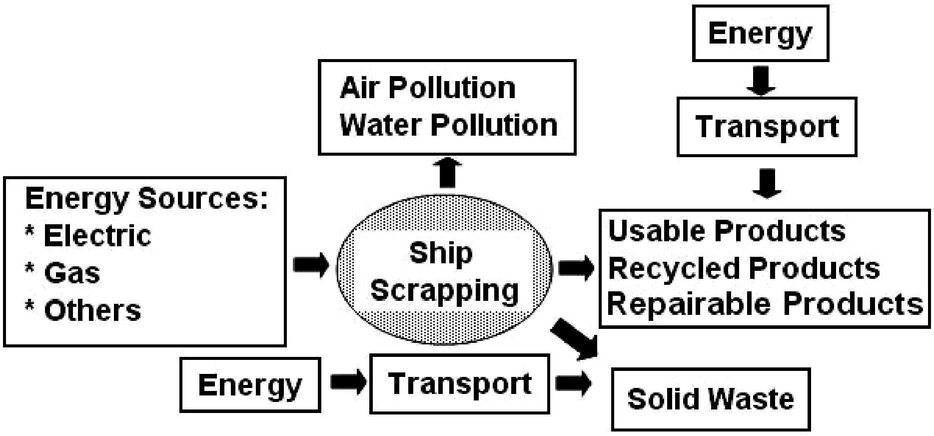

Figure 6: Energy use and environmental impacts in ship demolition (Shama, 2004)

2.3 Future challenges from cradle-to-grave

In the description of future challenges for maritime business, not only do the basic considerations concerning energy and environment during the ships' lifespan have to be mentioned, but also the legal and organisational challenges must be considered.

Ship building and repair

- Remaining ship building sites in Europe have to be highly innovative and efficient.
- Special ship building is no longer a domain of the European ship builders.
- More technology has to be integrated into the ships.
- Higher costs for raw materials - therefore high level recycling is needed and new materials will have to be tested and applied.
- Preparation of an Inventory of Hazardous Materials (IHM), and a "green passport" according to the Hong-Kong-Convention[23] will be a routine role of ship builders for new-build ships.
- Efficient ship repair can be achieved by data management of repair projects.
- Beyond IHM vast amounts of other product data are transferred between building yard, repair yard, ship, shipping company and classification society.

Ship operation

- Stricter legal requirements with regard to environmental impacts have to be fulfilled.
- Need for higher fuel efficiency due to high fuel prices.
- CO_2 - emission monitoring is inevitable for legal and market based purposes, such as CO_2 - emission trading, CO_2 - Indexing, carbon "footprinting", all of which are expected to be in place soon.

[23] Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009

- New technology on board needs to be monitored and maintained, e. g. ballast water treatment, alternative propulsion methods, security devices.
- Need for operational data for monitoring and efficiency purposes.
- Necessity to share ship building and repair data with shipyards and providers to gain cost efficient service.
- Data management in place which allows the fulfilment of all legal and voluntary documentation and data exchange tasks; IT tool interfaces individually adjusted according to the shipping company's policy and data management.

Ship scrapping

- The demand for recycling of ship components is high due to rising raw material costs.
- There exists a legal obligation due to legislation.
- Certification of a ship recycling facility is a legal duty.
- The demand for information on ship components provided by the IHM, respectively by the "Green passport" is high.
- There exists a demand in skilled personnel for ship scrapping.

2.4 Future universal challenges for maritime business

Apart from the cradle-to-grave-perspective the following universal challenges arise from globalisation, raw material shortage, climate change and transport security.

Globalisation

It is generally accepted to regard shipping *"as the first truly global industry"* (Smith 2000). The same author regards as the millennial question *"whether the long wave cycles may become less pronounced in the future"* and suggests that the over-supply of a wide range of industrial goods[24] is a sign of global downturn. The same author states: *"Even though the circumstance that by far the greatest proportion of world trade is carried by sea is unlikely to change it can be assumed that ship owners and other actors of the maritime business will face a growing degree of competition in the global transportation market."*

Raw material shortage and marine offshore activities

The growing world economy and related transport growth results in a high demand for raw materials, thus more competition and rising prices as well partial shortages. The challenge for shipping companies is at least twofold: To cope with rising fuel prices and to win or to expand a share in the offshore industries which increase, diversify and move from the continental shelves and inshore waters towards the continental slopes and deep ocean waters. Offshore industry needs advanced technology, new transportation services and supply. The environmental impacts of the marine mineral and energy industry increase and require impact assessment and management.

Apart from the challenge of developing and constructing innovative ships for the offshore industry mentioned above, the shortage of steel is a future challenge for the shipbuilding industry. The Hong Kong Con-

[24] Krugmann, P. (1999), cited in Smith

vention, described in section 3.3, is intended to contribute to the stimulation of ship scrapping in industrialized countries, and thus to increase shipbuilding activity.[25]

Climate change

Due to growing production capacities and related fuel demand, climate change is expected to speed up and legal regulations are expected to be much stricter in the future. All technical and organisational approaches to minimise ship emissions and to deal with emission certificates and other market based instruments respectively require supporting software for data evaluation and documentation purposes.

Transport security

"All manner of environmental monitoring and surveying together with surveillance of uses using a diversity of platforms ranging form satellites to remotely controlled unmanned submarines" is one important area of technological development for the marine industry according to Smith (2000).
The trend towards traceable transportation to fulfil security requirements is expected not to be regarded as a burden but rather as a complementary aspect to the other requirements of transparency and efficiency. This is expected to generate a demand in innovative computer assisted life support concepts, allowing both monitoring of single ships as well as the whole fleet, and documentation of environmental and security features. If well adjusted to the shipping companies' demands according to well defined purposes, ship life cycle assisting tools are helpful for future demands on the manifold purposes of fleet management.

Considering future maritime business, the Wärtsilä-Scenarios for 2030 [26] should also be taken into account.

Further description of the methodology can be found in the next section. First an exercise is suggested:

Exercise:
What do you think could be the motivations / advantages for the following maritime business actors to apply ship life cycle assessment?

The shipping company

- Reducing material, maintenance costs and fuel costs
- Higher charter rates
- Higher sales prices
- Better conditions for insurance and financial services
- Better marketing based on innovative and environmental sound practises

The charterer

- Reducing material, maintenance and fuel costs
- Better conditions for documentation of environmental performance, quality and safety
- Better conditions for insurance and financial services

[25] Information by Henning Gramann, Managing Director of Green Ship Recycling Services, March 2011

[26] http://www.shippingscenarios.wartsila.com

Authorities

- Establishment and control of regulations
- Good governance via helpful indicators
- Stimulation of better environmental performance

Public

- Less harm from environmental impact of ship building, operation and scrapping
- Lower costs resulting from medical care and environmental damage abatement

Ship designer

- Reliable information on environmental impacts caused by materials during ship building, operation and scrapping
- Data bases to be used for ship construction

The shipyards and related industries

- Improved environmental performance
- Data bases to be used for ship building and repair
- Better marketing based on innovative and environmentally sound practices

The insurance company

- Reliable information on the ships state
- Data bases to be used for prediction of repair and insurance cases

The advantages and motivations mentioned all rely on voluntary action in the maritime business sectors. Still there is no legal obligation for ship life cycle assessments in sight. But there are existing legal requirements which might be easier to fulfil through the support of life cycle assessment methodology.

Meanwhile the development of methods has led to commercial services for different maritime branches. Some will be discussed in the course of this module.

3 Ship life cycle assessment methodology

As mentioned already above (see section. 1.1), according to the ISO 14040 series, life cycle assessment consists of the following three steps:

1. **Goal definition and scoping**: identifying the LCA's purpose and the expected products of the study and determining the boundaries (what is and is not included in the study) and assumptions based upon the goal definition;

2. **Life cycle inventory**: quantifying the energy and raw material inputs and environmental releases associated with each stage of production;

3. **Impact assessment:** assessing the impacts on human health and the environment associated with energy and raw material inputs and environmental releases quantified by the inventory;

Earlier publications (Shama, 1995) mentioned a fourth step as inevitably belonging to life cycle assessment:

4. **Interpretation / improvement analysis:** evaluating opportunities to reduce energy, material inputs, or environmental impacts at each stage of the product life-cycle.

3.1 Goal and scope identification

The first step in the LCA is the goal and scope definition. The application, depth and the exact subject of the study has to be defined for specified functional units and system boundaries.

The functional unit

Comparing different products by LCA is meaningful only if these products fulfil the same function. Taking a ship, for example, it is obvious that it fulfils many functions: transport of different goods, passengers, vehicles and passengers, respectively, over different distances. The functional unit would have to be defined so that the different ships compared provide the same services over the same distance.

The system boundaries

The system boundaries define which flows (e.g. materials and energy used, emissions) are taken into consideration. It depends on the goal and scope of ship life cycle assessment where the system's boundaries should be set.

3.1.1 Example of a goal and scope analysis when comparing different fossil fuels

A life cycle assessment to describe the environmental performance of different marine fuels from well-to propeller was carried out and described by Bengtsson et al. in 2011.[27]
This study was very complex, as the comparison of fuels occurred in combination with different exhaust abatement techniques. In the difficulties of explaining the methodology, the complexity of the research design has become reduced!

Goal and scope analysis:
The goal was to clarify the question, whether a fuel switch in order to comply with the MARPOL VI regulations, would also lead to lower emissions in a life cycle perspective.
The scope is confined to a comparison of these fuels: Heavy fuel oil (HFO), marine gas oil (MGO), gas-to-liquid (GTL) and liquefied natural gas (LNG) - and by several methodological choices which are shown in the next table.

[27] "A comparative life cycle assessment of marine fuels, liquefied natural gas and three other fossil fuels" by Selma Bengtsson, Karin Andersson and Erik Fridell, in: Journal of Engineering for the maritime Environment (2011)

Table 2: Goal and scope analysis (extract from table 2 in Bengsson et al. (2011): Overview of methodological choices)

Functional unit	One tonne cargo transported one km with a RoRo vessel
Type o LCA	Consequential[28]
Time horizon	2010 -2020
Geographical bounda-ry	The SECAs in northern Europe (the English Channel, the North Sea and the Baltic Sea).
System boundaries	The study includes all activities from raw material extraction to the release of waste to the environment, e.g. from cradle-to-propeller. Production of lubrication oil is not included in the system nor is waste treatment of oil sludge and used lubrication oil. The differences in use of lubrication oil between the investigated fuel types are estimated to be small [53]. The amount of sludge and solid waste could differ more between the alternatives, e.g. since LNG and GTL are much cleaner fuels than HFO, but the sludge treatment has not been included. Manufacturing of capital goods is not included in this study, e.g. the man-ufacturing of the vessel, the catalytic converter and the scrubber

3.2 Inventory analysis

The second step in the LCA is the inventory analysis. This involves data collection and calculation procedures to quantify the inputs and outputs of the system.

Depending on the results of the goal and scope definition and the functional unit and system boundaries defined, raw material consumption and emissions of each process have to be identified.

3.2.1 Example of inventory analysis when comparing different fossil fuels

In the comparison of different fossil fuels, the data collection and analysis was a big task on its own:

For HFO (sulphur content 1%) and MGO (sulphur content 0,1 %) the required data were taken from the life cycle inventory databases of the *European Commission Joint Research centre on LCA Tools, Services and Data*, comprising the energy consumption from cradle-to-gate, which means from exploration, processing, transportation and refinery.
For LNG (sulphur content < 0,01 %) the data for extraction, processing and pipeline transportation were chosen from a database on natural gas from the North Sea. For GTL (sulphur content< 0,01 %) again different information sources that provided data for energy use and emissions of CO_2, CH_4 and N_2O in the liquefaction process were needed

Beyond the production of these fuels, the transport from the refinery to the harbour and onboard the ship were also assessed. Numerous assumptions on design speed, on the engines' efficiency, on the engine technology for LNG, on fuel consumption and on the emission factors used for HFO, MGO and GTL and LNG were made and described.

3.3 Impact assessment

In the impact assessment the calculated results of the inventory analysis were associated with environmental impacts.[29] As there is no generally accepted methodology for this, this part of LCA is rather controversial. [30]

[28] There are two fundamentally different types of LCA studies: attributional and consequential. While attributional LCAs strive to be as complete as possible, accounting for all environmental impacts of a product, the consequential LCAs strive to describe the environmental consequences of alternative courses of action.

Some major impact categories are listed below:

- Contribution to global warming
- Acidification of sea water, coral reefs and soils
- Formation of ground-level ozone
- Eutrophication of sea water and soils
- Smog formation on shore

3.3.1 Example of impact assessment when comparing different fossil fuels

For the LCA of the different fossil fuels, the impact categories global warming potential (GWP), acidification potential and eutrophication potential were chosen to be assessed. Due to the methodological choices within the goal and scope analysis, some environmental effects were excluded from assessment. These are the effects of CO_2 emissions on acidification of the oceans and the effects of secondary gaseous pollutants, such as ground-level ozone resulting from NO_x emissions.

3.4 Interpretation

The Interpretation is the step where synthesis is drawn from the findings of the former three steps.

3.4.1 Example of an interpretation of a comparison of different fossil fuels

In the case of the comparison of the environmental impacts of different fossil fuel in a life cycle perspective the synthesis was drawn for two stages: 1) "well-to-tank" and 2) "tank-to-propeller".

In the first stage from well-to-tank the potential of acidification and eutrophication are slightly increased for the marine gas oil (MGO) and the gas to liquid (GTL) when using a selective catalytic reduction (SCR). This is due to the production and transportation of the urea needed in the SCR process.

The gas-to-liquid fuel requires the most energy from well-to-tank and therefore has a high global warming potential (GWP). LNG from the North Sea was found to have the lowest GWP. Depending on the possible CH_4 slip in the LNG fuel chain the green house gas (GHG) emissions might be higher.

In the second stage from tank-to-propeller, heavy fuel oil (HFO) is the most energy efficient fuel alternative but comprises a significant higher impact on acidification and eutrophication compared to LNG-propulsion and the other fuel alternatives that fulfil the SECA and Tier III regulations.

The study showed that none of the fuels will decrease the impact category of GHG emissions significantly in a life cycle perspective.

For deeper insight in this study further reading is recommended.

[29] Background information on impact categories and further databases are offered by a publication of the European Environmental Agency: Appendix 4.2 of Environmental Issues Series no. 6: A guide to approaches, experiences and information sources Life Cycle Assessment (LCA) ,EEA, 1997

[30] There exist different impact categories proposed by OECD, ISO, LCANET, UN

3.5 The purpose of interpretation

There seems to be a difference between the intention of the founders of LCA application for ships and the nowadays mainstream perception of LCA. The ISO standard reflects the difference: it leaves out the interpretation as the fourth step of the assessment. Instead interpretation is carried out continuously.

While Shama (1995) called the fourth step: *"Interpretation / Improvement analysis"*, meant to evaluate *"opportunities to reduce energy, material inputs, or environmental impacts at each stage of the product lifecycle"*, Magerholm and Sørgård (1999) state [the results] *"may lead to recommendations or decisions"*. Another author, Sharma[31] (2006) states: *"Directly the LCA process does not give any final answers or improvement plans. Normally, the result of the LCA process is one of many factors affecting a final purchasing decision like technical performance, economic and social impacts."*

3.6 Exercises

3.6.1 Methodology and purpose

Please describe the differences between these three descriptions of Shama, Magerholm & Sörgard and Sharma. Have a look on the wording and content.

- According to the first statement, the interpretation belongs to the assessment and has to be pursued in order to minimize the environmental impacts.
- According to the second statement, the minimisation of the environmental impacts obviously is not the main object .Therefore recommendations and decisions are an option and no integral part of LCA.
- The third statement reflects an attitude where the results of the LCA have no decisive character at all but contribute to complex management decisions.

3.6.2 Exercise on a consequential LCA

Greenpeace intends to build a new ship and seeks to minimise the environmental impact. For the ship's hull the choice between steel and aluminium will be based upon results of LCA.

[31] Similar name but different author (Shama is not Sharma)

Aspects of the goal and scope analysis

The functional unit is easy to define: The ship's hull - whether made from steel or aluminium - fulfils the same function and therefore is the functional unit of a fictional LCA.
Concerning the systems' boundaries, the whole life span "from craddle-to-grave" should be taken into account. This means that the environmental impacts at the mining site, on the ship yard, during operation and on the scrapping site will have to be assessed.

Leaving apart the exact material specifications and the complex relation between material and design – please consider the following life cycle stages and features and find the relevant respective environmental aspects:

- Mining: Energy consumption and land use related to iron and aluminium (bauxite) ore
- Production of steel or aluminium: Energy consumption
- Origin of the material: Proportion of recycled material and virgin material, related transport costs.
- Manufacture and handling: Welding technique, anti corrosion means required
- Resulting weight of the ship hull and relating operational (fuel) costs
- Scrapping: Recyclability, energy input needed

It becomes obvious that this case needs specialized software, fed with data and algorithms for the impact assessment.

Aspects of environmental impact
We already mentioned global warming potential (GWP). Also the impact categories acidification and eutrophication are not *tangible* impacts. The LCA should express the *potential* for these impacts. Even if writing about impacts - why do you think it is better to have *potentials* for impacts in mind? (three answers are wrong, three right: 1, 5, 6)

1. Because no measurement exists where the emitted SO_x is acting.
2. Because other industries contribute to the impact categories.
3. Because also natural processes like sub-sea and terrestrial vulcanoes contribute to the impacts.
4. Because scientific research still suffers from inaccuracy.
5. Because wind direction, air temperature, radiation and other atmospheric conditions vary and therefore also the chemical processes in the environmental media (air, sea water, soil) take different courses.
6. Because positive back coupling / feedback occurs which are even more complex to quantify and to assess.

3.7 Addendum: Distinction from Environmental Impact Assessment EIA

Apart from the approximate character of the results of impact assessment one has to be aware of the varying sensitivity of different sea areas or coastal areas. It is obvious that it depends on the area, actual or predominant climatic factors whether the acidification process leads to slight acidification of the seawater, to damage to coral reefs or rather to damages of forests or buildings.

Concerning positive back coupling the effect of ocean warming and CO_2 absorption has been often described. As an example read the following Guardian article. [32]

Figure 7: The Wadden Sea, courtesy of GAUSS

Figure 8: Cruise Ship in Travemünde, courtesy of Jörg Sträussler

When thinking about impacts, we should be aware of not entering into the field of environmental impact assessment EIA). However, it is important to keep in mind that environmental impact in reality depends on many variables, local features and sensitivity.

[32] "Sea absorbing less CO_2 scientists dicscover" http://www.guardian.co.uk/environment/2009/jan/12/sea-co2-climate-japan-environment

4 Application of LCA from decision support to ship life cycle management

In 1999, a project called *"Life Cycle Evaluation of Ship Transportation: Development of Methodology and Testing",* was completed by Magerholm Fet and Sørgård. Their project, a simplified life cycle assessment for the cruise ship *"Color Festival"*, was intended to gain experience with a pre-existing tool existing. The main question was to see whether sufficient data and algorithms [33] of different impact categories were available to identify and assess the environmental burdens of a whole ship during its life span. The given conditions, data and methodology, were found to be a good starting point - therefore further improvement of relevant databases and analytical software tools were regarded to be too challenging.

A very different approach is followed by Thoben et al. (2009) ten years later. According to the design of their MarLife Project, carried out by a consortium of shipyards, shipping companies, logistic providers and other experts from 2007 to 2010, very different partial issues of a holistic so called *life cycle management system* were pursued.

Before plunging into these extensive studies, section 4.2 presents some smaller LCA studies.

In the first three applications, LCA served as decision support tool for non-recurring studies; the fourth is more complex as it deals with decision support but takes into account the whole life span. The fifth represents a continuous LCA operation.

The optional linkage of the life cycle approach with the requirements of the Hong Kong Convention and the inventory of hazardous materials (IHM) as its central issue is described in section 4.3; general assumptions concerning the application of LCA with regard to Environmental Management Systems and marketing purposes follow in section 4.4.

[33] In mathematics and computer science, an *algorithm* is a method consisting of a finite list of well-defined instructions for calculating a function step by step.

4.1 Decision support in non-recurring studies

4.1.1 Comparison of three anti-fouling coatings

Figure 9: Application of *International Paints* foul release coating to the hull of the 173,400 cu. m LNG carrier Sevilla Knutsen [34], courtesy of Knutsen OAS Shipping

An eco efficiency analysis which enables the comparison of different products is a typical application of the life cycle assessment methodology. The aim is to define the relative environmental and economic impacts of each product.

This example has been taken entirely from the journal *Propeller*, July 2010. In the case of the company *International Paints*, three fouling control coatings were compared. The three coatings taken for the eco efficiency analysis were: a conventional biocidial antifouling, a silicone foul release coating and a fluoro-polymer foul release coating.

The customers benefit was defined as optimising the vessel efficiency through providing a clean hydrodynamically smooth underwater hull.

In the case of hull coatings, the data needed are information on different raw materials and the energy to process them. Assumptions and approximations were made in the case of some variables. Waste and waste disposal, human toxicity and all emissions to air, land and water were described.

The ship chosen for the study was a 300,000 very large crude carrier (VLCC), consuming 100 tonnes of heavy fuel oil a day, working 80 % maximum continuous rating (MCR) activity and operating on a five-year docking cycle. One coating was assumed to be spread at the new-build stage and two more applications at repair dockings.

The variables to be assessed were

[34] To be found in (http://www.marinelog.com/IMAGESMMIX/540sev-Knutsen.jpg)

- Paint application and docking costs
- Fuel costs
- Environmental burden (energy, emission, toxicity)
- Global warming potential, on- and offshore

Result: The company's premium product was ahead of the other two products, because of

- overall fuel savings of 39,420 MT over 15 years,
- overall CO_2 reduction of more than 125,000 MT over 15 years,
- reduced dry-dock time and costs, and
- zero biocide emissions into the marine environment

The costs for such a LCA were mentioned to be normally between 20,000 € and 50,000 €, sometimes rising up to 70,000 €.

4.1.2 Comparison of hull materials

Figure 10: Rainbow Warrior III, being under construction at Fassmer shipyard. Delivery is expected in October 2011. Courtesy of Oliver Tjaden / Greenpeace

The decision as to whether the hull of the new Greenpeace flagship "Rainbow Warrior III" was to be built from steel or aluminium was decided upon using life cycle assessment methodology, carried out by the Dutch company TNO.[35]

[35] according to information of Mr. Sass, Fassmer ship yard, October 2010

Result: Due to the results of the LCA, steel was chosen for the hull, while superstructure and mast will be built from aluminium.

4.1.3 Comparison of different fuel cell systems

A life cycle assessment to compare a system of fuel cell systems on ships was carried out by Altmann & Weindorf (2004) according to the following variables:

- fuel cell production,
- operation,
- discharge from fuel cells and
- fuel production and supply including the required infrastructure.

The analysis did not include the construction and end of life of the ship itself (system boundary!). The same evaluation was carried out for conventional technologies for the purpose of comparison.

The fuels chosen included low sulphur car diesel (10 ppm sulphur content), liquefied natural gas (LNG), liquid and compressed gaseous hydrogen as well as heavy fuel oil (HFO) (3.5% and 1.0% sulphur content, respectively) and marine gas oil (MGO).

The primary energies used in the production of the different fuels are crude oil (for heavy fuel oil, marine gas oil, car diesel, liquid hydrogen), natural gas (for liquefied natural gas, liquid hydrogen, compressed gaseous hydrogen), renewable electricity (for liquid and compressed gaseous hydrogen) and biomass (for compressed gaseous hydrogen).

For the analysis two case ships were chosen:

Figure 11: Case ship 1, large passenger ferry MS Color Festival (Altman and, Weindorf, 2004)

Figure 12: Case ship 2, commuter ferry in Amsterdam, so called H-ferry
http://www.edie.net/news/news_story.asp?id=12617

Case ship 1 is a large passenger ferry. Based on this ship, a case analysis has been carried out using high or low temperature fuel cells for the supply of auxiliary power onboard the ship. The main propulsion is supplied by conventional marine engines.

Case ship 2 is a small (100-passenger) commuter ferry operating in the Dutch city of Amsterdam.

The life cycle assessment was limited to gaseous emissions (system boundary).

- Emissions with a climate warming potential: mainly CO_2, CH_4 (Methane) and N_2O (Nitrous oxide)
- Emissions contributing to acidification: SO_2 (Sulfur dioxide), NO_x (Nitrogen oxide), NH_3 (Ammonia) and
- Emissions contributing to eutrophication of waters: (NO_x, NH_3).

Result: Based on the life cycle assessment and the cost analysis several recommendations for improving cost effectiveness and further reduction of the environmental impacts of fuel cell ships were made.

4.1.4 Evaluation and choice of the cost-optimal ship design

The optimization of costs for a ship to be built requires both comparison of different designs of the ship with their adjacent technical and cost features and consideration of future operating costs; the so called life cycle costs.

The following figure, taken from a MacGregor presentation on the *ShipDex* system[36], shows the opportunities to influence ship life cycle costs during the ship's life span:

[36] ShipDex is a registered trademark and has a number of partner members who maintain and develop the ShipDex - subset. The supply company MacGregor is a partner member.

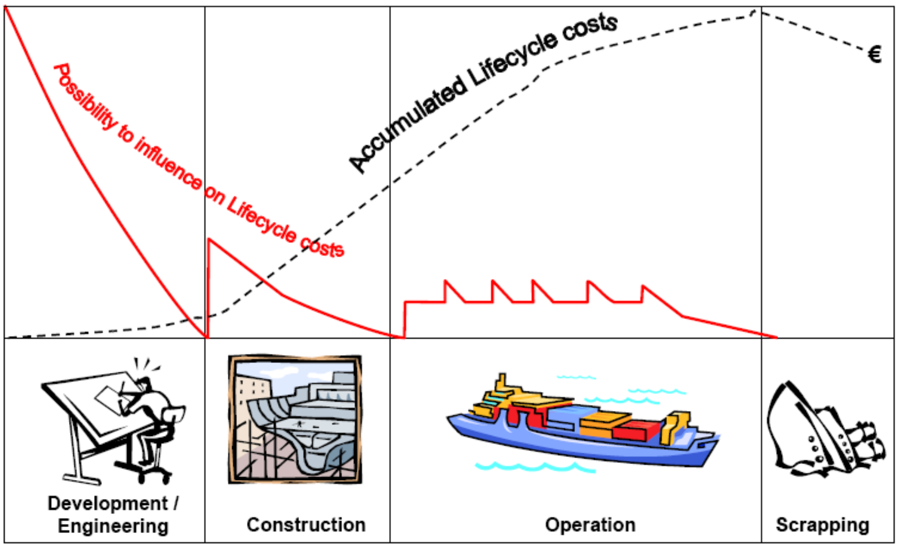

Figure 13: Influences on the ship life cycle costs. From a MacGregor presentation about the ShipDex system. Courtesy of Mac Gregor

Exercise

As an exercise, describe the red curve and then describe what elements comprise operating costs:

Possible answer: The red curve shows that first of all design and then construction determines the future costs. During operation the dry dock maintenance works also enable measures to raise efficiency such as, for instance, cleaning of the ship hull.

The operation costs consist of fuel costs, administration costs, crew costs, insurances, spares and maintenance costs.

The performance of cost estimations requires a sophisticated support system.

The application of the tool "costfact" for the calculation of life cycle costs was described by Fischer and Nagel (2010). In the case of the shipyard *Flensburger Schiffbaugesellschaft* the cost management system "Costfact" was applied for the comparison of two alternatives: A twin screw ship drafted strictly according to the tender offer and a single screw, which was expected to also meet the specifications of the customer in a more cost-advantageous way.

Costfact, developed by the GKP – *Gesellschaft für Kostenorientierte Produktentwicklung*, Köln, in cooperation with the department of design and operation of maritime systems, TU Berlin, includes the following functions:

- Cost prognosis,
- Acknowledgement of technical parameters for cost prognoses and comparison of projects
- Parametric cost prognoses based on regression functions
- Risk analyses for calculation of deviation of later actual costs from prognosis costs
- Automatic adjustment / alignment of costs due to specification and a quotation costing

The estimation of purchasing costs is far easier than the prognosis of operation costs because of the following assumptions to be made[37]:

- Annually fuel requirement
- Fuel price
- Damage costs and maintenance costs

The comparison of the two ships, the twin screw ship and a single screw ship, consisted more of relative fluctuations of costs in defined periods of time. Based on these cost phenomena different scenarios were calculated.

Result: In this case the assessment of the life cycle costs revealed that the single screw's inhibited function was accompanied by a small cost advantage in both purchase costs and operative costs. The twin screw was found to be more valuable in terms of fitting the customer's requirements.

Important note: The summation of all operating costs provides a figure, which in reality does not emerge all at once. Further consideration therefore requires the application of financial mathematics.

4.2 Continuous LCA operations

The following examples all refer to the MarLife project.

4.2.1 Ship repair documentation

In the course of the MarLife Project (Thoben et al. 2009, Lloyd Werft 2009) the Lloyd shipyard in Bremerhaven started to develop a tool for ship repair documentation.

Aim: To make better use of previous experience and information in repair planning, quicker preparation of offers, cheaper performance of repair due to accessible information and to allow successive improvements in a related guidance system.

Starting conditions were difficult as not enough data on former repair activities were easily accessible. Information on former works carried out for similar ships was missing and therefore the description of contract specifications or lists of bid items was time consuming.

Result: The creation of a register of construction types led to more efficient procedures from the beginning. The English version served as an initial structure for the life cycle guidance system in process. Lloyd shipyard now plans to use life cycle data to improve its existing maintenance, diagnostic and evaluation systems.

Apparent Benefits: Example offered by Lloyd shipyard (2009)

- A given project cost for a cruise ship of 5 Million € includes 1.5 – 3% of costs for transfer of information (travelling costs, acquisition of information). With better information transfer, the cost saving of the repair yard (*Lloyds shipyard*) amounts to about 10% or € 7,500 –10,000 per ship.
- Normal repair-works or class-works during the dry docking time is used for preparation of test records for ship inspection as well as for eventual acquisition of material and building data. In case of

[37] Some operating costs show high variability over time. Risk analyses therefore can be performed to prevent uncertainties. The usual methodology consists of the creation of best- and worst case scenarios.

a repair cost of € 1Million, these costs range from 2,000 – 5,000 €. If 25% can be saved, the amount is 500 –1,250 €.

In the long run Lloyd shipyard expects life cycle guidance to be introduced in all shipping companies and even interfaces between yards, the shipping companies and classification societies. It is obvious that ship repair yards which are provided with information from the shipbuilding yard, from suppliers, former repair yards and the shipping companies expect to realise cheaper repair advance planning.

4.2.2 Damage reporting

Within the MarLife project (Thoben et al. 2009) much importance was attached to the life cycle assessment options for damage control.

Aim: The project's cooperation-partner, the company *Beluga Shipping,* expressed the intention to save 10% of the damage related costs by using a tool derived from a sophisticated analysis of the given damage statistics of individual ships.

The development of this tool consisted of a systematic registration and categorisation of damages, whereby already documented damage claims served as a valuable information source, as shown in the following picture.

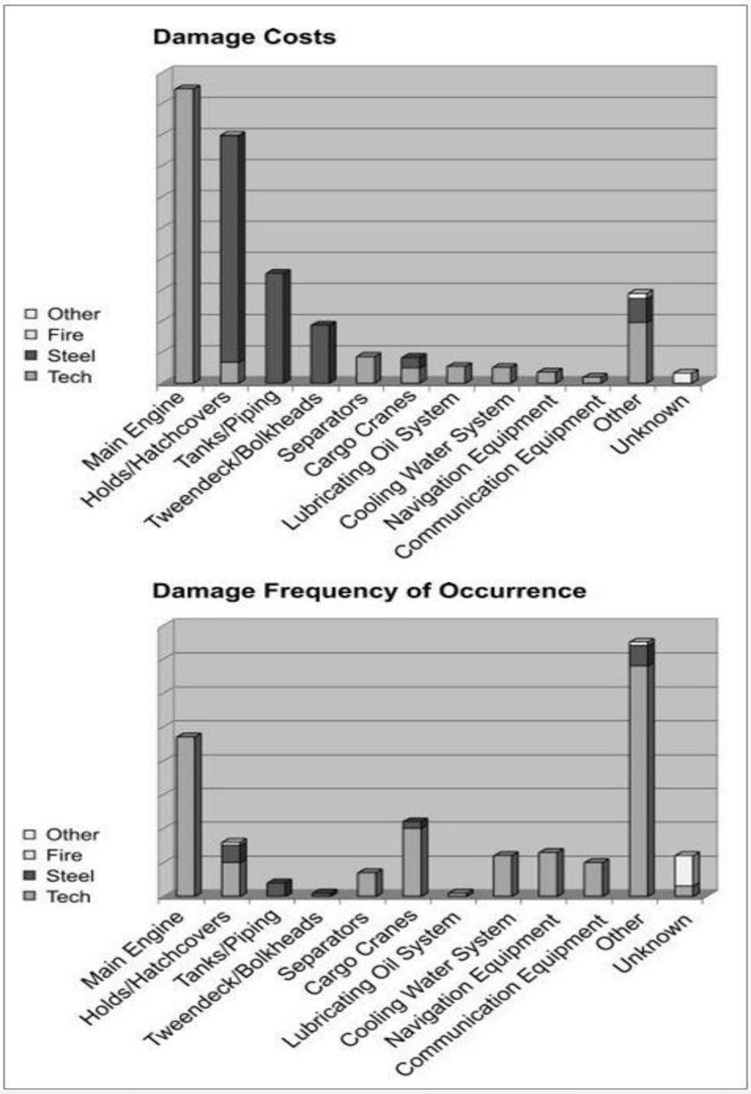

Figure 14: Main system related damage (Thoben et al. 2009)

Data about the ship, date, location, route data and other topics, such as occurrences, defective elements, accidents, costs, manufacturer information, expert's communication, manuals and photos were used.

Result: Systematic evaluation of damages contributed to growing knowledge about damage probability and secondary damages. The resulting tool disposes of filter mechanisms which allow structured requests on the registered information. It is web based and accessible from any workplace of the company. The tool is in use and helps to reduce 1-2% of damages.

4.2.3 Life cycle guidance system generated from ship operation data

Aim: To improve the efficiency of ship operations.

Operating data is generated and stored in several monitoring systems of a ship. In the course of the Mar-Life project (Thoben et al. 2009), cooperation with Hartmann Shipping led to life cycle guidance system, consisting of several common monitoring systems which were connected through appropriate interfaces and adapted to the needs of the project.

The figure below shows the structure of the systems, which were linked together:

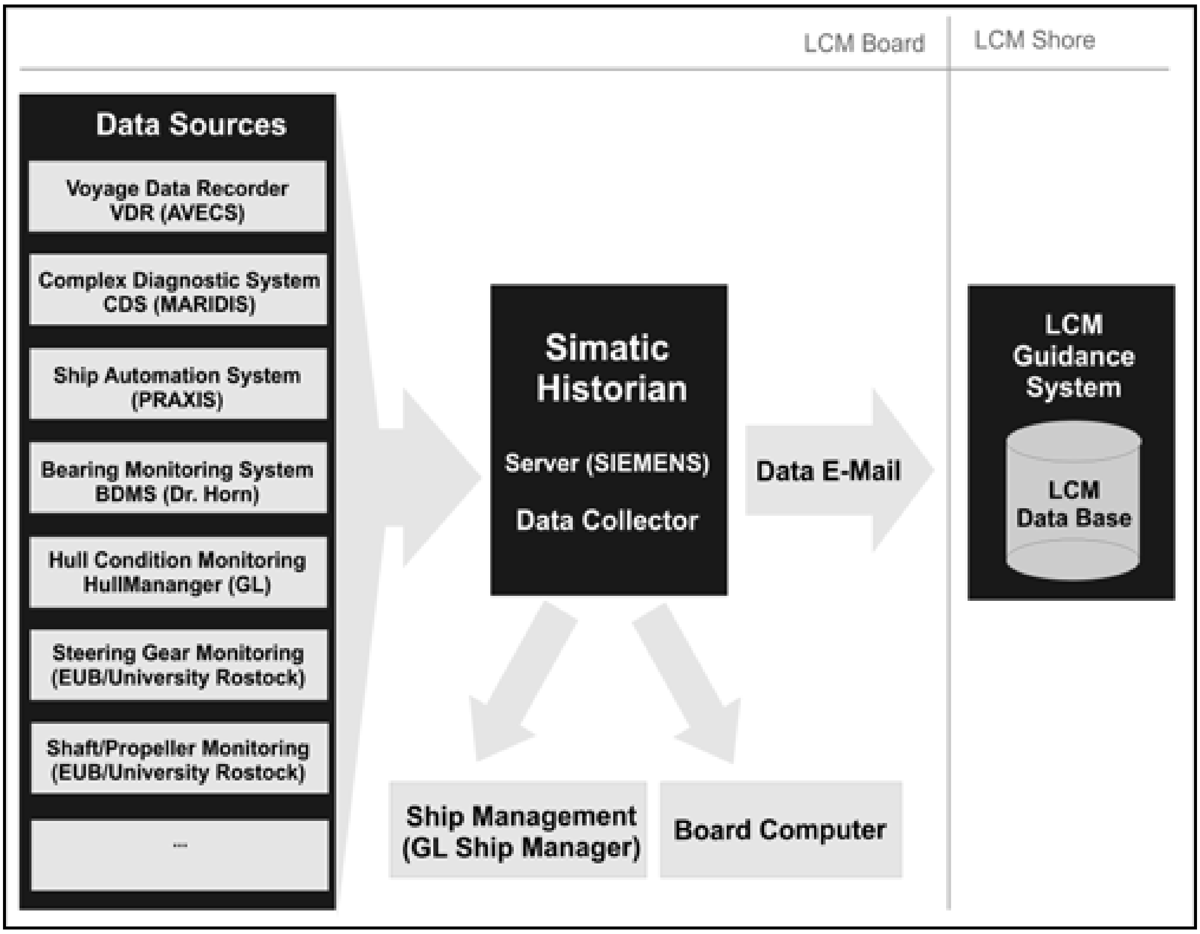

Figure 15: Operation data acquisition via historian server (Thoben et al. 2009)

As can be seen by the figure, the historian server[38] receives ship operating data from the systems shown on the left hand side. It provides the board computer with a multi-purpose software application of the classification society. The life cycle management guidance system was developed with the incoming data according to the different needs defined.

To give an insight into the variety of data needed for the guidance system the data sources are as follows:

- The voyage data recorder (VDR) offers navigational data at hourly intervals. These are: position, course, speed, heading, water depth and wind speed. For the ship life cycle guidance system these data enable route tracing and help to enlighten the relationship between the ship's route and damage risks.
- Ship automation system - offers snap shot - like information about the technical condition of the ship machinery systems linked with it at hourly intervals. Alarms are triggered through defined events if analogue measurement values delivered by the sensors (temperatures, pressures) exceed the permitted range. The life cycle guidance system is thereby fed with information, which allows remote control of the machinery.
- The bearing monitoring system offers monitoring information about actual operation conditions of the ship's main engine such as abrasion of base, piston rod and crosshead bearings.
- The complex diagnostic system CDS controls the engine continuously with the purpose of preventing damages. The CDS combines information from the following modules:
    - Crank angle encoder,
    - Cylinder pressure analysis,
    - Injection pressure analysis,
    - Piston Ring Analysis
    - Leakage measurement system

Crank angle, cylinder pressure and injection pressure are operational parameters of a diesel engine that allow for the assessment of the technical condition of engines and therefore serve as indicators to predict emerging damages. Furthermore, these parameters are essential to assess the operating efficiency of the engine, since the knowledge of the cylinder pressure at any given crank angle allows for the calculation of the actual effective power of the engine. Piston rings are essential spare parts subject to consistent wear, which in case of damage may cause a breakdown of the engine. Therefore, knowledge of the condition of piston rings is essential to avoid cost of non-operation and risk of accidents.

See http://www.marinediesels.info/, for more information on marine diesel technology.

Beyond the systems mentioned above, which are designed to monitor the ship's engine and to allow optimization of the combustion process and thus the emissions, two further diagnostic modules on the propeller system were integrated into the data flow: Both the steering gear monitoring, which allows the monitoring of the caviation effect [39] and the monitoring of the shaft up to the propeller which helps to optimize the ship propulsion quality.

The two latter monitoring modules prove that with regard to fuel efficiency propeller features have become very important recently.

[38] Type of database foreseen to archive automation and process data

[39] Caviation is one cause of abrasion of propellers and turbines

For manual data acquisition of such values which are not transmitted automatically a handheld data sheet was developed.

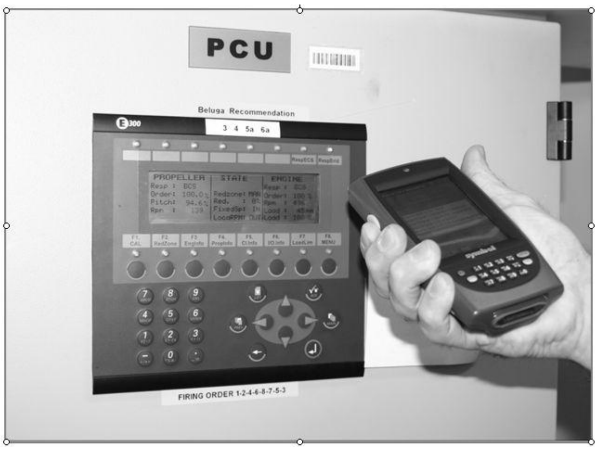

Figure 16: MDR – Manual Data Recording. Manual scan at a measuring point (Thoben et al. 2009)

Result: For successful data integration within the life cycle guidance system a data model is needed that describes a ship at an abstract level. Hartmann realized a reference environment of a container ship in authentic deployment conditions. The benefits of the ship life cycle guidance system have not yet been reported.

4.2.4 Integration of ship hull structure features into the ship life cycle guidance tool

Due to its overall importance, the ship hull was the subject of an individual development approach within the MarLife project (Thoben et al. 2009). The project partner, the classification society *Germanischer Lloyd* continued to develop the so called “hull manager”, a tool solely designated to the ship’s hull.

The hull is one of the few components without supply guarantees. Inspections occur on the order of the shipping company only. Therefore, the classification society Germanischer Lloyd created the service tool HullManager. The latter was applied and adjusted during the MarLife project to serve the ship life cycle guidance tool in terms of registration, display and interpretation of visual inspection data of the ship’s steel structure.

Practically this means that data about the hull thickness, in combination with other structural data is archived and transformed into a model. The actual state of the hull structure via 3D-model is accessible at any time and changes can be retraced and interpreted which assures a structural reliability and reduces the risk of structural failures, of damage to ship and cargo and the marine environment.

4.3 Inventory of Hazardous Materials for ships

Even though a continuous operation and therefore belonging to the next section, the Inventory of Hazardous Materials, also called "green passport"[40] is of different significance as the documentation duties will not be done voluntarily, but according to the legal obligation of the Hong Kong Convention, which is expected to come into force in 2014.

The interface with other life cycle assessment applications is obvious and respective LCA service tools therefore are currently under development.

Because of its significance for maritime business as a whole, the issue of ship recycling will be explained extensively.

In 2009 about 700 ocean-going vessels with a total capacity of 35 million gross tonnes were scrapped in different parts of the world. In 2010 ships with a capacity of 60 million tonnes were *"marked for the scrap heap"*.[41] Estimates about ships which are scrapped on the tidal beaches of India, Bangladesh and Pakistan range from 200 to 600 per year.[42]

According to ABS (2011) the differences between IHM and the green passport are that IHM requires more detailed and accurate accounts of the listed hazardous substances in the inventory booklet and sampling to be carried out for existing ships.

Figure 17: Ship breaking site in Bangladesh, courtesy of Henning Gramann, May 2011

[40] The "Green Passport", an expression formerly used in the IMO Resolutions, e. g. A.962(23) is no longer a synonym for IHM but rather became the name of a similar service offered by Lloyds Register

[41] End of the Line in MAN forum 04/2010

[42] EU advances towards coordinated action on ship dismantling, in Environment for Europeans, No.41.

For further information on ship braking activities in Asia please see the following website of the UNEP: http://maps.grida.no/go/graphic/shipbreaking_in_asia or: http://www.shipbreakingplatform.com/

Considering the variety of materials used for ship building and ship operations, the environmental problems arising from unprofessional ship scrapping are obvious.

Therefore, a set of measures has been drafted on an international scale to raise transparency about the use of hazardous materials and to enable environmentally sound ship scrapping. The so called inventory of hazardous materials (IHM) is foreseen as an information platform which provides at any time the type, amount and location of the hazardous materials on board an individual ship. Beginning with information from the ship builder, all subsequent constructional alterations and changes in material are to be registered in the IHM. Furthermore, authorisation and certification procedures of scrapping facilities will facilitate the controlled recycling of numerous materials.

The IHM is a central requirement of the Hong Kong Convention. Because of its importance for maritime business, a description of the evolution of the Hong Kong Convention follows:

What is an international convention?
International conventions can be adopted either at global (e.g. the International Maritime Organisation) or regional level. The rules of enforcement are various. Contracting governments have to comply with the provisions of the convention once they have ratified it.

4.3.1 The evolution of the Hong Kong Convention

The environmental impacts and working conditions in countries such as Pakistan, Bangladesh and India, where ship scrapping activities began in the 1970s, have been discussed for 20 years. But in spite of on-going discussions, ships were not covered by the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.[43] As a consequence the issue of ship recycling was first brought to the attention of MEPC (IMO's Marine Environment Protection Committee) in November 1998.

In December 2005 resolution A.981(24) was adopted instructing MEPC to develop a *"new legally binding instrument on ship recycling"*

The new resolution stated that the new instrument should regulate:

- Design, construction, operation and preparation of ships so as to facilitate safe and environmentally sound recycling, without compromising their safety and operational efficiency.
- Operation of ship recycling facilities in a safe and environmentally sound manner.
- Establishment of an appropriate enforcement mechanism for ship recycling (certification / reporting requirements).

In 2009 the "Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009" also known as Hong Kong Convention (HKC) was adopted by the International Maritime Organisation (IMO).[44]

Exceptions: The convention shall not apply to warships, government owned non-commercial ships, exclusively domestically operated ships and ships of less than 500GT.

[43] For more information, visit http://www.basel.int/

[44] http://ec.europa.eu/environment/waste/ships/pdf/Convention.pdf

The discussion on ship scrapping led to a different view on ship construction and operation. The approach towards professional ship recycling reflects a comprehensive view. The cradle-to-grave-concept was born!

4.3.2 The inventory of hazardous materials (IHM)

The inventory of hazardous materials (IHM) for a ship refers to the annex of the HKC[45] and consists of three parts:

- Part I. Potentially hazardous materials in hull and equipment
- Part II. Operationally generated wastes
- Part III. Potentially hazardous materials in stores

These parts are applicable to different stages in a ship's life cycle, as shown in the table below. (Germanischer Lloyd 2009).

Table 3: The three parts of the IHM

	Shipbuilding & Operating	Preparation for recycling	
Inventory of Hazardous Materials	Part I** Material contained in ship structure and equipment	Part II* Operational wastes	Part III* Stores
Table A Materials Mandatory for new and existing ships	X		
Table B Mandatory for new ships and voluntarily for existing ships	X		
Table C** Potentially hazardous goods		**X***	**X***
Table D Regular consumer products	List of exclusions		X*

* applicable only directly prior to recycling / last voyage

** operational relevant goods like lubricating oil, anti-seize compounds or grease, which are applied to keep normal performance of gear and equipment and machinery, are out of scope of IHM Part I.

[45] To be found in chapter 2.2 Safe and Environmentally Sound Management of Hazardous Materials, HKC, p. 44

Exercise

Give five examples of goods for each field of the table below. The “Guidelines for the development of the inventory of hazardous materials” Annex 2, is attached to the resolution MEPC.179(59) (IMO 2009).[46]

Table 4: Examples of materials and goods to which the IHM applies

Hazardous materials and goods according to Annex 2	
Table A Materials Mandatory for new and existing ships	Asbestos: Insulation agents PCB’s: Hydraulic oil Ozone depleting substances: Cooling agent Anti-fouling systems
Table B Mandatory for new ships and voluntary for existing ships	Cadmium compounds and lead compounds: Corrosion prevention Mercury compounds: Accumulators PBBs: Flame protection Radioactive substances: Smoke detector Certain short chain chlorinated paraffin: Lubricants
Table C** Potentially hazardous goods	Waste oil, engine coolant additive, paints, solvents/thinners, battery electrolyte
Table D Regular consumer products	Computers, refrigerators, printers, consumer batteries, TV sets

Concerning the collection of necessary information, section 4.2.1 of the above mentioned MEPC guidelines state: *“The shipowner should identify, research, request, and procure all reasonably available documentation regarding the ship. Information that will be useful includes maintenance, conversion, and repair documents; […] technical specifications; product information data sheets (such as Material Declarations); and hazardous material inventories or recycling information from sister ships. Potential sources of information could include previous shipowners, the ship builder, historical societies, classification society records, and ship recycling facilities with experience of working with similar ships.”*

Section 4.3.2 outlines: *“If any machinery or equipment is added to, removed or replaced or the hull coating is renewed, Part I of the Inventory should be updated [….] Updating is not required if identical parts or coatings are installed or applied.”*

4.3.3 Relevance of the ship life cycle approach for the IHM

Conceptually

According to Shama (1995), (see section 1.3), LCA is a process guiding the selection of options for design and improvement.

- For the selection of options one needs to have accessible descriptions of the design and information, provided by product data sheets, about related environmental features and properties, which will be offered by IHM.

46 http://www.imo.org/OurWork/Environment/ShipRecycling/Documents/RESOLUTION%20MEPC.179(59)%20Inventory%20guidelines.pdf

Qualitatively

LCA is seen as an *"assessment of key environmental burdens or releases at the different stages of the life cycle of a product"* (Shama, 1995).

- Considering the materials and goods of the tables A, B, C and D the internal structure of the IHM (see above) provides well sorted information which can be used to map burdens and releases over the ships life span.

Methodologically

LCA is seen as a *"quantitative inventory of environmental burdens or releases and forms the base for consideration about alternatives to improve environmental performance"* (Shama, 1995).

- Even though the IHM does not offer information about the amounts of the used working materials and releases, some qualitative information is provided. There is some consistency between the LCA approach and the structure of the IHM

4.3.4 The interface between IHM and the life cycle management system

Even though it is the responsibility of the ship owner, it is expected that part I of the IHM for new built ships will be carried out by the shipyard in cooperation with the suppliers, detail depending on contractual agreements.

During ship operation all relevant changes in the case of conversion, major repair and modifications have to be reflected in the Inventory of Hazardous Materials.

The IHM will also form the basis for the preparation of the "Ready for Recycling" Certificate and the Ship Recycling Plan prior to recycling. It will be subject to re-certification and be checked by the Port State Control (Germanischer Lloyd 2009).

The future will show whether the IHM will remain on board ship and in the shipping companies' office only or will also be kept in the office of the classification society or other certifying bodies.

The collection of a huge number of material declarations (MD) from equipment manufacturers and suppliers is an additional burden for shipbuilders. The challenge of development and maintenance of the IHM by the shipping companies adds a new application to existing software tools to reduce the workload and cost associated with this process.

Because of the importance of the Hong Kong Convention, the partners of the MarLife Project agreed to create an interface between the ship administration system, the life cycle management system and the hazardous material monitoring system (Ms Logistik Systeme, 2008).

In the course of the MarLife Project an interface for the creation of an actual Inventory of Hazardous Materials was realized. Currently software is being developed. It enables data exchange between suppliers and ship builders, shipping companies and certifiers.

4.3.5 ISO standards for the ship recycling industry

While service providers and software developers work out their combined LCA / IHM solutions, international standardisation continues:

The series **ISO/PAS 30000:2008,** includes the documents *Ships and marine technology – Ship recycling management systems – Specifications for management systems for safe and environmentally sound ship recycling facilitie*s.

Further publications are:

- **ISO 30001:** Ship recycling management systems – Best practice for ship recycling facilities – Assessment and plans
- **ISO 30002:** Ship recycling management systems – Guidelines for selection of ship recyclers (and pro forma contract)
- **ISO 30003:** Ship recycling management systems – Requirements for bodies providing audit and certification of ship recycling management systems
- **ISO 30004:** Ship recycling management systems – Guidelines for implementing ISO 30000
- **ISO 30005:** Ship recycling management systems – Information control for hazardous materials in the manufacturing chain of shipbuilding and ship operations
- **ISO 30006:** Ship recycling management systems – Guidelines on surveying of ships for hazardous materials and minimum amount or content of hazardous materials to be reported
- **ISO 30007:** Ship recycling management systems – Methods to remove asbestos in ships

Does LCA have to be carried out according to ISO standards? No, not necessarily, but "*when using more extended and complex life cycle assessments, ISO standards become more important",* TNO states in its fact sheet.[47]

4.4 Business strategy using environmental performance information

The following three statements show that information on environmental performance, related management and marketing may play a certain role in a company's overall business strategy.

A conclusion of the Environmental Information Study was that "*customers of ship transportation assume that environmental performance information may be important for them in the future. At present, such information is used only to a limited degree when choosing transportation partner. However, it is believed to be applicable for marketing purposes, but is seldom asked for or considered important*" (Magerholm Fet and Sørgård 1999).

"There will be growing environmental regulation and taxation. Insurance and financing might rise and a poor environmental image is disadvantageous for marketing strategies. Thus it is in the self-interest of the industry to pay attention for its environmental impact." (Sharma, 2006).

"*Gradually, shipping companies realise the need to operate in a way that respects the marine environment. An increasing number of companies move towards a proactive approach of managing the environmental aspects of their operation. They design and develop management systems that conform to the re-*

[47] http://www.tno.nl/downloads/106e_bo_mil_life_cycle.pdf

quirements of standards like the ISO 14001, and certify their proactive environmental approach. Many of them, report their relevant activities to the public through their annual environmental reports or through environmental performance documentations needed for class notations." (Theotokas and Kaza ,2007).

Concerning investment and benefit for marketing purposes it can be assumed that the adoption of a life cycle management system into shipping business requires a high investment which does not lead to immediate returns or benefits. Therefore the reason for introduction of LCM systems should be accompanied by information campaigns of potential clients. "*A less technical but more psychological aim is to inform the target groups about the existence and the capabilities of such innovative solutions, and to develop proper marketing strategies*", Wagner (2004) states.[48]

4.4.1 The relevance of LCA for emission control and the option of emission trading

Shipping was excluded from the emission trading programmes according to article 17 of the Kyoto Protocol. Being responsible for 3-4% of global emissions while transporting approximately 85% of goods, shipping is recognized as an efficient mode of transportation but an important SO_x emitter. The size of the sector and related emissions are not only high but expected to double by 2050 if no action is taken. Ships' CO_2 emissions are directly proportional to the fuel consumption, with 3.1 tonnes of CO_2 being released from each tonne of fuel burnt, on average. The EU commission recently proposed that greenhouse gas (GHG) emissions by the maritime sector should be reduced by 20% between 2005 and 2020.[49] Furthermore the commission announced that inclusion of maritime transport into the European Emission Trade System (ETS) was an option in case no emission reduction targets were agreed upon by the United Nations Framework Convention on Climate Change (UNFCCC) for international maritime transport until end of the year 2011.

Where does emission trading meet the ship life cycle concept?

As soon as emission trading is practised in shipping, all means to lower the energy consumption and related emissions will have to be evaluated. The LCA methodology provides valuable information for both, for the documentation of the emission rate and for providing a data base for further diminution, aiming to sell emission permits.

4.4.2 The relevance of LCA for environmental management system EMS

Shipping companies which are certified according to requirements of an environmental management system (EMS) need to document their continuous improvement. Decision support based on life cycle assessment for environmentally advantageous purchase of ship components or a life cycle management guidance system like the one presented in section 3.2.3. help to identify issues of ship operation which need to be improved.

[48] According to Wagner, M. & Schaltegger, S. (2004): The Effect of Corporate Environmental Strategy Choice and Environmental Performance on Competitiveness and Economic Performance. An Empirical Analysis in EU Manufacturing, European Management Journal, Volume 22, Issue 5, October, 557-572.

[49] According to: http://ec.europa.eu/clima/news/articles/news_201107180

5 Resources

5.1 Common features of LCA

The participating parties decide if and to what extent LCA is applied. Several service providers are ready to apply their systems to the different branches of maritime business. The resources needed depend on the management approach and the strategic aims pursued. All LCA- tools have the following common features:

- It is a highly sophisticated software application to be used by respective service providers.
- Product data management plays a big role. The supporting life cycle software tool needs to be fed with product data deriving from the ship builder or adjacent suppliers.[50]
- The tool needs access to data bases also used and generated in product planning systems and enterprise resource planning (PPS/ERP), in computer aided design (CAD) for construction purposes, in computer aided engineering (CAE) for the purposes of modelling and simulation and in computer aided manufacture (CAM) systems.
- The impact assessment is based on numerous algorithms reflecting the technical expertise and scientific findings and assumptions which may be consolidated or controversial in detail.

A variety of LCA service providers provide life cycle assessment support for different issues. Adjustment of a life cycle management system to the companies' needs seems to be the basic challenge.

Commercially available life cycle assessment tools are numerous. A long list can be found in the very comprehensive publication of the European Environment Agency:[51] For the maritime business sector, the recent developments of the classification societies seem worthwhile mentioning.

5.2 Available support tools provided by the classification societies

In the field of life cycle assessment several products and services already exist. The classification societies all seem to be very busy with the development of their own multi-purpose software with enduring service characteristics.

The American Bureau of Shipping, ABS developed under the key words of "Life Cycle Care" the ship management program "ABS SafeShip", containing components of ship design (SafeHull), ship construction (SafeHull Construction Monitoring Plan) and ship operation (Hull Maintenance).

Lloyd's Register offers the products "Safer operation", "More efficiency" as well as "Support for drafting and operation"[52] all aiming *"to manage your ship through its life cycle".*

Det Norske Veritas offers a ship life cycle management solution among its "Nauticus" tools, aiming to optimise the inspection; to analyse the hull condition, to organise management functions and to structure work orders and repair specifications. The system links up the onboard systems and the onshore management systems.

Bureau Veritas describes their own services for ship owners as a contribution *"to cover the entire life cycle of ships from ship design until end of the operational phase"*. The LCA software and database package

[50] According to oral information from Dr. Wiegand Grafe, Germanischer Lloyd August 2010

[51] EEA, Environmental Issues Series No.6 from 1997

[52] http://www.lr.org/sectors/marine/products/index.aspx

EIME has been chosen by Bureau Veritas Consumer Products Services as the ecodesign solution for its clients worldwide.[53]

Germanischer Lloyd offers several products and services with reference to the ships' life cycle. As a result of the MarLife project a module about Hazardous Material Monitoring is emerging; the further integration of the HullManager has been agreed upon and further efforts to include aspects of fleet management are foreseen.

5.3 Conclusions and outlook

5.3.1 General outlook for the different branches

There are various evaluation tools and decision support tools for different purposes and different players in maritime business. By 2020 integrated data flow is expected to embrace different departments of a shipping company plus shipyards, suppliers, and further related service sectors like insurance, brokers and transport clients in the following ways.

- Repair yards will have to be supplied with data from the ship builder and ship equipment providers.
- Ship construction data, maintenance, environmental and safety performance and related certification from cradle-to-grave are the classifications societies' interests and fields of responsibility.
- Ship supply companies will be in a position to use their data to forecast maintenance works, to foresee and to prevent collateral damage and in the case of access to operating data, to install the services of remote monitoring as a new business field.
- Fuel consumption data will be evaluated and provide information on ship efficiency required for documentation on continuous improvement in the field of environmental management or for the purposes of emission trading and other market based instruments.
- Ship tracking data adds to the transparency not only of the ship's efficiency, but also on the ship crew's mode of operation.

As an example of a supply companies' view, see the following figure, taken from a MacGregor presentation about the data exchange protocol *ShipDex*.

[53] according. to a press release of Bureau Veritas: http://www.bureauveritas.com

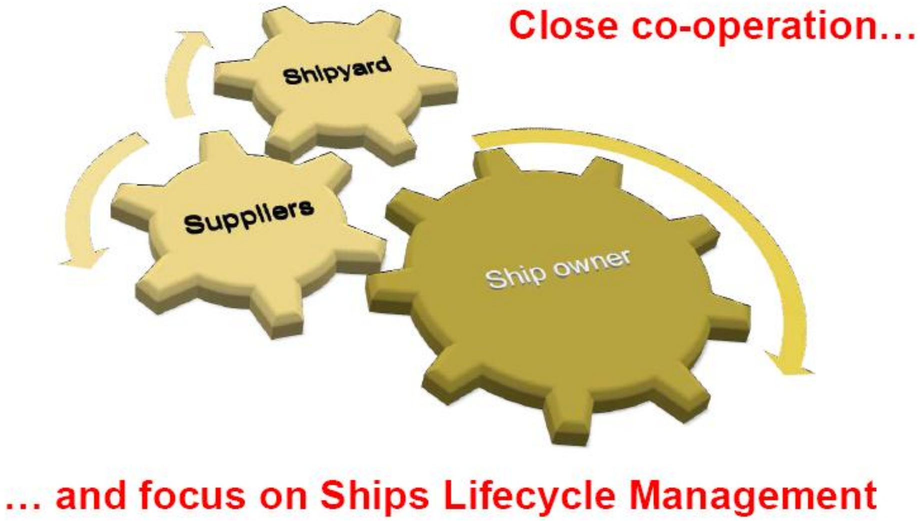

Figure 18: Life cycle management seen as co-operation between suppliers, shipyard and ship owner. From a MacGregor presentation about the ShipDex system, courtesy of MacGregor

5.3.2 Life cycle management in shipping companies

Comprehensive life cycle applications are currently being developed. As we have seen the classification societies play an important role in this.

The differences between the existing life cycle management tools result from the order of service integration. This tendency shows that the following management aspects will be integrated and supported within a sole system:

- Technical management
- Procurement management
- Quality and safety management
- Incident management
- Voyage management

Each life cycle management approach described above is based on processing huge amounts of data.
The shipping companies, as core actors in maritime business, face the challenge of deciding whether the application of LCA and more complex management tools should be provided in-house or by specialized companies. As in all questions concerning outsourcing, the competing aspects of convenience and independence have to be considered.

6 Summary

Life cycle assessment is a method of evaluating the environmental impact of products and services. The methodology contributes to fundamental research, offers decision support or supports a company's comprehensive management. The formerly formulated principle “from cradle-to-grave” varies according to the clients’ needs or the purpose of the assessment.

Once again the benefits according to a major LCA service provider’s perspective are: [54]

- Insight into the environmental impacts
- Improvement options
- Competitive advantages of green image
- Implementation of sustainability strategies
- Comparison of alternatives

When using the results of the LCA one should be aware of the limits of the informational value and the purpose of assessment. Complex algorithms for ship emissions reflect some knowledge but do not express the real environmental impacts because many factors cannot be reduced to a number and inserted into a model, or the model simply is not good enough.

It can be expected that the application of LCA will be driven further by legal obligations like that of the “green passport” for ships or ship emission trading. As soon as these are in force, new tools for evaluation and documentation of environmental performance will be introduced.

Other “driving forces” are the voluntary initiatives of shipping companies, for example the introduction of environmental management systems in accordance with ISO 14000, which also implies the use of an evaluation and documentation tool.

Environmental "preferability" has emerged as a criterion in both consumer markets and government procurement guidelines

The following four features of life cycle assessment have evolved in the course of the previous years and therefore might become more accentuated in future years to come:

- The holistic view of earlier life cycle approaches seem to have been displaced by smaller but more profound studies, in line with the partial interests of ship building yards, repair yards, construction offices or the shipping companies.
- The holistic approach seems to be currently being followed by the classification societies, aiming to provide an all round service for their customers.
- LCA is a very demanding IT application but needs human skills for interpretation and application of the results.
- The common features of all life cycle activities, the need to collect, store and process huge amounts of data, leads to questions of cooperation and control.

[54] acc. to TNO Products and Services, http://www.tno.nl/downloads/106e_bo_mil_life_cycle.pdf

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8 Abbreviations

CEN	Comittée Européen de Normialisation / Committee for Standardisation, one of the three institutions responsible for European standards (EN)
cu m	Cubic metre
GT	Gross tonnage, unit of measurement of ship volume, all enclosed spaces
HC	Hydrocarbons, ship emission, result of incomplete combustion
HFO	Heavy fuel oil, ship fuel, highly viscous refinery residue
IHM	Inventory of Hazardous Materials, also called green passport, Hong Kong Convention
ISO	International Standardization Organization
LCA	Life cycle assessment
LCM	Life cycle management
LNG	Liquefied natural gas
MEPC	Maritime environmental protection committee
MGO	Marine gasoil, ship fuel made from distillates only
MT	metric ton = 1000 kilograms
N_2O	Nitrogen dioxide, the aqueous solution is acid
NH_3	Ammonia, the aqueous solution of ammonia is basic
NOx	Nitrogen oxide
PM	PM10, PM2,5 Particulate matter, Thoracis fraction) <=10 µm PM2.5 (respirable fraction) <=2.5 µm
ppm	Parts per million
PSSA	Particular sensitive sea area
SO_x	Sulfur oxide
UNEP	United Nations Environment Programme
VDR	Voyage data recorder
VLCC	Very large crude carrier

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9 Figures

10 Tables

11 Revision one-liners

The following questionnaire is intended to serve as a tool for your self assessment. After working through the learning module you should try to answer the questions on your own and then check your answers. All questions can be answered with reference to the text of the learning module.

1)

How can process oriented, product oriented and management oriented methods to improve the environmental performance of an organization be distinguished? See p. 5

2)

What fields of application of a life cycle assessment can be identified according to Sharma (2006)?

See p. 7

3)

List at least five purposes of the application of an LCA. See Table 1 (p. 8)

4)

What series of ISO-standards refers to the LCA methodology? See p. 8

5)

List four international standards that refer to the LCA methodology and name their particular subject

See p. 8

6)

What are the definitions of „environmental impact", „life cycle", „life cycle assessment" according to ISO 14040 ff.? See p. 9

7)

What is the difference between „product data" and „operational data" when we think about a ship's life cycle? See p. 11

8)

What does the term „life cycle accountability" mean? See p. 11

9)

What stages of a product do the „cradle-to-grave“, „cradle to gate“ and „cradle to cradle“ approaches comprise? See p. 11

10)

In what field of application can we speak of a „well to propeller“-approach? See p. 11

11)

What is an eco efficiency analysis? See p. 12

12)

From a cradle-to-grave perspective, list three phases of the ship's life cycle. See p. 13

13)

List three environmental impacts for each stage (building, operation and scrapping) of a ship's life cycle.

See p. 14 f.

14)

What is the subject of the Hong Kong Convention?

See p. 15

15)

What is an IHM?

An Inventory of Hazardous Materials is a document containing a list of any material on board a vessel that may cause a hazard to people or the environment during the scrapping process. These comprise building materials such as insulation or paint as well as materials used for the operation of the ship such as fuels, lubricants or refrigerants. The preparation of an IHM and its maintenance throughout the ship's life cycle is mandatory according to the Hong Kong Convention.

16)

What steps does the life cycle methodology according to the ISO 14040 standards comprise? See p. 19

17)

What is a „functional unit“ according to the ISO 14040 terminology? See p. 19

18)

What is the meaning of the term „system boundaries“ according to the ISO 14040 terminology? See p. 19

19)

Describe the process of the goal definition and scoping within an LCA. See p. 19 and 20

20)

What is a life cycle inventory within the process of an LCA? See p. 19 and 20

21)

What is an impact assessment within the process of an LCA? See p. 19 and 21

22)

What ISO standards refer to the scrapping and recycling of ships? See p. 40

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