Grant Agreement no: 690770

# Ship Lifecycle Software Solutions (SHIPLYS)

Project Deliverable Report

## D3.1 Existing prototyping models and approaches in shipping and other industry sectors

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| **Deliverable due date:** | 2017-03-31 |
| **Actual submission date:** | 2017-06-29 |
| **Work package:** | WP3 |
| **Task:** | T3.1 |
| **Dissemination level:** | Public (PU) |
| **Lead beneficiary:** | AES |
| **Status:** | Final |

SHIPLYS

# VERSION AND CONTROLS

| Version | Date | Reason | Editor |
|---|---|---|---|
| 0.0 | 2017-01-17 | First release to internal contributors | Francisco del Castillo / Thomas Koch |
| 1.1 | 2017-03-21 | Almost complete version including contributions from all authoring partners | Francisco del Castillo / Thomas Koch |
| 1.2 | 2017-03-28 | Draft for review, added Annex A and B.2 | Thomas Koch |
| 1.3 | 2017-04-10 | Prepare for draft incorporating all comments | Thomas Koch |
| 1.4 | 2017-04-12 | Some additional comments and literature updates | Thomas Koch |
| 1.5 | 2017-05-04 | General review and formatting | Ujjwal Bharadwaj |
| 1.6 | 2017-06-29 | Review to conform to (PU) status | Ujjwal Bharadwaj |

**Acknowledgement:**

The research leading to these results has received funding from the European Union's Horizon 2020 research programme under grant agreement No. 690770.

SHIPLYS

# EXECUTIVE SUMMARY

## Background

SHIPLYS is a three-year project that started in September 2016. The project is in response to needs of SME naval architects, shipbuilders and ship-owners, who, in order to survive in the world market, need to improve their capability to reduce the time and costs of design and production, to be able to reliably produce better ship concepts through rapid virtual prototyping and to meet the increasing requirements for LCCA (Life Cycle Cost Analysis), environmental assessments, risk assessments and end-of-life considerations as differentiators.

## Introduction

SHIPLYS project is mainly focused on developing and integrating rapid virtual prototyping tools with life cycle tools, in order to empower European SME designers and production yards to make their own decisions on how to arrive at early stage via a life-cycle approach, at both: optimum ship design configurations and optimal retrofitting/conversion.

Existing established approaches and tools such as Building Information Modelling (BIM) and product life cycle management (PLM) are investigated for the relevance of such functionality to meet SHIPLYS objectives.

Additionally, relevant work done in previous projects such as the Life Cycle Assessment Tool (LCAT) developed in the FP7 project MAINLINE, the approach developed within MOSAIC, another FP7 project, and many other projects that SHIPLYS participants have been involved are also reviewed.

## Aims and Objectives

Review existing approaches and tools for ship design prototyping, production management, life cycle cost modelling, assessment of environmental impact, and risk assessment.

## Methodology

Work done in this Deliverable draws on work done by individual partners on various EC funded projects, software or relevant approaches developed within their own organisations and experience in the use of or knowledge of relevant third-party off the shelf available software. Where applicable, for example in the use of BIM, experts have been consulted and their work referenced. Cognisance has been taken of relevant work outside the shipping sector with a view to learn from such experience and, where applicable, transfer such technology to the project.

## Summary

This Deliverable contains a summary of models and approaches considered for their applicability to SHIPLYS concepts. The Deliverable lays the background for D3.2 in which a selection will be made from the models considered in D3.1. This involves the assessment and identification of, a) existing models to be integrated, and, b) functionality to be developed within the project and integrated within the SHIPLYS software platform.

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# Abbreviations used

| | |
|---|---|
| **AAM** | Application Activity Model |
| **AP** | Application Protocol (as defined by ISO 10303, ISO 13584, and others) |
| **API** | American Petroleum Institute |
| **BEP** | BIM-enabled practice |
| **BIM** | Building information modelling |
| **BWT System** | Ballast Water Treatment Systems |
| **CoF** | Consequence of Failure; |
| | Consequences of a Failure or an adverse event, as used in some Risk Assessments (RA). |
| **EC** | European Commission |
| **EI** | Environmental impact; |
| | Possible adverse effects caused by a development, industrial, or infrastructural project or by the release of a substance in the environment. |
| **GHG** | Greenhouse Gas(es) |
| **HSLA** | High Strength Low Alloy |
| **ISO** | International Standardisation Organisation |
| **LCC** | Life Cycle Costs; it includes the costs of design, production, operation and maintenance, retrofitting/ life-extension and end-of-life costs. |
| **LCCA** | Life Cycle Cost Analysis; |
| | Alternative terminology for Life Cycle Costs (LCC). |
| **MAINLINE Project** | "Maintenance, renewal and improvement of rail transport Infrastructure to reduce Economic and environmental impacts"; |
| | Research project with a funding support from European Commission 7th Framework Programme. |
| **MCDA** | Multi-Criteria Decision Analysis; |
| | A sub-discipline of operations research that explicitly evaluates multiple conflicting criteria in decision-making. |
| **MOSAIC Project** | "Materials On-board: Steel Advancements and Integrated Composites"; |
| | A research project funded under theme SST 2012.5.2-3 Innovative structural and outfitting materials for ships including inland ship priority within the 7th Framework Programme for Research and Development of [grant number 314037]. |
| **O&M** | Operation and Maintenance |
| **PoF** | Probability of Failure; |
| | The likelihood or probability of failure or an adverse event occurring |
| **RA** | Risk Assessment; |
| | Systematic use of information to identify sources and to estimate the risk. Risk |

Assessment provides a basis for risk evaluation, risk mitigation and risk acceptance. Information can include historical data, theoretical analysis, informed opinions and concerns of stakeholders.

| | |
|---|---|
| **RBI/ RBM** | Risk Based Inspection/ Risk Based Maintenance;<br>RBI/RBM typically involve an evaluation of risks and prioritization of actions (inspection/maintenance) based on such evaluation |
| **RiskWISE®** | The RBI / RBM software developed by TWI Ltd to support the implementation of certain American Petroleum Industry (API) standards. |
| **Scenarios** | The scenarios used in development of SHIPLYS software |
| **SHIPLYS design workflow** | The term used to include all activities pertaining to rapid virtual design prototyping, production simulation, life cycle cost analysis (LCCA), environment impact and risk assessment that will be considered during the early ship design stage. |
| **SHIPLYS LCT** | SHIPLYS Life Cycle Tools;<br>The suite of tools providing life cycle cost analysis, environmental assessment, risk assessment, and decision support functionalities |
| **SME** | Small and Medium Enterprises |
| **VC** | Value Chain |
| **VP** | Virtual prototyping |
| **WD** | Working Draft (of a Standard under preparation) |
| **WP** | Work Package |
| **CML 2010** | CML-2010 – is an impact assessment tool developed by the Centre of Environmental Science of Leiden University (CML). The CML methodology groups the LCI results into midpoint categories, according to themes. These themes are common mechanisms (e.g. climate change) or groupings. |

# 1 Introduction

In order to maintain and develop Europe's position as a high value specialist shipbuilding region, it is crucial that the design tools and paradigms are improved to allow new designs and processes to minimise the total costs of production, operation, refits and scrappage, thus meeting the new sets of legislative and client based requirements.

Europe's SME designers and production yards need new tools and paradigms to:

- Integrate the different design stages through more standardised information, using an approach such as the one which successfully worked for Building Information Modelling (BIM) in construction, to be able to keep the bid- stage technical information and pass it through into the detailed design stages.
- Introduce a reliable modelling method for life cycle analysis (costs, environmental, risk) for designs at the early design stage (supporting bid decisions) and later stages of detailed design.

# 2 Deliverable Objectives

The main purposes of this deliverable can be summarised as follows:

- To identify transferable knowhow from existing prototyping models and life cycle approaches in shipping/ ship building and other industry sectors.
- To transfer experience from the development of industry modelling coherence schemes and product life cycle management approaches and use them to produce new techniques for quick, reliable multi-disciplinary modelling capability for the marine industry.
- Sharing knowledge among all stakeholders, including shipyards, ship owners, R&D developers and academics, for cutting-edge practices and assets' performance for minimal total costs over the useful economic life.
- Analysing Life Cycle Cost Analysis (LCCA), environmental and risk assessments, product and process lifecycle management (PLM) and Virtual Product tools developed from previous national and EU level projects for integration into a comprehensive, customised and single package simulation and analysis tool, to achieve the goals of the SHIPLYS project.

# 3 Approach to meeting the Deliverable objectives

Following in the footsteps of the automotive, aerospace and construction industries, our underpinning concept is to transfer the lessons learnt during the introduction of BIM systems in construction, rail and oil & gas across to the shipping design situation, to provide an integrated framework to generate cost effective simulations based on reliable data, and to provide data format improvements to allow the persistence and re-use of information through the process.

The shipbuilding industry has aspired to adopt the business models of the aerospace and automotive industries, where products are more standardised, and higher profit margins can be achieved with less manpower.

Ship design activity often requires handling and storage of large amounts of data related to different systems inside the vessel, demanding a structured way to organise it. We intend to use an object-oriented approach to handle virtual prototyping data during conceptual ship design. This exercise will develop and improve existing data quality and interoperability standards, including the new AP242 application protocol, designed for interoperability of 'lightweight 3D" digital mock-ups within the STEP standards (ISO 10303 series), to help with transferring the automotive and aerospace learning into shipbuilding. By incorporating this standard, we can make a good start at getting suppliers into the equation, since they will be working with the automotive and aerospace users that have generated the AP.

# 4 Traditional ship design process

As indicated in [108], the traditional role of a ship designer is the preparation of an overall design of a vessel that will have a performance satisfying the owner's operational or functional requirements while complying with the statutory rules and regulations. The concept of design for performance, design for safety, design for production, design for environment and design for minimum life cycle cost, requires that in satisfying these requirements, the ship designer must also give attention to improve the performance, to reach the safety goals, to ease of production and to reduce the environment impact and the life-cycle cost.

The role of the ship designer can be seen in this context as one of arbiter, having the ultimate responsibility of deciding whether performance, safety, productions, environmental or cost considerations shall take precedence in any particular case or of deciding the nature of the compromise to be reached.

The design process goes through a variety of stages (describing the classic design spiral), each developing information in greater detail and in different formats. Following the early design activities concerning concept design that are performed today in shipyards technical offices are the requirement analysis and management. The ship owner requirements define the ship concept and the applicable standards. Requirement analysis is the first activity to perform and it continues along the whole ship design, ship construction and testing until the delivery to the ship owner. The next step is the definition of baseline concepts. The design of a new ship usually begins with an analysis of the existing fleet to obtain general information on the type of vessel of interest. If a similar design exists, the design proceeds using this vessel as the basic ship. If a design is to be a new vessel within an existing class of vessels the world fleet of recent similar vessels can be analysed to establish initial estimates for ship dimensioning and characteristics.

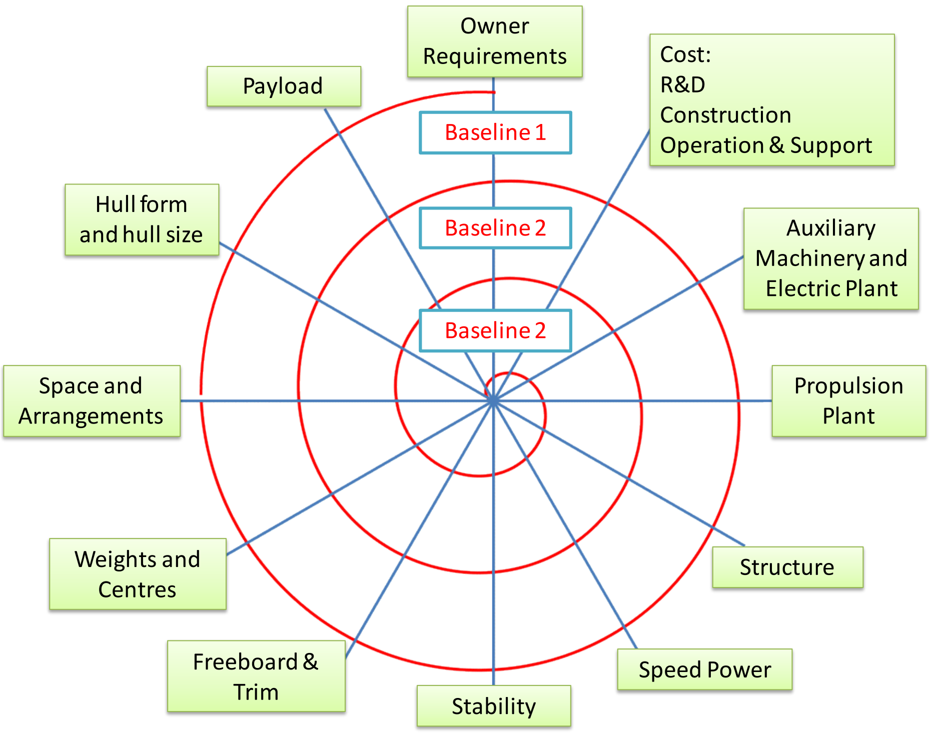



**Figure 1: Design spiral based on (Gale 2003)**

The first issues that normally are contemplated are the vessel capacities, performances and layout. (Spaces design – Baseline concept). It is necessary to develop a consistent definition of a candidate design in terms of just its dimensions and other descriptive parameters such as L, B, T, and DWT. But also, in a very early stage of the project, the lightship weight and centre of gravity location are estimated in order to consolidate the design in terms of stability, performance, etc.

**The design spiral** was first described in 1959 by J.H. Evans in the paper “Basic Design Concept” within ASNE journal, summarising the common way ahead along ship design process from requirements reception up to the final definition of the ship.

The paper shows a schematic representation of this spiral design process. The ship designers move through the design process in a sequential series of steps, each dealing with a particular synthesis or analysis task. After all the steps have been completed, the design is unlikely to be balanced (or even feasible). Thus, a second cycle begins and all the steps are repeated in the same sequence. Typically, a number of cycles (design iterations) are required to arrive at a satisfactory solution. This process is not sequential, unless the design is entirely developed by one person [32].

In fact, the design process in the early stages is rather unpredictable. Once a baseline concept has been identified and defined in sufficient detail to be understood and used by the principal design disciplines, for example, structures, propulsion, electrical, general arrangements, weight estimation, etc., then the design work in these principal disciplines will generally proceed in parallel as shown in Figure 2.

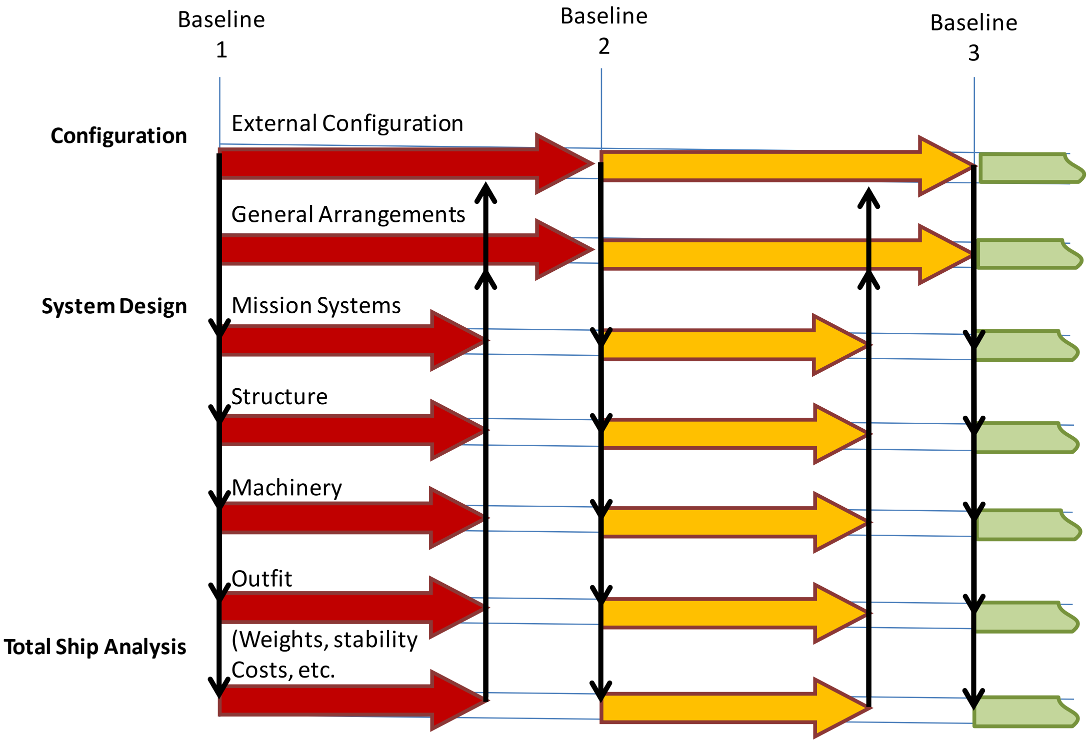



**Figure 2: Parallel advancement of design aspects (Gale 2003)**

For each discipline, a series of tasks must be performed and there is usually a preferred sequence for the tasks. As each task is completed, the products of the task can be shared with the other members of the design team. The number and severity of problems identified are generally larger in the early design; they tend to decrease in both respects as the design is developed in increasing detail.

A major design effort is planned so that formal updates of the design baseline occur at regular intervals. At these milestones, the current hull form and general arrangements are formally issued to the other members of the team and they are directed to shift to these configurations in their subsequent work.

Figure 3 below summarises the key stages and activities of a ship acquisition program [24]:

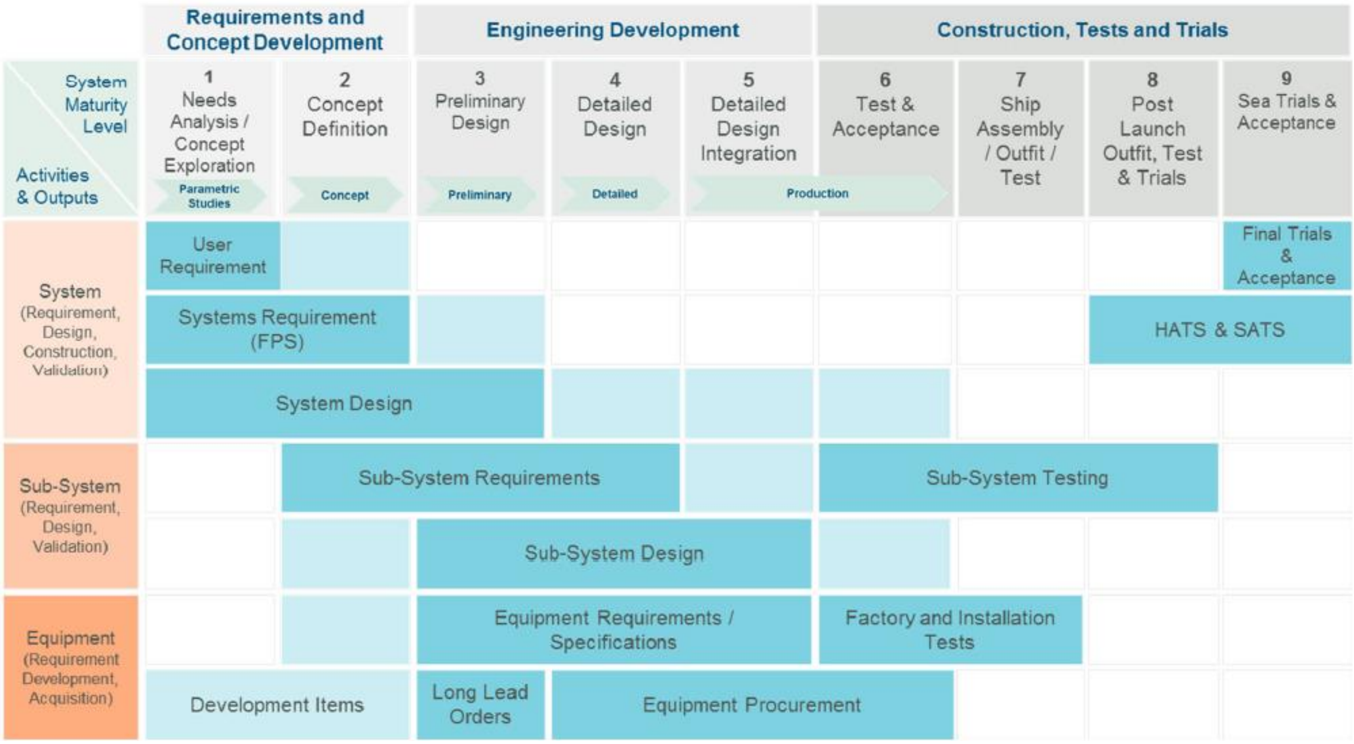



**Figure 3: Ship Acquisition Process [24]**

## 4.1 Challenges

Ship designers count on extensive databases from previous designs, together with lessons learned from operational experience with the ships built to those designs. In addition ship designers rely on a great number of different tools used to accomplish the design process. These tools work with different types of input and output formats and generally exist in the form of computer software used to model the ship geometry or perform particular analyses of various types.

Nowadays these ship design and analysis tools are in many cases linked into integrated design systems. An example of this integration could be several software systems for hull form generation by 3D NURBS surfaces models, which link this form with calculations for different disciplines such as hydrostatic, seakeeping, hydrodynamic, stability, weight distribution, propulsion (speed-power), structure (in design and production department), etc.

Since the Ship Design Spiral concept was developed, the ship designers have usually moved through the design process in a sequential/parallel series of steps. Although modern design methods were capable of producing very good designs, they were unlikely to yield optimum ones. This was because the process required a great deal of design time and thus designers were limited to explore all potential designs. Moreover, without being able to recognise the effects of slight modifications on the design at once, designers may adversely alter other design requirements while concentrating on a particular design aspect.

As indicated in [24], it is well known that decisions made in the early stages of ship design have a significant impact on functional outcomes, through-life cost and the overall effectiveness of the resultant vessel which makes the early stage design is subject to the same constrains as all other design phases; namely time, resources and budget. This drives a need for innovative approaches and the development / integration of intelligent tools to aid in the early stage ship design process.

# 5 General Models for product information and for exchange & management of product data

## 5.1 Process and Activity Models

### 5.1.1 Activity models in ISO 10303

**Background**

ISO 10303 is an International Standard (also known as STEP) which was started around 1984 as an effort to develop a suite of data exchange standards and tooling methods for the computer-interpretable representation of product information and for the exchange of product data [104]. The objective is to provide a standard reference capable of describing products throughout their life cycle. This mechanism is suitable not only for data exchange, but also as a basis for implementing and sharing product databases, and as basis for archiving. The standard is organized into a large collection of parts, grouped by type of content.

The most visible and relevant parts are numbered 2*nn* which format the group of Application Protocols (AP). These parts focus on the domain-specific definition of exchangeable data models. In this family of APs, a number of parts exist which are focused on or relevant for shipbuilding related application:

- AP215 – Ship arrangement [45]
- AP216 – Ship moulded forms [46]
- AP217 – Ship piping [47]
- AP218 – Ship structures [48]
- AP226 – Ship mechanical systems [49]
- AP227 – Plant spatial configuration [50]

According to the ISO 10303 rules, any AP document is expected to provide a common set of sections and annexes. For our purposes the most relevant section is found in each respective Annex F, which contains the Application Activity Model (AAM). Due to the full synchronisation between the shipbuilding related APs (which was accomplished by establishing a “Ship Common Model”) all activity models in the “Ship” series of standards link well together and can be seen as subsets of a complete activity model.

**IDEF-0 notation**

All shipbuilding related APs documents use the IDEF-0 modelling method to describe the activity model. Every activity is drawn as a rectangle, identified by a unique id and a descriptive name. IDEF-0 activities are interacting by means of flows which can represent data items, physical items or triggers. These flows are characterised either as inputs (incoming data/material), outputs (outgoing data/material), controls (rules, constraints, triggers) and mechanisms (executing entities such as resources, facilities, algorithms). Inputs are marked as incoming arrows from left, outputs as outgoing arrows to the right, controls as incoming arrows from top and mechanism as arrows from bottom.

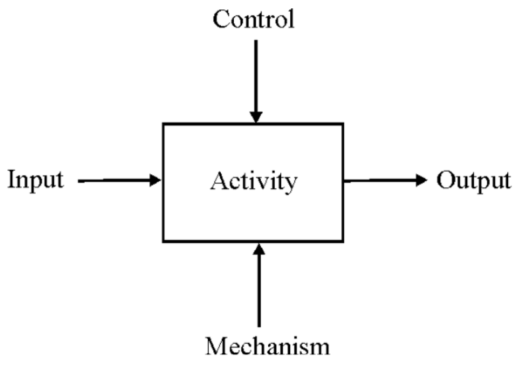



**Figure 4: IDEF-0 notation**

Activities are organised to create a hierarchy. An activity can be composed of other sub-activities. The top activity is usually called A0 or A1. Sub-activities will be identified by adding the number of sub-activity to the activity parent ID, e.g. A1 will be divided into A11 to A13. Sub-activities can inherit the connection arrows (input, output, control, mechanism) from their parent activity.

IDEF-0 has been chosen as one popular method for description of AAMs in ISO 10303, because it provides good balance between clear formal definitions and being accessible to domain experts with no or little background knowledge in data or process modelling.

**ISO Ship Activity Model Overview**

The Activity models defined for the ship-related parts define the full life-cycle of a vessel within their scope. This is very convenient from the SHIPLYS perspective, as this model targets (at the higher levels) the full scope of the project, as far as LCCA is concerned. Figure 5 shows the top-level "world" view of the activity model.

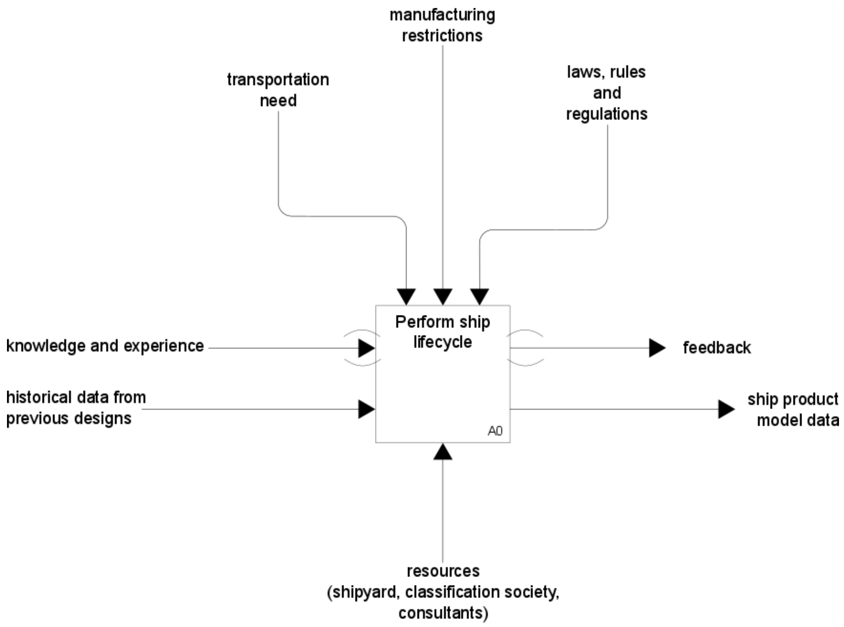



**Figure 5: Ship Life Cycle Activity Model [ISO 10303]**

**The internal structure of the model (i.e. the content of activity A0) is shown in**

Figure 6, which defines the main phases of the life-cycle from the design and production to decommissioning and scrapping.

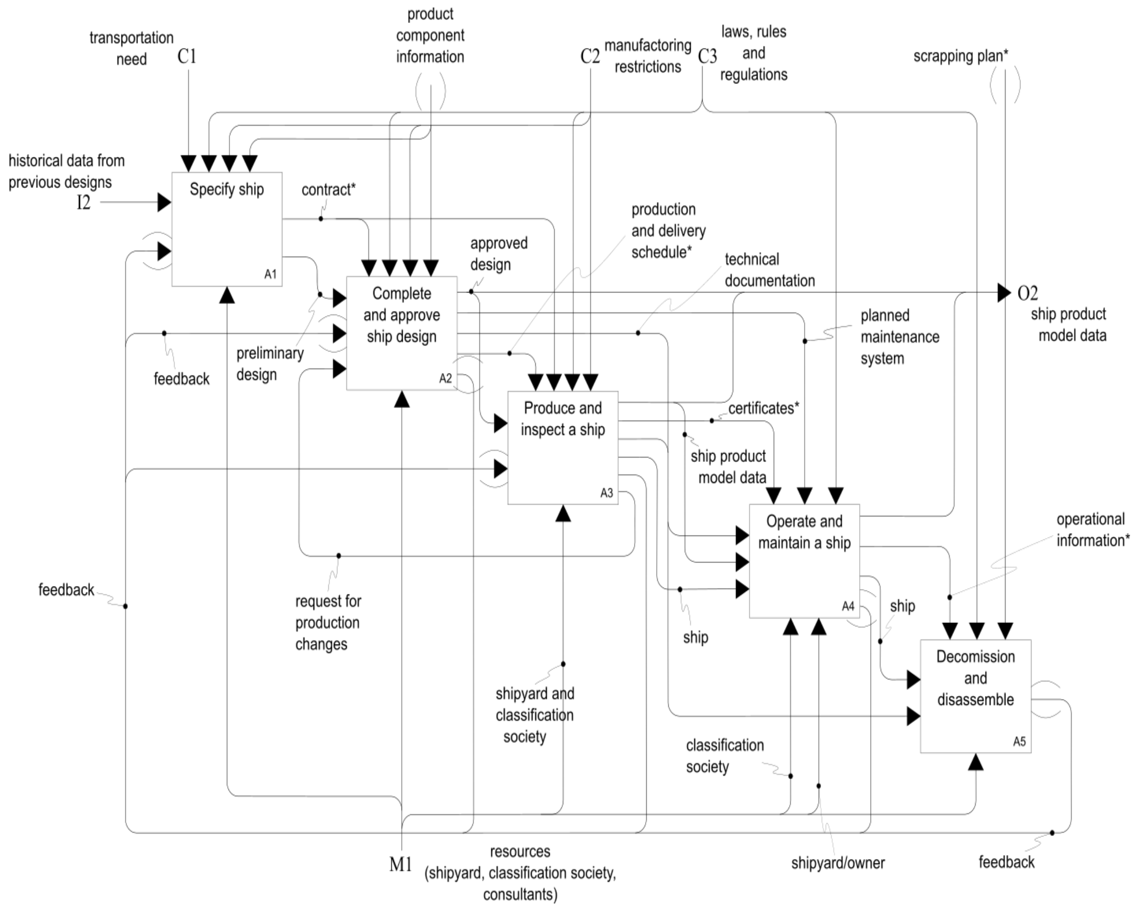



**Figure 6: A0 – perform Ship Life Cycle**

The activity model is then further refined to different levels of detail depending on the scope of the individual AP. As an example, Figure 7 shows the details of activity A12 – prepare bid, which addresses the main design related tasks applicable to the scope of planned SHIPLYS design tools. This is still at a high level; however, these models contain considerably more details, in some areas down to the 6th level. A typical detailed example is shown in Figure 8 for A12224 – Calculate stability and trim.

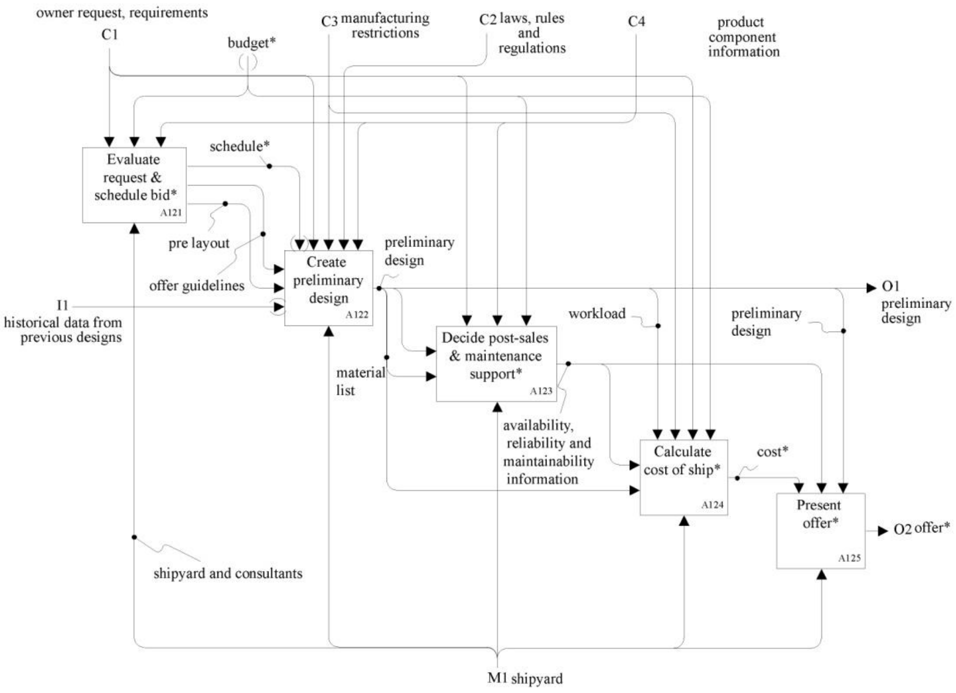



**Figure 7: A12 – Prepare Bid**

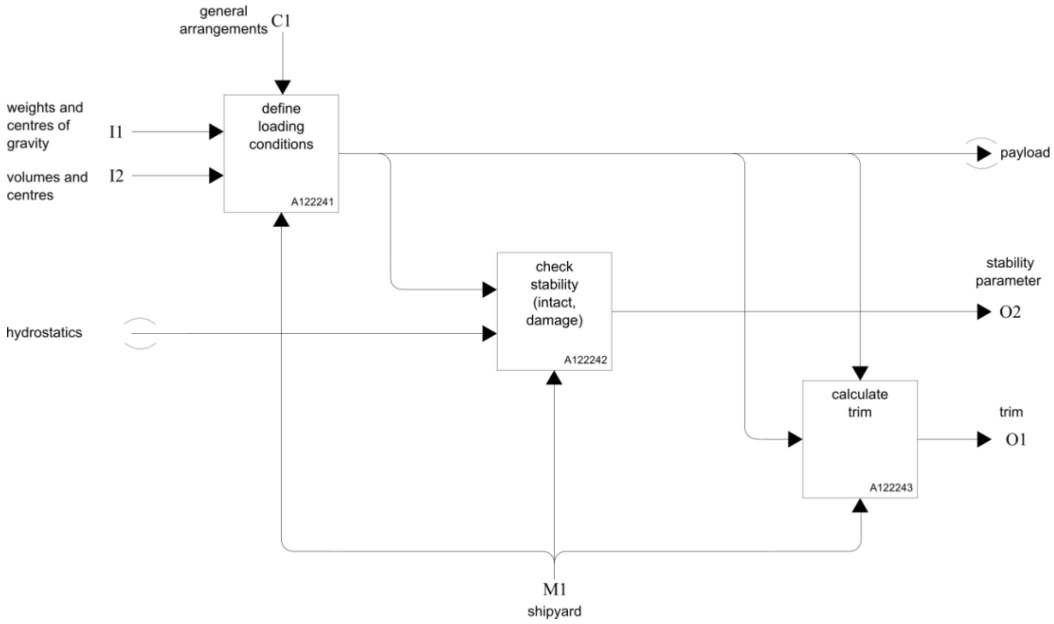



**Figure 8: A12224 – Calculate stability and trim**

For more details refer to [45],[46],[48]. Table 7 (in Annex B) shows a complete listing of all activities defined in the activity model.

### 5.1.2 Potential Usage in SHIPLYS

THE INTENDED USE OF THE MENTIONED ISO 10303 ACTIVITY MODELS IN SHIPLYS IS TO PROVIDE THE UNDERLYING MODEL TO BE USED AS GUIDANCE IN WORK FLOW CONTROL.

The ISO activity models can be considered to provide a well elaborated starting point for the definition of a detailed process flow model to be applied in the envisioned SHIPLYS design tools and the surrounding framework.

In addition,

THE SOFTWARE BASED MODELLING APPROACH CAN BE USED TO CREATE A MACHINE-READABLE REPRESENTATION WHICH IS AN IMPORTANT FEATURE FOR USE IN SHIPLYS. SINCE THE PUBLISHING DATE OF THE RELEVANT PARTS OF ISO 10303 SOME MODIFICATIONS HAVE SURELY BECOME NECESSARY, NOT LEAST DUE TO THE WIDER AVAILABILITY OF NEW OR IMPROVED COMPUTATIONAL METHODS.

## 5.2 Data Models

### 5.2.1 Product Model Data

Product Model data is the combination of 3D geometry with non-graphic properties to define ship objects such as a piece of equipment, a deck, a bulkhead, etc.

Product Model data can be organized to define interim products and ultimately the entire ship.

- Part & System Definition (e.g. Caterpillar 3512, Starboard Main Engine, Propulsion System)
- Design Definition (e.g. 12 cylinder 4 stroke diesel engine)
- Physical (Geometry, material connections, etc.)
- Engineering Definition (e.g. 1175 HP, 6464kg, 170mm bore, 190mm stroke)
- Process Definition (e.g. Starting instructions, shaft alignment)
- Logistics Support

### 5.2.2 ISO 10303

As already introduced in section 5.1.1, STEP is an international standard (ISO 10303) for exchanging data between different CAD/CAM and product data management (PDM) systems. It is a proven way to ensure fast, reliable data exchange between partners and suppliers using different systems.

STEP supports engineering, manufacturing, electrical/electronics, architecture, and construction life cycle information (e.g., design, engineering, manufacturing, and maintenance).

Industry sectors using STEP in production or in pilot tests around the world include aerospace, automotive, shipbuilding, electronics, architecture, and the process industries.

The primary purpose of ISO 10303 Application Protocol documents mentioned in section 4.1 is the definition of a domain specific application oriented data model. The scope covered by these models is quite broad and therefore it can be expected that substantial portions of these definitions are applicable within the early design and life-cycle oriented perspective used in SHIPLYS.

To formally describe the data models established in ISO 10303 parts, the data modelling language EXPRESS is used, which is also defined in ISO 10303, part 11 [44]. There exists also a method to represent data models written in EXPRESS in a graphical form, called EXPRESS-G [44], Annex D.

The data model definitions from all applicable APs pertaining to the ship life-cycle domain are well documented. They have been used in various projects for establishing subsets of data models tailored to specific used cases [81].

### 5.2.3 ISO 13584

The scope of ISO 13584 series (often referred to by the acronym P-LIB) is the standardization of catalogues or part libraries for general use in digital applications. ISO 13584 developments evolved along with the ISO 10303 activities. There is a conceptual similarity such as the use of related methods to define models (using the EXPRESS language) and in the structure the standard itself.

One important aim of P-LIB series of standards is to provide all data model and exchange definitions needed to share part libraries information among business entities for use in specification, design (e.g. CAD systems), visualization, purchasing and documentation.

A key element of the approach is the use of a dictionary to capture the meta-data information describing the structure and content capabilities of a library of parts. The combination of the dictionary and the (optional) actual part description content is defined as a catalogue. This is a concept used in many database technologies and repository systems. However, in most common database environments, this is not accessible at the user level. The advantage of this approach is that the actual data structures for describing parts are no longer static. It does not require software modification to extend or modify the data structures.

P-LIB defines a complete and complex set of meta-data description elements in order to capture all possible scenarios distributed from supplier catalogues to visualization or simulation of components in a CAD environment. The important aspects of this approach are clear separation of meta-data information and actual content as well as the definition of the library implementation architecture. The problematic issues are mainly focused on the complexity of the data definitions due to the broad scope and the lack of matching in terms of conformance classes.

### 5.2.4 Potential Usage in SHIPLYS

THE APPROACH FOR SHIPLYS SHOULD BE TO THOROUGHLY EVALUATE AND EXPLOIT THE ISO 10303 MODELS TO HELP ESTABLISH A SHIPLYS DATA MODEL WITHOUT THE NEED TO REDESIGN OR CREATE FROM SCRATCH SUBSTANTIAL PARTS OF THE DATA STRUCTURES REQUIRED CAPTURING EARLY DESIGN INPUT AND OUTPUT AS WELL AS LIFE CYCLE DATA.

Doing so provides two major advantages:

(1) no time and effort is consumed to “reinvent” data structures pertaining to engineering data for ships which has already been done as part of the ISO developments and
(2) The SHIPLYS data model will share a common set of definitions for those entities that are covered by the ISO standard which will result in compliance with several conformance classes defined in those standards.

Since SHIPLYS design scope will require handling of equipment and material catalogues it is expected that P-LIB concepts will be useful in the definition of the data model.

Nevertheless, it will be necessary to extend and enhance the SHIPLYS data model beyond the ISO models.

#### 5.2.4.1 Data coverage

- **ISO 10303 parts 215, 216, 218** provide application data definitions which are directly applicable to the early design application scope of SHIPLYS covering general ship design and hull structure aspects. Therefore, these standards can be viewed as a repository to be exploited to establish a SHIPLYS data model. This has been successfully done in other projects, such as OpenHCM [81] or in commercially available products such as Topgallant Information Server [7].

It must be noted, though, that for purposes of SHIPLYS only a subset of these models will be needed, as the level of detail in some areas will go well beyond the requirements of SHIPLYS developments.

- **ISO 10303-226** WD Ship Mechanical Systems was a proposed Application Protocol part that was carried out from the mid-1990s to 2002 [8][107]. The focus has been on the standardised definition of ship equipment primarily from a mechanical engineering perspective. The project did not advance to the DIS or IS stages for mainly two reasons: (1) substantial overlap of scope with AP227 (Plant spatial configuration, see below) with respect to design model aspects and (2) complexity issues capturing the expected data requirements for the almost infinite potential collection of ship-board equipment types in view of the general modelling approach taken. In this draft project, mechanical systems are defined by adding a classification and property definition layer on top of generic product definition entities available in ISO 10303. This is comparable to the dictionary meta-data approach of P-LIB but effectively creates a static dictionary definition. The main outcomes of this project are detailed snapshot compilation of on-board equipment type classes and related property that found to be relevant at the time of project execution. This is in any case a good starting point for the definition of an equipment catalogue dictionary suitable for on-board equipment.

- I**SO 10303-227 IS Plant Spatial Configuration** is an ISO standard [50] has substituted several projects (i.e. ISO 10303-217 WD [47] and ISO 10303-226 WD [49]) relevant to ship design and ship life cycle applications. While the initial scope was on plant design and maintenance models, the involvement and increased focus on plants such as those installed on offshore platforms has led to an extended effort to include aspects of on-board equipment as well. Consequently, the current standard has a strong focus on general plant modelling, but it is flexible enough to be applied to shipboard systems.

  The standard assumes that supplied components are defined using ISO 13584 (P-LIB) catalogues with explicit references to such catalogues. Additionally, it offers the possibility to define individually dimensioned/configured components through the use of explicit combined and generically configurable types and properties. Therefore, this standard can provide additional input to the collection of component classes and properties in an on-demand mode of operation which may be useful for handling and introducing innovative components at the early design stage.

### 5.2.4.2 Additional Data Model Requirements

WHILE THE STANDARDS ISO 10303 AND ISO 15384 DOUBTLESSLY PROVIDE A BROAD FOUNDATION FOR CREATING A FULL-BLOWN DATA MODEL FOR SHIPLYS THEY NEVERTHELESS DO NOT COVER ALL ASPECTS RELEVANT TO THE PROJECT. The following areas will require further data model development:

- Production data
- Shipyard facilities (a lightweight shipyard production asset model)
- Processes and Resource definitions
- Analytical Data and Computation Supervision
- Operational Data (Life Cycle)

## 5.3 Information models

### 5.3.1 Building Information Modelling (BIM)

The Building Information Modelling (BIM) concept is particularly applicable to the construction sector. Data models (such as discussed in the previous section) present mechanisms enabling approaches such as BIM in the management, sharing and exchanging of information between various stakeholders.

#### 5.3.1.1 Introduction

BIM is a collaborative way of working, underpinned by the digital technologies which unlock more efficient methods of designing, creating and maintaining our assets. BIM embeds key product and asset data and a three-dimensional computer model that can be used for effective management of information throughout a project lifecycle – from earliest concept through to operation. BIM is increasingly considered essential in the architecture, engineering and construction (AEC) and the real-estate industries to manage, share and exchange information among project stakeholders (Eastman, 1999). BIM is not only an advanced design tool, but also an efficient management tool. In the recent years, there has been rapid expansion of BIM adoption in the AEC industry ([59]; [117]).

BIM is a multiple dimensional model, which is based on the conventional 3D visual model and applies additional dimensions, such as technical performance, cost, schedule and coordination. There are different levels of development in BIM, which can be potentially applied in every stage through the ship lifecycle.

#### 5.3.1.2 The transferability of BEPs (BIM-enabled practice) to shipbuilding industry

Four BEPs were identified as most important in the research by [60]. It was found that the identified BEPs, described below, are already enabled by 3D CAD in shipbuilding industry to a larger or smaller extent.

- **Clash detection**

A ‘clash’ occurs when there is a mis-match between different models that can preclude their integration as required in a construction/ fabrication project. Clash detection is deemed as a key benefit by both AEC (Architecture, Engineering and Construction) sector that use BIM and the shipbuilding industry that use a variety of 3D CAD models.

A clash can be physical or have a time element to it as described below:

1) Hard clash that occurs when structural components are planned to use the same space, thereby creating a conflict;

2) Soft clash or Clearance clash that occurs spaces required for fitting, inspection or maintenance are inadequate or when the clearances between structural components that need to fit together are incompatible, and

3) 4D workflow clash resulting from mis-match in the scheduling of delivery, fabrication and other logistical tasks.

The first two clashes are physical in nature and are called often called ‘collisions’ to differentiate from the third clash that has involves time (scheduling).

Collision detection is one of the key benefits desired by AEC and shipbuilding industry to find out possible collisions between different models and thus to ensure that the integration of these models is carried out successfully.

Although there are three types of clashes (hard clash, soft clash and workflow clash, as mentioned above) that BIM software can typically detect only hard clash. it is believed that 3D CAD can carry out more comprehensive collision detection than BIM. This is mainly due to the fact that collision detection in shipbuilding industry is more complicated as pointed out by Luming Ran and Vishal Singh (2016) in their paper.

- **Visualization**

Visualization is another functionality present in both BIM and 3D CAD approaches enabling an advance from 2D drawings. However, it seems that that shipbuilding sector has more experience of using object-oreinted 3D models than AEC industry.

- **Quantity take-off**

BIM software enables measuring quantities automatically, and quantity information can be automatically generated and reused. Likewise, in the shipbuilding sector, a bill of materials can be obtained from 3D model. If a cost database is also available and liked to the 3D model, accurate cost estimates can be obtained. However, at the bidding stage, as no detailed 3D model is available, the cost estimates are usually based on experience and historical data that the shipyard may have of their own.

- **Scheduling**

'4D BIM' integrates design with scheduling of delivery, fabrication and other logistical tasks processes that are required to build according to the design. nDBIM as applied in the AEC industry can have other dimensions: 4D (scheduling); 5D (estimating/ forecasting); 6D (life cycle modelling) and so on. However, in 3D CAD as used in shipping projects, the purpose is mainly to support the design activity. There have been recent advances, though - software packages like AVEVA, FORAN and SHIPCONSTRUCTOR already implement production planning to a certain extent.

#### 5.3.1.3 Potential Usage in SHIPLYS

BIM can provide a complete solution in shipbuilding industry particularly by including Quantity take-off and Scheduling functionality that are currently not integrated with 3D tools in a majority of cases. An ideal software that has provision to appropriately process both early and detailed design may include Collision detection, Visualisation, Quantity take-off and Scheduling. However, the limitations of the current 3D tools will need to be overcome, particularly, the lack of interoperability among different CAD systems, the lack of proper 3D CAD tools for interior design, and the lack of 3D CAD usage in the initial design phases (from [60]).

The third limitation is particularly applicable to SHIPLYS: SHIPLYS is aimed at early design stage and the type of detailed information required for detailed 3D models is not available due to time and cost constraints.

However, taking cognisance of the benefits of BIM-enabled practices, THE ASPIRATION WITHIN SHIPLYS IS TO DEVELOP EARLY- DESIGN-STAGE SOFTWARE THAT IS INTEROPERABLE BETWEEN NOT ONLY DIFFERENT 3D AND OTHER SYSTEMS, BUT ALSO BETWEEN SYSTEMS THAT ARE USED DURING THE DETAILED DESIGN AND OTHER LIFE STAGES OF THE SHIP ASSET.

### 5.3.2 PLM (Product lifecycle management)

Ships are complex products operating within an old and traditional industry. The shipping value chain (VC) is complex and engineering standards with direct application to shipbuilding are mainly deterministic. Key items that impact ship production in terms of LCA can be summarized as follows:

- Ships are self-contained structures operating in an unpredictable environment.
- Management of ship safety and performance should be considered from specification stage.
- Errors at concept design may lead to inefficient, costly and unsafe design.
- Management of big data associated with concept design, resources (working hrs. & personnel) is critical in terms of engineering decision making and ultimately cost control.
- Ship design decisions are based on key performance indicator (KPI) trade-offs. They may relate with: (1) structural strength vs building cost vs cargo capacity, (2) vessel speed vs fuel consumption, (3) seakeeping vs seafaring. The cost and complexity of these decision-making

processes make Virtual prototyping (VP) a very handy tool to simulate designs in a controlled environment.

Currently there is lack of unification among VP tools and the industry is reluctant to adapt to new technology. For example, a 3D model used in concept design will usually not be used for structural analysis. 2D CAD drawings, document editors, spreadsheets and presentations tools are indeed the only tools widely used. In terms of databases the most common tool is the mapped drive, without modern assembly / tag / filtering options. On this basis, the development of LCA tools with focus on concept design is meaningful in terms of technical and business priorities.

#### 5.3.2.1 PLM in Ship Design and operations

PLM is a software model activity with many attributes that are common to BIM described in the previous section. It comprises of modularisation tools with focus on product and systems architecture, libraries, Product Data Management (PDM) and Enterprise Content Management (ECM) systems (see Figure 9).

| | |
|---|---|
| ❑ Modularisation tools<br>❑ Product Architecture<br>❑ Systems Architecture | ❑ Product data management<br>❑ Systems<br>❑ 2D – 3D analysis |
| ❑ Product Library<br>❑ Systems Library | ❑ Enterprise Content Management<br>❑ Bill of Information<br>❑ Lifecycle documentation |

**Figure 9: The PLM system**

PLM involves not only control over production, but also over operation. For example, scheduled maintenance of vessels implies that the hull should be cleaned and components repaired. If the charterer manages this process properly, he can reduce the time spent on non-profitable activities and reduce system risk failure.

PLM comprises of 6 elements namely:

1. A Database with indexation tools and document management.
2. Modelling and Simulation tools (VP tools) composed by the software products used to design the vessel.
3. Value Chain Processes that relate to the management of the processes and offer the commercial realization of the end product value.
4. A Product Hierarchy management system classifying ship systems and components for manufacturing.
5. A Product Management system that administrates all the information related to every component idealized by 2D or preferably 3D models.
6. A Project Management system that connects every process to the entire vessel life-cycle via workflows.

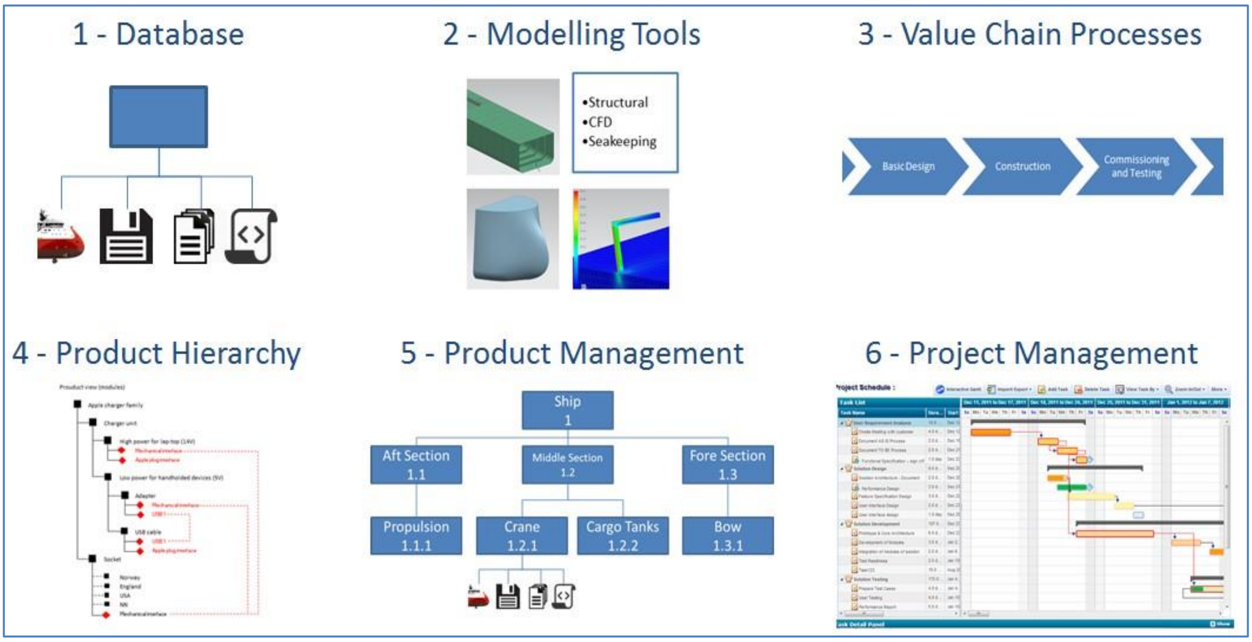



**Figure 10:The PLM Elements (CIMdata Inc., 2011)**

#### 5.3.2.2 Virtual Prototyping (VP)

VP is a design tool used during product development. It consists of using virtual digital models instead of real physical prototypes to: (1) generate, (2) analyse and (3) verify the product feasibility according to different requirements and standards (e.g. ISO 10303). By using this approach, faults in the modelling and design process can be detected before investment. The approach is advantageous because:

- Reduces the need of physical modules at concept design,
- Helps to manage costs involved in detailed design (or repairs),
- Considers the priorities of diverse VC stakeholders under the umbrella of a scenario.

VP methods are classified in terms of: (1) visualization, (2) fit and interference of mechanical assemblies, (3) testing and verification of functions and performance, (4) evaluation of manufacturing and assembly operations and (5) human factor analysis. For example, visualization can be used in concept design to support sales arguments along the lines of the specification. At detailed design phase it can be used as accurate visualisation of the final vessel. Fit and interference of mechanical assemblies relates to the outfitting verification. Engineering system components (engines, rudders and thrusters) are also part of VP. Testing and verification of functions and performance can be done using computer aided engineering (CAE) tools (e.g. CFD software for hydrodynamics and FEM software for structural analyses). It is also possible to simulate shipbuilding production processes (e.g. block fabrication and assembly) and human factor systems / functions (e.g. ship bridge, engine room) to measure crew performance and risk or carry out operational training ([42]).

#### 5.3.2.3 PLM and the ship Value Chain (VC)

VC is a concept that links with LCA from raw materials to the final product and then scrapping, through a series of processes that may help to add or retain the value of the product. At concept ship design stage the VC objective is to help with focused to the best value products for the least cost. Below we explain how PLM links up with different part of the maritime VC.

- **Concept Ship Design:** VP can be used to help visualize results from basic calculations (e.g. resistance, seakeeping, strength) using Computer Aided Design (CAD) software as modelling tools.
- **Basic Ship Design:** During this phase the characteristics of the vessel (e.g. mid ship section scantlings, engine power etc.) are estimated. Depending on the level of design novelty approval by a Class Society is necessary with the view to prepare competitive technical specifications. The use of modelling tools is more extensive. It is very common to use CAD tools to refine the hull and

structures, perform analyses about the vessel behaviour using CAE tools (such CFD and FEM), and CAD systems for planning electric systems, hydraulic arrangements, human factors.

- **Construction and Assembly:** Processes applied during this phase are planning, construction, final assembly and outfitting. To ensure good usage of the shipyard time and avoid errors, VP is used to verify the fit and interference of mechanical parts, outfitting, plan the construction steps and the assembly process. The VP methods used are, mainly, visualization for fit and interference of mechanical assemblies as well as the evaluation of manufacturing and assembly operations.
- **Commissioning and Testing** aims to verify if the vessel is able to perform as designed. This is done by a series of testing/trial procedures to verify all project components (e.g. instruments and equipment, construction specifications and quality, modules and vessel systems). Critical performance factors such as vibration, comfort and general behaviour are also supervised by Classification Societies. VP can be used in order to visualize the vessel model and confirm performance. There are no mandatory modelling tools usually applied to this phase.
- **Operation** is the longest phase of the life-cycle and developing an appropriate maintenance strategy plays an important role, in order to ensure that the vessel will perform well. A key VP process is the so called ''Hardware in the loop- HIL'' testing. This process uses real values from vessel operations to calibrate system performance. For example, real values may be used to feed control systems and evaluate if they generate the desired responses. Similar procedures may be used for cargo planning and operation tools, spreadsheets software (stability, logistics) etc.
- **Decommissioning**: Once the vessel reaches its service time (usually, between 15 - 25 years) the ship can be refit and re-commissioned, sold or scrapped. This phase is a responsibility of the ship owner, who should guarantee that the process is in accordance to the actual regulation. VP can be used as a tool to plan the scrapping process with the view to make the operation safe and cost efficient. Methods used are, mainly, visualization, evaluation of manufacturing and assembly operations, human factors.

**Table 1. LCA across the value chain**

| LCA | Database Composition | Product Hierarchy | Product Management | Project Management |
|---|---|---|---|---|
| **Concept design** | Similar vessels used to establish engineering decisions | Vessel groups & main component requirements | Initial system breakdown | Past knowledge |
| **Basic design** | Composed by 2D and 3D Models, vessel equipment drawings, simulations, tank test results, analysis, specifications, classification Rules, etc. | Complex and well defined | Complete system breakdown flowcharts / plans | Output from different shipyard departments & outsourced outfitting offices |
| **Construction & Assembly** | • Components for construction, technical design, documentation & drawings<br>• Bill of information with the cost/hours of every part/task | Final product breakdown, with all components acquired | Construction components to the ship system breakdown | Follows strict shipyard routine, with designer, owner and classification societies acting usually as external agents |

| LCA | Database Composition | Product Hierarchy | Product Management | Project Management |
|---|---|---|---|---|
| **Commissioning & testing** | • Sea trials results<br>• Detailed ship manuals | | Final vessel description ready for delivery including data of all subsystems and parts. | Reassesses the compliance of the final product against concept design requirements as set in the specification |
| **Operation** | • Vessel log with various operational schedules (e.g. performance records, periodic local and dry dock maintenance schedules, crew inspections etc.)<br>• List of components and spares | | Detailed information records on maintenance of components | • Maintenance and operation schedules<br>• Retrofit actions when new equipment is installed on board |
| **Decommissioning** | • Structural plans, components and inventory of materials acquired throughout the life cycle of the vessel.<br>• Decommissioning plan, components breakdown, recycling, scrap sale etc. | • Vessel components for decommissioning<br>• information on toxic and dangerous substances | All detailed ship documentation | Decommissioning schedule |

### 5.3.2.4 The scope for an integrated ship design platform

Today PLM concepts are informally used by different companies although they are not practically integrated in terms of LCA.

A successful ship sale completes on the basis that an owner is persuaded to invest in that ship. In pursuance of a contract a shipyard department works on the concept, on an exclusive 3D model, while designers in other departments recreate the same model until the final basic documentation completes.

Following the basic ship design process the ship yard collects all drawings and the owners operate the asset along the lines of a scheduled maintenance scheme. It is not rare for the shipyard to re-produce many of the drawings to adjust the outfitting.

Within the context of PLM, VP can help to carry out LCA provided that market projections are accurate and a database of similar vessels, with similar operational profiles and financing options, exists. There are two main perspectives in this process namely:

(1) the techno-economic leading to incremental product improvements in terms of technical, operational and commercial aspects and
(2) the innovative that makes use of technologies leading to smart, safe, efficient and environmentally friendly operations. Special consideration of human factors is considered an advantage although its practical application is limited ([58])

Product data are stored for reference throughout the VC in a unified database applicable across different design phases. Modern PLM tools allow multi-user/department access with security levels, versioning and share across different offices worldwide. Data relate to different information sources, such as the owner specification, engineering analyses, 2D drawings and 3D models. The database is updated at each stage of the project development. During design, data is usually connected to a physical part of the ship, and a well-established Product Hierarchy may add the data search process, focusing on a visual language instead of just words.

The **project workflow** is, basically, an organizational method (e.g. Gantt chart), where all the project phases are laid down in a timeline, being possible to see when each process is supposed to begin, end and when some processes overlap with each other. This is essential for scheduling. A PLM software must connect such processes with the deliverables (documents, parts, construction items), in the same database by using a Gantt chart. A good design procedure should store this data and use them to perfect the mathematical models of the basic and concept design phases.

During **basic design** the use of VP is extensive. The use of CAE software, such as CFD and FEM tools, is well spread. Modern PLM tools ([106]) allow for the re-use of 3D models to automatically create 2D drawings. At **detailed design** VP prevails for 90 % of the tasks. Drawings, specification, components, parts and processes are defined and all data are stored. During **construction,** the vessel is divided in grand blocks. Their sizes depend on yard capacity and an ideal PLM system would be able to incorporate documentation for a similar ship constructed in different yards. The integrated database provides the material and components list, the construction workflow and construction drawings.

The **construction workflow** can be defined using VP tools, like CAD software. During commissioning and testing phases the quality of the design and construction are rated.

Accordingly, information from trials is used to verify the design to client's satisfaction and VP can be used in the operational verification process.

The **operation phase** is also part of modern PLM systems. For example, it could be connected to an operational log demonstrating the rate at which the equipment is deteriorating and the vessel requires maintenance. The information gathered should not be dismissed, since it can feed future conceptual designs. This phase is also crucial for training simulators and the calibration of control systems. The characteristics of the vessel in a real operational environment should be used to feed, test and calibrate VP tools and systems. For example, an ideal PLM system would be able to connect to on-board information, such as the ship's response to different sea states, operational profile and cargo, while measuring fuel consumption and capacity to perform the offloading procedure at the platform.

**Decommissioning** links with the end of the life-cycle. It can be planned in advance through the use of information of previous designs. It is highly dependable of the market circumstances and is difficult to predict with high accuracy. However, it can be improved by an active database. For instance, during scrapping, the database would provide information about the structure, materials and toxic components that require special care. Such information would be useful if the owner desires to sell the vessel or in case of refitting and re-commissioning. Notwithstanding the later would require the inclusion of new equipment, maintenance procedures and their updates.

#### 5.3.2.5 Conclusions

A WELL-DEFINED INTEGRATED DESIGN PLATFORM ALONG THE LINES OF PLM CAN HELP DESIGNERS AND ASSET OWNERS TO GET THE MOST FROM PRODUCT VALUE CHAIN. AN INTEGRATED PLM PLATFORM IS THE ONE WHICH RE-USES AND BUILDS UP FORMER DESIGNS, WITH A SAME LANGUAGE AMONG THE SIX PLM ELEMENTS. A VIRTUAL ENVIRONMENT ALLOWS THE DESIGNER TO REALLY USE DATABASES, BUILDING UP NEW CONCEPTS BASED ON PREVIOUS INFORMATION, AS WELL AS RE-USING ADVANCED 3D MODELS ACROSS THE VALUE CHAIN.

# 6 Approaches for assessing sustainability criteria and reference projects

## 6.1 Approaches for Life Cycle Cost Assessment LCCA

### 6.1.1 MAINLINE LCAT Tool

MAINLINE was a three-year project that started from 1st October 2011 with a total Budget of €4.5 million under the auspices of the European Commission's 7th Framework Programme (FP7). [61]

The inspiration behind MAINLINE was that growth in demand for rail transportation across Europe was (and is still) predicted to continue. Much of this growth will have to be accommodated on existing lines that contain old infrastructure. This demand will increase both the rate of deterioration of these elderly assets and the need for shorter line closures for maintenance or renewal interventions. However, interventions on elderly infrastructure will also need to take account of the need for lower economic and environmental impacts. This means that new interventions will need to be developed. In addition, tools will need to be developed to inform decision makers about the economic and environmental consequences of different intervention options being considered.

The objective of MAINLINE was to develop methods and tools contributing to an improved railway system by taking into consideration the whole life of specific infrastructure – tunnels, bridges, track, switches, earthworks and retaining walls. This was achieved by:

- Applying new technologies to extend the life of elderly infrastructure
- Improving degradation and structural models to develop more realistic life cycle cost and safety models
- Investigating new construction methods for the replacement of obsolete infrastructure
- Investigating monitoring techniques to complement or replace existing examination techniques
- Developing management tools to assess whole life environmental and economic impact.

Although MAINLINE focused on certain asset types, the management tools developed is applicable across a broader asset base. An overview of the MAINLINE project process is depicted in Figure 11.

The 19 partners in the MAINLINE Consortium brought in a mix of competencies and experiences to the consortium. The consortium included leading railways, contractors, consultants and researchers from across Europe, including from both Eastern Europe and the emerging economies. Partners also brought in experience from other industry sectors. The partners were:

- The International Union of Railways (UIC), France;
- Network Rail Infrastructure Limited, United Kingdom;
- Deutsche Bahn, Germany;
- MÁV Magyar Államvasutak, Hungary;
- TCDD, Turkey;
- TRAFIKVERKET, Sweden
- COWI, Denmark;
- TWI, United Kingdom;
- COMSA, Spain;
- SKANSKA, Czech Republic;
- Sinclair Knight Merz (SKM), United Kingdom
- University of Surrey, United Kingdom;
- University of Minho, Portugal;
- University of Luleå, Sweden;
- Polytechnic University of Catalonia, Spain;

- Graz University of Technology, Austria
- ARTTIC, France;
- DAMILL, Sweden
- SETRA, France.

Further information about MAINLINE can be found from the project official website: http://www.mainline-project.eu/

#### 6.1.1.1 Relevance of MAINLINE to SHIPLYS

A key objective of SHIPLYS is the development of SHIPLYS Life Cycle Tools (SHIPLYS LCT), which is the suite of tools providing the evaluation of life cycle cost (LCC), environmental impact (EI) and risk assessment (RA), together with the multi-criteria decision support functionalities to integrate such evaluations. SHIPLYS LCT is aimed at supporting the SME naval architects, ship builders and ship-owners to make appropriate decision that reduce the time and cost while improving the production at the ship's conceptual design stage.

SHIPLYS LCT will incorporate several rational decision support approaches that consider not only economic, but also environmental and risk factors. This concept is similar to one of the MAINLINE project main outputs – a lifecycle tool named "MAINLINE LCAT (Life Cycle Assessment Tool)".

The MAINLINE LCAT evaluates whole life environmental and economic impact for maintenance and renewal activities of three specific rail assets – bridges, track and earthworks. The models aimed at reducing whole life cycle costs thanks to better planning and maintenance, [61] such as:

- The LCAT for Bridges was designed to combine condition and capacity, together with environmental and economic impacts.
- The LCAT for Cuttings uses a risk-based analysis.
- The LCAT for Track is based on boundary conditions. As the depreciation of investment causes the biggest portion of life cycle costs, the tool is focused on predicting the possible technical service life in a simple way.

The lifecycle approaches employed for the development of MAINLINE LCAT will provide an informative reference which SHIPLYS LCT can benefit from.

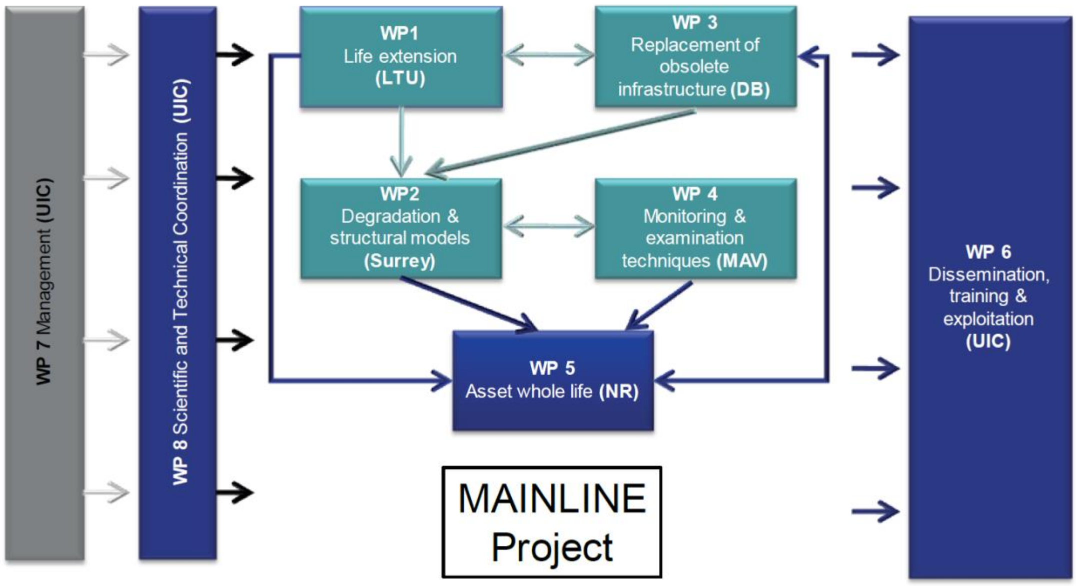



**Figure 11: Overview of the MAINLINE project**

### 6.1.2 MOSAIC Project

The MOSAIC project (involving NTUA, IST, AS2CON, TWI and others) developed a vessel design and construction approach involving new lightweight materials and steel advancements, demonstrating their impact on operating and maintenance costs, reliability and energy efficiency of maritime assets.

MOSAIC project is the abbreviation for “Materials On-board: Steel Advancements and Integrated Composites”, which is a research project funded under theme SST 2012.5.2-3 Innovative structural and outfitting materials for ships including inland ship priority within the 7th Framework Programme for Research and Development of [grant number 314037]. The project was launched on September 2012 and closed three years later, in August 2015. [73] The MOSAIC consortium included:

- CETENA S.p.A. Centro per gli Studi di Tecnica Navale (CET),
- National Technical University of Athens (NTUA)
- The University of Birmingham (UoB)
- Instituto Superior Técnico (IST)
- TWI Ltd (TWI)
- FINCANTIERI – Cantieri Navali Italiani S.p.A. (FC)
- ALVEUS l.l.c. (AS2CON)
- LLOYD’S REGISTER EMEA (LR)
- Asociacion de Investigacion Metalurgica del Noroeste (AIMEN)
- Estaleiros Navais de Peniche, S. A. (ENP)
- Danaos Shipping Company Ltd (DAN)

MOSAIC was proposed to address one of the most challenging topics of research in the marine field in the few last years – making lighter ships. Weight is a key factor that affects the fuel consumption and the payload capacity of the ship. The aim of the MOSAIC project was to investigate the implementation of advanced materials in the ship structure and their life cycle implications. This was with a view to reducing operational costs and improving life cycle performance by using stronger, thinner and lighter components. Three objectives were identified as foremost priorities for the evaluation:

- Minimisation of life cycle costs,
- Minimisation of health and safety risk,
- Minimisation of environmental impacts.

In MOSAIC, this goal was pursued through two technologies: the use of a special category of high performance steel called HSLA (High Strength Low Alloy) steel and the replacement of steel components with components in composite material. By understanding if and by how much the new materials can contribute to achieving the MOSAIC objectives, the potential for implementing the solutions proposed could be determined.

The approach for assessing the different material options holistically comprised the following tasks:

1. Identification of stakeholders and relevant criteria and performance measures.
2. Identification of suitable approach and execution of life cycle costing, risks and environmental impact assessment.
3. Integration of individual aspects in an appropriate way that provides clear and useful decision support about further investigation and future implementation.

More details about the project can be found from the project official website:

http://www.mosaicships.com/index.php

#### 6.1.2.1 Relevance of MOSAIC to SHIPLYS

As one of the tasks in SHIPLYS WP5, a multi-criteria decision analysis (MCDA) support tool to support identification of optimal solutions will be developed. The multi-criteria decision support tool will enable optimal trade-offs to be carried out by considering LCCA (Life Cycle Cost Analysis), environmental assessment and risk based criteria. The approach will enable what-if scenarios to be carried out to assess impact on user defined factors. This functionality is important for the key stakeholder – the SME shipyard – to assess the impact of decisions on other stakeholders such as classification bodies and ship owners.

SHIPLYS CAN BUILD ON THE WORK DONE ON THE MCDA FRAMEWORK DEVELOPED FOR MOSAIC TO DETERMINE OPTIMAL TRADE-OFFS TO BE CARRIED OUT BY CONSIDERING LCCA (LIFE CYCLE COST ANALYSIS), ENVIRONMENTAL ASSESSMENT AND RISK BASED CRITERIA [74].

FIGURE 12 shows comparisions carried out within an MCDA framework developed in MOSAIC project

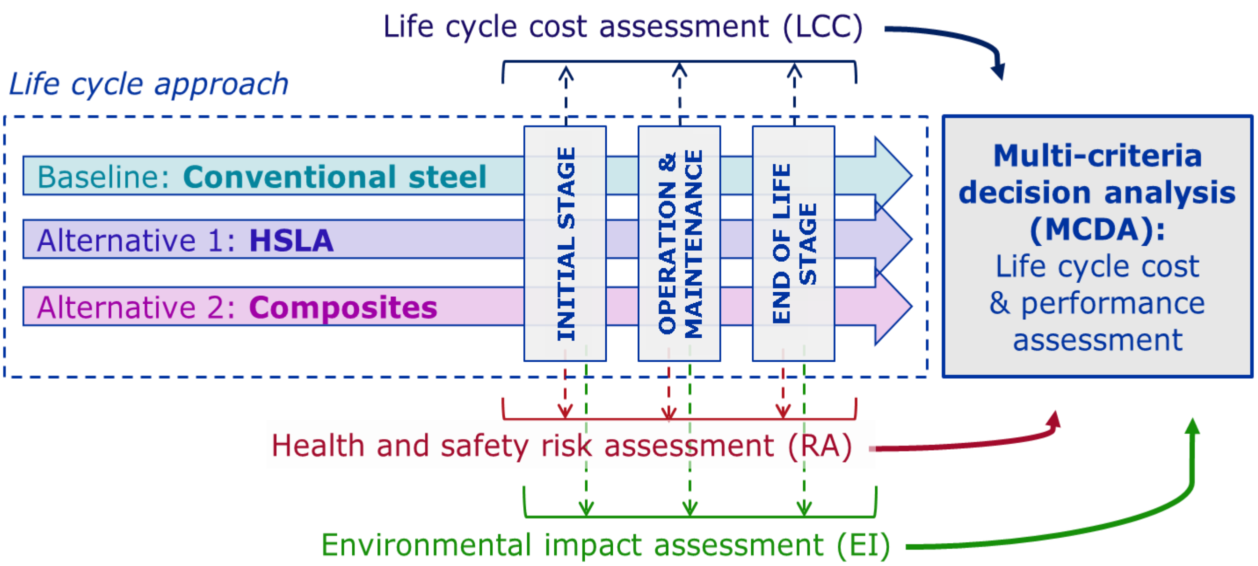



**Figure 12: The MCDA framework to compare the use of HSLA and composites through the lifecycle perspective. Diagram adapted from: [55]**

IT IS ENVISAGED THAT FOR EACH SHIPLYS SCENARIO, THE INITIAL STEPS USED IN THE DEVELOPMENT OF THE MCDA FRAMEWORK IN MOSIAC, STATED BELOW, ARE RELEVANT:

1) DEFINING DECISION CONTEXT AND APPROACH
2) DATA COLLECTION AND EVALUATION
3) LIFE CYCLE PERFORMANCE ASSESSMENT, IN SHIPLYS THIS INCLUDES EVALUATION OF LCCA, EI AND RA.
4) SENSITIVITY ANALYSIS AND UNCERTAINTY TREATMENT
5) DEVELOPMENT OF MCDA.

## 6.2 Life cycle assessment

### 6.2.1 Eco_REFITEC project

The ECO-REFITEC project (FP7 project; 20011-14) involving several partners of SHIPLYS included the development of a database of eco-innovative processes, materials and specific modules to be used in the repair and modernisation of existing ships in small and medium-size shipyards.

SHIPLYS will further develop and merge the shipyard processing simulation software and life cycle tools developed in ECO-REFITEC towards an LCCA package that is integrated within the SHIPLYS framework.

The ECO-REFITEC project helped repair shipyards and ship operator to perform a refitting of existing fleet, through of technological development and new tools, helping shipping benchmark their performance, improving the retrofit processes and products, and assessing environmental and life cycle cost impact. For ECO-REFITEC project it is mainly emphasising the operation phase where eco-innovative processes, materials and modules can be applied, retrofitted and analysed so the methodology can be extended and used for other three sections. The flows and boundary of operation phase in ECO-REFITEC project is presented in Figure 13. This phase was divided into three categories for modelling (Figure 14).

The LCA methodology used in ECO-REFITEC project are referred to ISO standard 14040 (2006) and 14044 (2006). The details of the methodology will be presented in Section 5.2.5. Life cycle modelling.

To carry out a LCA study in ECO-REFITEC, the goal and scope of the study was considered and determined first in order to define product/process and purpose of the analysis and also the targets of the product/process. The analysis is to evaluate the environment impact of different innovative processes to help shipyards or other institutes to make decisions. Then with definition of goal and scope, the system flows and boundaries can be determined to help construct the database. For one case study from ECO-REFITEC as an example, it investigated the environmental impact of three types of ballast water treatment systems (BWT Systems) and the energy flows involved in this process were determined. The boundaries of the processes were also indicated so the database categories can be identified. The analysis method used in ECO-REFITEC project was CML, 2010. This method is open to use and also is available in the GaBi software. It focuses on the mid-point level of environment impact, such as global warming potential, acidification potential and so on. With CML method, these impacts can be quantified, compared and analysed for selected BWT systems.

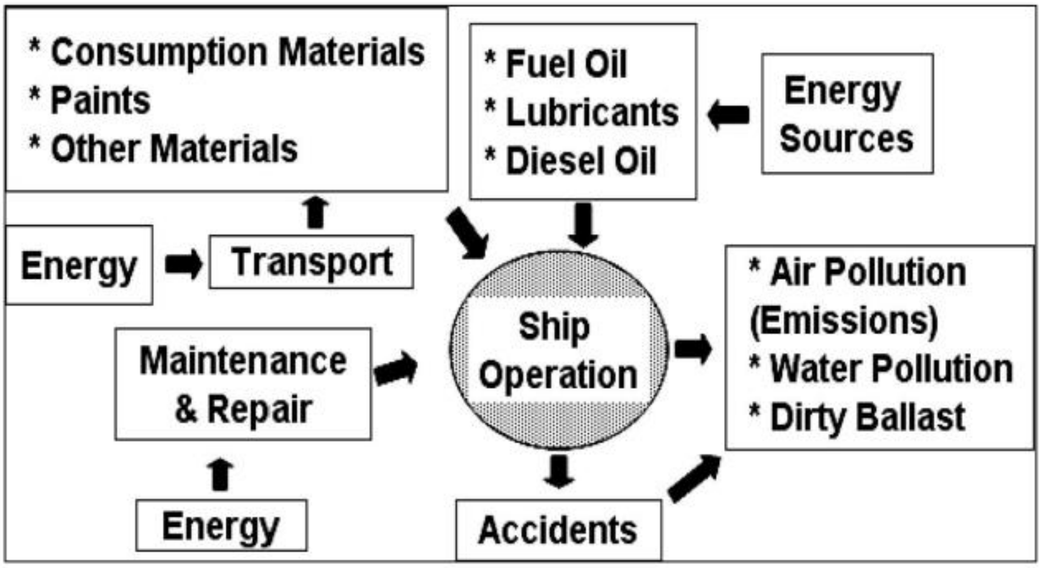



**Figure 13: Ship operation flows and boundary**

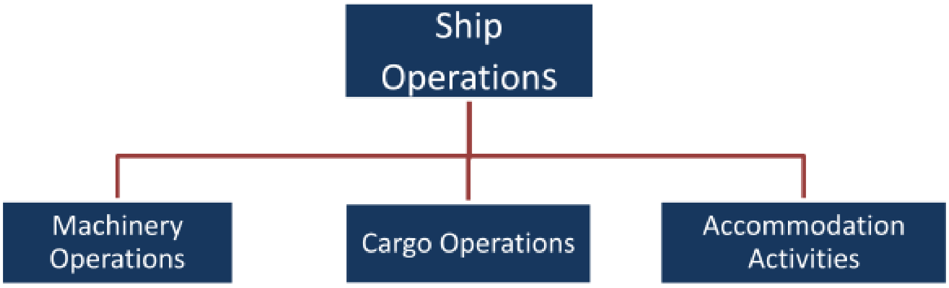



**Figure 14: Major Ship-Operations Category**

The characterisation model (CML 2010) was used to identify the environment impacts of emissions from the ship life cycle. For Global Warming Potential as an example, each type of emission has its own characterisation factor in database. In CML 2010, the GWP of CO2 is set to be 1 kg CO2 eq. which is the baseline for GWP 100. The GWP 100 for methane is 28 kg CO2 eq. With the conversion factors and fuel consumption, the quantities of emissions can be derived. Therefore, the Global Warming Potential can be obtained.

Figure 15 indicates the principle of characterisation method.

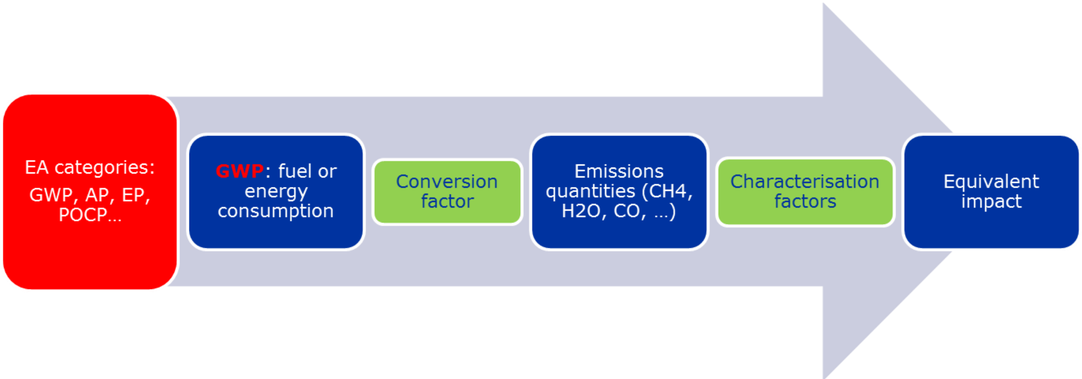



**Figure 15:Flowchart of characterisation method principle**

To investigate the environmental impact during ship's operation, International Maritime Organization (IMO) has presented Energy Efficiency Operational Indicator (EEOI). As the existing EEOI is only forced on the environmental impact associated with carbon dioxide, the ECO-REFITEC project has upgraded this formula based on to cover all types of emissions contributing to global warming. Being combined with CML's characterisation method, the upgraded equation can be presented as below:

$$LCA_{effGWP} = \frac{\sum_i gGWP_i}{\sum_i (m_{cargo,i} \times D_i)}$$

Where,

| | |
|---|---|
| D | Distance (nautical miles) corresponding to the cargo carried or work done; |
| gGWP | LCA $CO_2$ inventory aggregate in grams comprising classification and characterisation of releases analogous to $CO_2$; |
| $LCA_{effGWP}$ | LCA energy efficiency GWP score in g $CO_2$/tonne-nm; |
| $m_{cargo}$ | Cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships; |
| i | Index of summation. |

In addition to the environment assessment method, ECO-REFITEC project also conducted a cost-benefit analysis using the net present value (NPV) method. The net present value formula is presented as following:

$$PV=PV_0+FV\cdot(1-(1+i)^{-n})/i$$

Where:

| | |
|---|---|
| $PV_0$ | CapEx: amount spent initially for the implementation; |
| FV | OpEx: Cost of operative expenses, for any given year; |
| i | Interest rate; |
| n | Lifetime of vessel (years). |

#### 6.2.1.1 Relevance of ECO-REFITEC to SHIPLYS

With the above in mind, SHIPLYS project is to present a new software tool of LCCA by integrating prototyping software, and possibly, CAD and other software packages.

The effectiveness of this software will be verified through investigating a hybrid ferry design and optimising its operational profile. Different propulsion systems for the ferry will be investigated and the emissions for each individual propulsion system installation will be predicted based on a predetermined operational scenario. To the best of our knowledge, no specific study exists which aims to investigate the possible benefits for a hybrid ferry by carrying out life cycle assessment for its all life span.

SHIPLYS project therefore may be useful to understand the operational emissions of the above hybrid power generation system by comparing its emissions to those from other propulsion system configurations installed on the same ferry.

IN ADDITION, DURING OUR LITERATURE REVIEW, IT WAS SEEN THAT ALTHOUGH SIGNIFICANT PREVIOUS RESEARCH HAS CALCULATED THE ENVIRONMENTAL IMPACT OF SHIPS' ACTIVITIES USING SOME EMPIRICAL METHODOLOGIES (FORMULAS), NO SPECIFIC STUDY EXISTS WHICH AIMS TO DIRECTLY ESTIMATE THE GHG EMISSIONS OF THE VESSEL DUE TO ITS OPERATION USING A LIFE CYCLE MODELLING TOOLS.

### 6.2.2 ENVISHIPPING – Total Environmental Footprint from Ships

ENVISHIPPING was a domestic (Greek) research project partially funded by the Greek General Secretariat for Research and Technology of the Hellenic Ministry of Education. This project aimed at bringing together leading domestic companies and institutions (a consortium[1] with interdisciplinary expertise and capabilities of important representatives from the Greek maritime industry under the coordination of the Laboratory for Maritime Transport of the National Technical University of Athens LMT – NTUA) with the aim to explore the total environmental footprint of ships from a life cycle perspective. The overall analysis considered the conditions of the Greek broader sea transportation framework by examining specific ship types and domestic maritime transport scenarios.

[1] Apart from LMT who coordinated the project, the rest of the partners of the Consortium were: POLYECO SA (leading company in integrated ship-waste management services in Greece), Hellenic Sea Ways (HSW, major Greek passenger shipping company), the Research and Innovation branch of Det Norske Veritas (DNV, located in the local office at Piraeus), the Hellenic Marine Environment Protection Association (HELMEPA, a well known environmental NGO), Naftotrade Shipping and Commercial SA (a Greek owned cement carrier company), and the Company for Shipping Development Support and Cooperation (NAFS, a non profit subsidiary of the Hellenic Chamber of Shipping).

The main target of the project was the ship's life cycle assessment through which the identification and categorization of all-important factors contributing to the total environmental footprint of a ship could take place. The examined ship life cycle stages were: the shipbuilding (i.e. the construction of the ship), ship operation including major maintenance activities and environment related aspects of the interface between ship and port, and finally the stage of ship dismantling/recycling.

According the methodology, an integrated framework for the analysis of the total environmental footprint of ships was created. The framework considered the ship as a system that may be detailed into sub-systems and further more into system elements - this cut down process was consistent with familiar practices used in shipbuilding operations. The framework structure enabled the identification and examination of all important pollution drivers of the ship (e.g. air emissions, oily and non-oil wastes, ballast water, garbage, noxious substances, etc.) on a life cycle basis. For each one of these system elements the basic features in a context of a life cycle approach were identified and elaborated as (a) inputs, (b) processes, and (c) outputs (in the form of specific pollution drivers).

### 6.2.3 ECOMARINE – Fuel consumption reduction in marine power systems through innovative energy recovery management

The reduction of fuel consumption in marine power systems is of great importance, because it leads to reduction in CO2, NOx and SO2 emissions[2], in travel costs and so to optimal use of fossil fuels. Moreover, the ship autonomy becomes higher. Until now, the most common energy saving solutions, which have been applied in marine power systems were based on the cogeneration of heat and power scheme (Waste Heat Recovery - WHR systems). Additionally, energy saving concepts for marine power systems based on the introduction of an exhaust gas boiler that supplies steam to a steam turbine, increasing so electrical energy production about 10% (Exhaust Gas Recirculation - EGR systems) are introduced recently.

During this project, in order to maximize electricity production by waste heat recovery (WHR) and to simultaneously improve electric power quality, a supplementary static energy recovery unit was introduced, which could be installed at new buildings or retrofitted to existing vessels easily and economically. In more details, the heat of the produced gases could be directly converted to electrical energy with the use of a thermoelectric generator. It is worth mentioning that energy recovery using thermoelectric generators has already been implemented in automotive vehicles, aircrafts and rotorcrafts. Consequently, with the use of the above energy recovery system, fuel consumption as well as emissions can be decreased, improving so the efficiency of the marine power system.

Another challenge within this project was the introduction of supercapacitor-based energy storage systems, as an intermediate energy bank for the thermoelectric modules generation. The final system was tested in the laboratory and in situ (generator heat recovery on-board the vessel) to accurately assess its applicability in retrofitting and new shipbuilding operations.

At the end, a sustainability and eco-efficiency report was produced applying LCC/LCA and cost-benefit analyses. Construction, installation and operation costs were taken into account as well as different TEG types, engine fuels and loading conditions to produce quantitative LCC results and investment repayment period. Furthermore, LCA assessment was carried out based on specific assumptions related to various application opportunities.

[2] NO2, CO, NMVOCs and SO2 and primary particles cause problems in coastal areas and harbours because of their impacts on human health and materials. Furthermore, absolute increases in surface ozone (O3) due to ship emissions are pronounced during summer months, with large increases found in regions with heavy traffic

## 6.3 Approaches for Risk Assessment

### 6.3.1 Reliability assessment

The process of ship structural design goes from the primary structure (midship section) to the detail design of substructures and components such as plates and welded joints. Design of primary load-carrying structures is mainly governed by fatigue and ultimate strength. Fatigue analysis is based on different principles than ultimate collapse.

Both the environmental loads and the corresponding stress in a structural component vary with time and can be modelled as stochastic processes. Theory and methods of reliability assessment have been developed significantly in the last two decades and now there are two main types of reliability methods. Time-invariant methods consider that both the strength of the components and the loads do not change with time, i.e. they are random variables. Time-dependent formulations are able to model the case when a component is subjected to a random fluctuating loads and its capacity deteriorates with time.

The developments of structural reliability theory, which occurred in the late 60's, started being applied to ship structures in the 70's. Since then several improvements have occurred in the theoretical formulations and in the computational methods of structural reliability, some of which have been applied to the analysis of ship structures.

Presently the first and second order reliability methods provide a way of evaluating the reliability efficiently with a reasonably good accuracy, which is adequate for practical applications as provided by [95] and [25]. These approaches take into account the information about the type of distribution of the basic variables, and these analytically based methods have been extended to combine their capabilities with Monte-Carlo [68] simulation methods which in turn have been made efficient through different strategies. Non-linear limit state functions are adequately dealt with and the analysis of systems, either in parallel or in series, can be performed with current methods. Furthermore, various interesting formulations for time-varying reliability have been proposed [99],[20].

One problem to study is the behaviour of the whole hull girder of a ship and in particular, the way in which the structural design process is addressed from the point of view of the Regulatory Agencies.

Classification Societies have been interested in the subject since the early days, as can be seen in the studies of [2],[5],[90],[108],[82],[29],[36]. The interest of Classification Societies is very important since, one of the main applications of reliability theory is in design codes which, in the case of ships, are elaborated by the Classification Societies.

The formulations that have been used for the safety check of the primary ship structure adopt the same approach as prescribed in the Rules of the Classification Societies. The main difference is that in those studies the basic variables are modelled as being random while the Rules of the Classification Societies specify their nominal value as a function of ship parameters.

The ship hull is considered to behave globally as a beam under transverse load subjected to the still-water and wave induced load effects. In general, the governing variable is the vertical bending moment, which will induce the longitudinal bending of the hull. The resulting stresses are distributed linearly across depth of the hull and their intensity at bottom and deck is the ratio of the applied moments by the respective section modulus.

Thus, in this formulation the strength variables are the yield strength of the material and the section modulus, while the load variables are the still-water and the wave induced bending moments. This formulation has the limitation that the system behaviour of the hull girder is not taken into account. In fact, when the whole girder is subjected to a bending moment the stiffened plate elements in the deck and bottom are subjected to a cyclic tension and compression. Since the different elements may have different dimensions and different levels of initial defects, some will fail before others. This means that some elements will fail before the hull girder is able to develop its full ultimate load carrying capacity as quantified by [16].

Depending on the geometry of the hull cross-section, the relation between the load corresponding to the initial yield stress at deck or bottom and the ultimate collapse load will vary. This means that the elastic stress that is used as the reference value is not a consistent parameter for comparative purposes of hull collapse. However, this has been the basic approach used in the Classification Societies checking procedure and in the former reliability formulations.

The first references to structural reliability of ships were presented by [1]. He provided a discussion about the role of safety factors, which is still actual. However, the first reported work on ship structural reliability is due to [77]. He formulated the reliability problem between a normally distributed still water loads, a Weibull distributed wave-induced load and a normally distributed resistance. He calculated the probability of failure i.e., he defined the three variables by their probability distribution functions and calculated the probability of failure by integrating them in the appropriate failure domain.

The first complete reliability analysis of a ship structure was performed by [65][67]. [64] developed a probabilistic model for ship strength and analysed a Mariner ship, a tanker and a warship. They adopted Nordenstrom's model for wave induced loads, considering different modes of failure of the structure.

Another major contribution is the introduction of second moment methods by [66], [27] adopting the reliability index formulation of [19] and applied it to 19 merchant ships.

To assess the reliability of the ship structure, it is necessary to compare the values of the load effects in the various components with their respective load bearing capacity. In view of the different load components present and of the corresponding different behaviour of the structural elements several modes of failure or limit states must be considered.

In general, the modes of failure of the structural components are due to yielding and plastic flow, to elasto-plastic buckling and to crack growth by fatigue or fracture, as discussed for example by [67]. When considering the primary hull structure, reference is usually made to the midship section, and checks on the capability of secondary structures were only made in some studies.

Interesting developments can also be identified in the application of systems reliability to ship structures. The initial applications have used frame models and looked at the transverse strength of ships ([76]). However, an approach has now been presented of systems reliability using plate elements, which has been applied to a tanker ([79]).

The time variant formulation of ship reliability results from modelling the problem with stochastic processes that represent the random nature of the load and strength parameters. In general, failure is seen as the up crossing of a threshold level that separates safe from unsafe state.

The initial formulations of the time variant approach to ship structural reliability were developed in connection with the fatigue problem, in particular to be able to deal with the time degradation of reliability by [38] and with the improvements made by maintenance actions by [37],[39].

Formulating the inspection and maintenance planning problem as a problem where the overall service life costs are minimized the pre-posterior analysis from the classical decision theory is given by [9], [96] providing a consistent and systematic framework for its solution.

The problems related to assessing the serviceability and safety of ships including the assessment of the structural condition (in view of corrosion, fatigue cracking and local denting), methods for repair, quantification of strength of deteriorated and repaired ships (as well as criteria for acceptable damage), accounting for the uncertainties involved and cost-benefit and risk-based decision procedures for remedial actions have been the main objective in two consecutive reports of International Ship Structure Congress ([15][83][116]).

Earlier approaches were based on using structural reliability theory but it may be based on statistical analysis of structural degradation data leading to probabilistic models of time to failure, which are used as basis for maintenance decisions.

Classical theory of system maintenance describes the failure of components by probabilistic models often of the Weibull family, which represent failure rates in operational phases and in the aging phases of the life of components as described in various textbooks ([75][97][52]).

[33][34][35] adopted that type of approaches and demonstrated how they can be applied to structural maintenance of ships that are subjected to corrosion by employing historical data of thickness measurements or corresponding corrosion wastage thickness in ships.

Some examples of software that can be used to perform reliability analyses for the first group of problems is COMREL [18], covering FORM/SORM approaches and for the second group of problems an example of supporting software is Reliasoft [98]. However, nowadays, we may find out many different commercial software that can be employed for a reliability assessment.

### 6.3.2 Safety integration into design decision-making: SAFEDOR project

SAFEDOR, an Integrated Project developed funding by the sixth framework programme of the European Commission, pooled together leading expertise from across the whole maritime spectrum to pursue its vision of strengthening the competitiveness of the EU maritime industry by enhancing safety through innovation. This entailed development of a holistic approach that links risk prevention / reduction to ship performance and cost, with safety treated as a lifecycle issue and a design objective, implying focus on risk-based operation and need for risk-based regulations within an integrated risk-based design framework, utilising routinely first-principles tools. This all-embracing system was the key to attaining optimum design solutions and it acted as catalyst to pan-European cooperation with strong structuring and integration effects. SAFEDOR produced a series of prototype ship designs to validate and implement that novel approach and ascertain its practicability.

The integrated project SAFEDOR introduced a risk-based design methodology and regulatory framework that systematically embraces design knowledge and innovation, thus offering economic benefits and competitive advantage to the European maritime industry.

SAFEDOR development activities focused on risk-based ship design (which is an enhanced ship design process) and approval of risk-based ships (which requires an enhanced approval process and a modernised regulatory framework):

- Risk-based ship design requires a novel process to incorporate safety as an objective, sophisticated methods and tools to assess ships in extreme and accidental scenarios with due account for the human element and improved knowledge on cost elements in construction and operation of ships. Optimisation of ship designs also needs integration of available tools. SAFEDOR addresses all of the above.
- Approval of risk-based designed ships requires a new approval process, which takes into account the rule-challenging character of the innovative ship. Qualitative and quantitative assessments of innovative concepts are required and knowledge on current risk levels is needed to establish suitable risk acceptance criteria. High-level FSA studies of ship types deliver just this piece of information. SAFEDOR addresses these elements and develops a proposal for a modernised regulatory framework to facilitate the above.

Risk-based design demands advanced tools to predict the safety performance of a given ship design. It was the specific objectives of work package 2 the development of advanced tools to predict the safety performance of a given ship design and their integration into a risk-based design procedure with the aim to provide tools for fast and reliable evaluation of various risks associated with failure of the ship or its subsystems.

- Fast and accurate flooding prediction
- Probabilistic assessment of the strength of ship structures
- Probabilistic assessment of intact stability
- Prevention of collision and grounding events
- Prevention of fire and explosion events

Another objective of SAFEDOR was to establish an alternative new risk-based regulatory framework in shipping that allows linking performance optimization with risk minimisation as a means to providing solutions in order to increase the safety and security of waterborne transport cost-effectively. On this basis, SAFEDOR performed Formal safety Assessments (FSAs) for selected ship types, to make explicit the current implicit safety levels in existing rules and regulations, developing necessary documentation for a risk-based regulatory framework that can be implanted in shipping

SAFEDOR aimed as well to provide the necessary conceptual and practical developments to facilitate the implementation of risk-based design. In terms of the conceptual developments, the main objective was to consolidate a high-level understanding of risk-based design as a process in the light of current ship design practice.

In terms of the practical developments, two objectives were pursued:

- to develop performance-earning-cost-risk parametric models specific ship types (cruise, ropax, gas tankers and containerships) and to propose a generic formulation for use in ship design optimisation
- to develop a specification for an integrated ship design platform, incorporating the elements of risk-based design and implement and demonstrate its applicability with an IT platform incorporating the developments of SAFEDOR (safety-performance evaluation and risk analysis tools)

More information on the project can be obtained from http://www.safedor.org/news/index.htm .

### 6.3.3 TWI's RiskWISE software

#### 6.3.3.1 An overview of RiskWISE®

RiskWISE® is the Risk Based Inspection (RBI) / Risk Based Maintenance (RBM) software developed by TWI Ltd to support the implementation of certain American Petroleum Industry (API) standards. The software aims at enabling plant personnel to confidently manage the risk and associated issues for the continued safe and economic operation of their plant and equipment. RiskWISE® meets the audit team concepts detailed in API Recommended Practice (RP) 580 – Risk Based Inspection (RBI) and API RP 581 – Risk Based Inspection Technology [6]

RBI and RBM are integrity management practices that are employed to identify plant and equipment at risk of failure. The criticality ranking derived through RiskWISE® consequently forms a framework within which inspection and maintenance resources can be allocated to optimally mitigate risk in a safe and cost effective way.

The risk-based approach is in accordance with industry accepted and proven concepts of formal RBI and RBM. The uptake of such approaches is increasing as the benefits to plant integrity management through improved targeting and scheduling of inspection and maintenance effort are being recognized.

In RiskWISE®, the risk of failure is evaluated as the combined effect of probability of failure (PoF) and consequence of failure (CoF). Due to the nature of the failure mechanism and the data availability, a Risk Assessment (RA) can be performed quantitatively, semi-quantitatively, or qualitatively. The risk is demonstrated using "risk curve", "risk matrix" or "risk ranking". Example of "risk curve" and "risk matrix" are shown in Figure 16.

Further information about RiskWISE® can be found from: www.twisoftware.com/riskwise

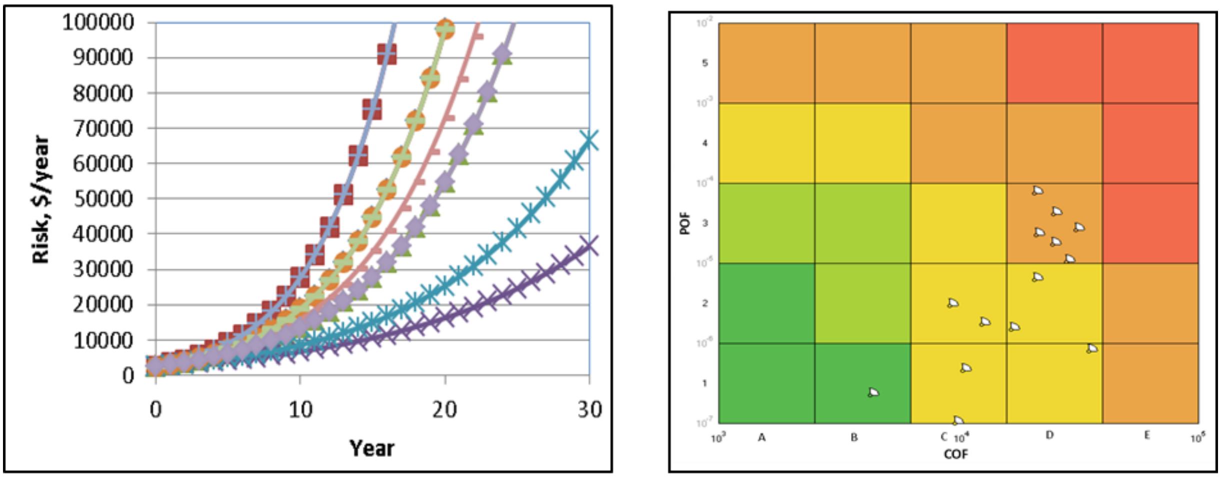
#### 6.3.3.2 The relevance of RiskWISE® to SHIPLYS

The development of a risk assessment model is one of the tasks in SHIPLYS Work Package (WP) 5. Although RiskWISE® focusses on risk assessment (RA) during operation & maintenance (O&M) stage, and API 581 is mainly intended for oil, gas & chemical plant and power plant, the fundamental framework / procedure and supporting theory for RA is relevant to the development of SHIPLYS RA model.

IN SHIPLYS, THE DEVELOPMENT OF THE RA MODULE REQUIRES A THROUGH LIFE PERSPECTIVE. SUCH RISK ASSESSMENTS ARE PARTICULARLY IMPORTANT IN SCENARIOS WHERE NOVEL CONCEPTS ARE BEING PROPOSED OR MODIFICATIONS TO THE ORIGINAL DESIGN (SUCH AS IN RETROFITTING) ARE BEING CONSIDERED.

A through life perspective requires an assessment of degradation in conjunction with strength/ capacity models over time in order to predict expected behaviour in terms of structural integrity. For SHIPLYS, such profiles will be approximate, given the limited data available during the early design stages and the inputs available from the rapid virtual prototyping carried out. However, the profiles will be sufficient to assess the risk of failure where ‘risk’ is the combination of the probability of an event happening and its potential impact which could be economic, societal and environmental.

At the time of writing of this report, the details of the SHIPLYS scenarios are being investigated. The final approach to risk assessment in SHIPLYS needs to consider the level of detail available at the early design stage. IST, the task leader of Task 5.3, titled ‘Development of risk module’, have proposed a promising risk-based approach using conceptual design. TWI are part of this team headed by IST, and will support them in this activity by bringing in TWI’s expertise in the development of risk based approaches and tools in a variety of industry sectors.




a) Risk curves    b) Risk matrix

**Figure 16: The example of a) risk curve and b) risk matrix for demonstration of RA assessment in RiskWISE®.**

# 7 Shipbuilding modelling methodologies

## 7.1 Hull parametric modelling

The current process of design of the hull shape is built on a low-level definition of geometry using a surface modeller CAD software system. There are two main approaches to this process. In the first, the designer creates the geometry starting with points, then curves and finally with surfaces created by patches [114] and eventually meshes [110]. In the second approach, the designer manipulates the geometry, moving each point separately, associating each surface with a polyhedron of vertices as in the Bézier and the B-spline concepts, in order to achieve the desired geometry. This process is highly interactive and therefore time consuming and difficult to reproduce: even the same designer, with the same tool and the same input data, will end up with somehow different surface models of the hull.

During the concept stage of ship design, while the hull dimensions are still to be determined, a number of hull characteristics and properties are estimated using empirical expressions which are mainly a function of the main dimensions and some additional form parameters [113]. Because they are based on statistical data from existing ships, these expressions not only become quickly outdated when there are any changes in the configuration of the ship, but also they cannot cope with less common configurations or shapes. Therefore, the accuracy of the results of some tasks carried out at the concept design can be much improved if there is the capability to generate hull shapes in accordance to a set of dimensions, form coefficients and some design parameters. The availability of the hull form at such an early stage can also provide support to other tasks such as compartment layout [72], [51] and structures modelling ([112], [111]). Due to the increasing use of optimization procedures at the concept design stage ([102], [70], [115]), the form created must be produced in a short time interval and with the shape characteristics and accuracy in accordance to the intended use, which means that the resulting hull has not necessarily a completely faired shape.

The objective of this work is to develop a method to generate the shape of a complete hull form of a merchant ship in a parametric way, without user interaction, so that the same set of parameter gives always origin to the same surface model. Merchant ships have more complex hull shapes in comparison with other types of vessels. The existence of some shape characteristics such as parallel middle body, transom stern, bulbous bow, etc. must be taken into consideration. The parameters used must belong to the set commonly defined in the early stages of ship design and they must present a clear geometric meaning to the designer. The form generated must be complete up to the deck level so that it can be used not only in computations associated to the hydrostatic or hydrodynamic characteristics but also in other tasks such as compartment definitions, capacity evaluations or structural design.

Most of the previous work on this subject has been developed in the scope of optimization procedures associated with hydrodynamics, namely the propulsion resistance ([11], [119]) which explains why many of these procedures are focused on modelling only the submerged hull part.

[40] presented a modelling technique that is based on a parametric curve generation, and later [41] they successfully utilized it for the generation of bare hulls, and proposed a set of form parameters for general planar curves.

[78] presented a new approach for to the geometric modelling of hull forms, for the preliminary phase of ship design. The approach is based on form parameters and use B-Splines and surfaces to mathematically describe the hull geometry. The B-Splines presented an outstanding behaviour due to the possibility of local shape control, convex hull property and invariance under coordinate system transformation. The modelling process was viewed as an optimization problem, where fairness measures are considered as the quality criterion. The form parameters are treated as equality constraints and the B-Splines as free variables. This new parametric approach provided means for a faster an accurate form generation and variation with better fairness.

[4] presented a parametric approach for the modelling and hydrodynamic multioptimization, focus on complex hull shapes with bulbous bow, in particular the FantaRoRo, a Ro-Pax ferry elaborated within the European project FANTASTIC, using the FRIENDSHIP-Modeler. The main goal was to obtain a minimum wave resistance in calm water, varying some parameters of the design waterline (DWL), the Sectional Area Curve (SAC) and the bulbous bow, and considering some constraints as the displacement and the longitudinal centre of buoyancy.

[53] presented a multi-surface modelling method. In this method the hull is divided into a forebody and a stern body. The SAC is the basis of the generation process. First the SAC shape is obtained from a set of required ship main dimensions and hydrostatic characteristics.

In [63] is presented an algorithm that automatically generates the submerged part of the hull shape of sailing yachts, using parametric modelling. The algorithm has two steps. The first one is the design of the keel line and the DWL, according to a set of parameters such as the length of the water line, draft and some others, and using B-Spline curves. Then it was made the fairing of the hull surface, considering a different set of parameters as the displacement and the waterplane area. He used B-Spline surfaces to define the hull, the gradient method the determine a reliable solution and the weighted sum approach. The design variables vary depending on the optimization type. He also presents a set of different form coefficients and their acceptable range of values for yachts.

In 2006, Bole and Lee presented another two different hull generation techniques ([12]). The first is a single cubic B-Spline surface yacht hull generator, based on 19 geometric parameters and performing a longitudinal fit to the control polygons of each section. The second one produces a B-Spline surface of a single-screw cargo ship hull form with and without bulb, based on 25 geometric parameters, but this time presented not so satisfactory results due to not being possible to control the hydrostatic properties independently of the other input parameters.

[3] presented a study of the application of the Lackenby Method available on the FRIENDSHIP-Framework. They made two different examples. On the first they shift all the sections until they could get the wanted hydrostatic properties. On the second they shift slightly forward the maximum section and the centre of buoyancy, increasing the displacement.

[89] presented a geometric modelling of the bulbous bow using a set of parameters. They used a wire model, constructed with cubic B-Spline curves, and NURBS surfaces to create the bulbous bow model. They also studied how to obtain certain bulbous bow parameters and their influence on the hydrodynamic properties of the ship. Controlling the location of the waterline that crosses the point of maximum bulb protuberance and the SAC, they were able to manipulate the longitudinal distribution of the bulb volume and to control the phase lag between the bulb and the hull wave trains. An example was presented, based on the modification of a bulbous bow of a fishing vessel considering some CFD optimization calculations.

[41] presented some fully-parametric methods, experimental results and potential economic aspects, related with the optimization of a new family of container ships. In addition, using FRIENDSHIP Framework, they presented a study for a potential new form feature located in the hull's forebody that displays addition inflection points in the sectional area curve and in several waterlines, the InSAC. To validate this method, they did some model tests that confirmed improved transport efficiency.

[88] presented a simple parametric method for the hull generation of simple hull shapes without bulbous bow, as sailing boats and round bilge hulls considering some hydrodynamic coefficients imposed by the designer on the definition of the SAC and the DWL. The definitions of those curves were mathematically made, and they presented all the equations of the curves and their parameters. The method begins with the development of a wire model of spline curves and ends with the automatic generation of the B-Spline surfaces of the hull and the analysis of the surfaces fairness. They also presented some examples for the use of this method. In ([86]) in addition to the SAC and to the DWL, two additional curves, the centre line contour and the deck edge, are used to define the extreme boundaries and the corresponding tangents. Next, a set of cross sections is computed to match the previously defined constrains. Finally a single surface is obtained by lofting the section curves. All the curves and the surface are modelled as B-splines.

The development of the hull form is a task carried out using software tools that can be either generic CAD systems with surface modelling capabilities able to deal with free-form shapes, such as:

- Rhinoceros3D (www.rhino3d.com),
- CATIA (www.intrinsys.com),
- Siemens PLM NX (www.plm.automation.siemens.com)

or specialized systems for naval architecture, such as:

- AutoShip (www.autoship.com),
- FastShip (www.proteusengineering.com/fastship.htm),
- MultiSurface (www.aerohydro.com),
- DELFTship (www.delfship.net/DELFTship/),
- Bentley MaxSurf (www.bentley.com),
- QinetiQ (www.paramarine.qinetiq.com),
- CADDS 5  (www.ptc.com),
- Napa Hull (www.napa.fi).

Not many of these systems provide a parametric modelling capability, but they all include a scripting or programming language which allows the user to develop some kind of automation codes that can be used for parametric modelling of the hull form.

One of the most powerful tools for parametric geometric modelling that can be used for the generation of ship's hulls is the Modeler, one of the components of the CAESES (www.caeses.com), a commercial system previously known as Friendship Framework, described in [4] based on B-spline curves and surfaces. This system has introduced a new concept of curve, the k-spline ([21]). This curve can be created by interpolating a number of data points while simultaneously complying with some integral properties such as the area under the curve and is inherently smooth which makes it a powerful tool to model cross-sections of the hull in compliance with the area up to the design waterline defined by the SAC.

## 7.2 Spaces arrangement modelling (Conceptual Ship design)

The space and weight arrangement are modelled through a large number of analytical parameters, which are more difficult to deal with in an optimal design approach. More global models, possibly relying on advanced integrated CAD tools could maybe be used to solve this issue.

For the spaces modelling, **FORAN** has a specific module called FGA whose main purpose is the definition and management of the compartment arrangement of the ship. Theoretical surfaces, which may be imported from IGES or STEP files, are the reference of the limits in the compartment definition.

Space definition could be addressed through different methods being a space a set of properties (name, type, load, ...) and a geometric definition. That geometric definition is based on one or a set of subspaces: solid models. The space could be defined by selecting six limits, by a set of surface, and also based on parametric. Once created the spaces FORAN allows both: to export them to other formats as STEP, BREP or IGES and to create a spreadsheet with the modelled spaces.

**Rapid Ship Evaluation Tool**

The Rapid Ship Evaluation Tool is a prototype software development by BMT Design & Technology that uses computer algorithms to automate the ship design process. The tool enables in-depth exploration of the design space and trade-off of critical and typically competing design aspects.

## 7.3 Structural modelling

### 7.3.1 Introduction

Various flow charts of the steps in a ship structural modelling and assessment procedure can be found in the literature, indicating more or less the same sequence of activities. The preliminary design phase determines the basic parameters of the overall design problem. Structural design follows the preliminary design. The first step in the structural design is the determination of the structural arrangements. The next step is usually the determination of the scantlings, which is done mainly on the basis of local strength requirements. Their adequacy is checked primarily (and in most cases) on Class rules. The next step is to check and, if needed, to enhance the overall hull girder strength. Again, this is mainly guided by Class rules. The final step is the design of details such as connections, openings and transitions. These details are guided by Class rules, general published guidance and by yard practice and experience. With this step completed, the structural drawings can be prepared. However, there is yet a final step that can affect the structural design: structure must be reviewed for suitability in light of numerous other constraints. These include compatibility with other ship systems, produceability, maintainability, availability of materials and cost.

An important requirement of hull basic design is to ensure safety and performance concerning structural strength, as well as to rapidly respond to inquiries from the ship owner or from another basic design section. To meet such demands, a procedure is usually needed for estimating the total hull steel weight quickly and accurately using simple formulas or charts from experience of sister ships. To this end, a data base system, including a feedback system, is essential. The drawing to be studied first is the “rough midship section”, considering classification rules, design standards, production methods, etc. It is important that it satisfies not only the requirements of the classification society, but also amalgamates the experience from previous successful designs, including the knowledge on structural damage history (cracks and buckling) [80].

### 7.3.2 Classification Societies Rules Structural Modules

In recent years, the principal classification societies have developed software packages for use by shipyards and design offices that incorporate dynamic-based criteria for the scantlings, structural arrangements, and details of ship structures. The computer programs made available to shipyards incorporate a realistic representation of the loads likely to be experienced by the ship and are used to determine the scantlings and investigate the structural responses of critical areas of the ship's structure. A brief description of the basic characteristics of the most important of these software packages is presented below.

SafeHull (ABS)

SafeHull is a Finite Element Analysis software for the design and evaluation of hull structures for tankers, containers and bulk carriers based on steel vessel rules. It is a standalone and complete structural assessment tool based on ABS "Rules for Building and Classing Steel Vessels (2016)" criteria. SafeHull considers a 3D global FEA model with sufficient mesh density to assess both global hull-girder and local main supporting structural yielding and buckling strengths. A local very fine mesh model may be developed when a detail design or critical structural area needs to be analysed. This approach is referred to as "Global 3D Fine Mesh FEA Method". Structural idealization, load application, analysis procedures and evaluation of analysis results are carried out in a consistent manner within the software.

CSRS (ABS-LR)

Common Structural Rules Software LLC (CSRS) is a joint venture company established by American Bureau of Shipping (ABS) and Lloyd's Register (LR) to provide industry with a validated and verified suite of software tools for CSR, which will meet the concerns of industry about the possibility of different interpretations of the requirements of CSR as a result of the software used in assessment.

The software includes the "CSR Prescriptive Analysis" module which assesses ship structures based on the January 2015 Common Structural Rules for Bulk Carriers and Oil Tankers and the "CSR FE Analysis" module which uses finite element analysis to perform direct strength and fatigue assessment of ship structures for compliance based on the January 2015 version of the Common Structural Rules for Bulk Carriers and Oil Tankers. The CSR FE Analysis product incorporates MSC Software's PATRAN to provide capabilities needed for Design Review.

MARS2000 (BV)

MARS2000 is a software developed by BV for the assessment of scantlings of plating and ordinary stiffeners of any cross-section and any transverse bulkhead according to Bureau Veritas Rules and IACS Common Structural Rules for Bulk Carriers and Tankers. MARS2000 allows the input of sections, bulkheads and torsional loading and is organized in various modules. It allows checking a section according to BV Rules resulting ultimately in a conclusion whether the section meets these rules or not. It allows the input of general data common for all transverse sections, bulkhead arrangements and torsional loading, as well as the input of any section along the ship length. It is able to perform calculations in any bulkhead along the ship length and carry out torsion calculations based on a simplified model, correct for large opening ships, where the ship is made of continuous holds and each hold is defined by a section (ship beam with variable section).

VeriSTAR Hull (BV)

VeriSTAR Hull is a finite element calculation tool for building 3D models of the ship and performing a relevant structural analysis. It applies Bureau Veritas rules for bulk carriers, oil tankers, container ships, gas carriers and passenger ships and is fully compliant with the latest version of Common Structural Rules, including new requirements concerning buckling, foremost and aft most cargo hold, strength assessment and fatigue check. It is used for the rule compliance check providing global strength assessment of cargo hold structures (yielding and buckling criteria), stress assessment of structural details (local refinement) and fatigue strength assessment of structural details (life time computation).

VeriSTAR Hull combines the FEMAP processing tool for the building of the finite element model, and NX and MSC NASTRAN solvers, for the solution, with in-house developed features for modelling and results assessment. Generation of 3D finite element model of the ship or section is facilitated by the import/export from various CAD formats. The results of the analysis and the assessment of the criteria are output and visualized in a graphical user interface (GUI).

POSEIDON (DNV-GL)

POSEIDON is an integrated software for the strength assessment of ship hull structures. POSEIDON is a design and dimensioning tool that can be used throughout the engineering process. Full 3D modelling scope can be covered, but modelling and analysis of complex midship sections is also possible. POSEIDON is also capable of full automatic determination of initial scantlings covering all rule sets and ship types relevant for hull approval (including CSR). It provides full integration of complete prescriptive checks based on local and longitudinal strength calculations with all the required yield, buckling and fatigue assessments as well as full integration of cargo hold FE analysis with yield, buckling and fatigue checks. All required sets of loading conditions and load cases are automatically covered. It allows rapid changes in structural layout and fast full re-analysis to promote the optimization of the design. Finally, full model transfer from NAPA Steel is implemented, including returning of results.

Nauticus Hull (DNV-GL)

Nauticus Hull is a DNV-GL software package for the strength assessment of hull structures. It offers tools for hull design and verification according to DNV-GL Rules for ships and IACS Common Structural Rules for bulk carriers and oil tankers (CSR BC & OT). Nauticus Hull encompasses a complete module-based structural analysis package and an environment for strength assessment, design and verification. It supports the latest updates of CSR BC & OT for prescriptive and finite element method calculations and is integrated with Sesam GeniE (DNV-GL FEM software) for FE modelling, post-processing and code check. Nauticus Hull can import FE models from common 3D design and FE systems such as MSC PATRAN/NASTRAN, ANSYS, AVEVA Marine, NAPA Steel, etc. It also enables modelling of entire cargo hold region, including the transition to the fore body and the engine room and import of the hull shape from stability software, like AVEVA and NAPA. It is open to yard standards for exchange of models, regardless of yard system.

Sesam GeniE (DNV-GL)

Sesam GeniE represents the latest-generation design and analysis software for maritime and offshore structures. With its concept modelling techniques, Sesam GeniE allows engineers to focus on the structure, loads and environmental conditions, rather than on nodes and elements. Combined with strong features for 3D visualization and advanced automated meshing, this significantly reduces the time spent on modelling and documentation and provides efficient verification. The software is able to perform static and dynamic structural analysis incorporating environmental load calculation (wind, waves, current). All analyses are based on the Finite Element Methodology (FEM software) where beams and plates are connected. There is a wide range of analyses within offshore and marine structural engineering including code checking, load-out, transportation, launching, installation, fatigue, earthquake, progressive collapse, accidents, explosions, etc. With Sesam GeniE the user uses one common model from the initial design phase through all design revisions to the final design of the structure. Later modifications, repairs and life extensions are based on the same model. From the same concept model you create analysis models for hydrostatic, hydrodynamic and structural analyses. The concept model can also be based on imported data from other CAD/CAE systems.

ShipLoad (DNV-GL)

ShipLoad software provides support in modelling the mass distribution of the ship, including outfitting, cargo and selecting the appropriate design waves. The resulting static and dynamic loads (both from inertia and water pressure) for global Finite Element (FE) analyses are exported to FE codes. The load types are combined to yield balanced load cases. ShipLoad can be applied in a typical design environment since it only requires a global FE model of the ship as input. The output from ShipLoad consists of nodal forces that can be applied in any standard FE program. Tanks or other enclosed volumes in the FE model are found automatically. Input of containers is achieved in the standard bay-row-tier system with graphic feedback. By combining mass distributions, different loading conditions of a ship can be examined very efficiently. To find the most relevant regular waves, ShipLoad analyses numerous wave situations. ShipLoad supports the specification of which design waves are to be chosen for the global strength analysis. The outcome is a small number of balanced load cases that are sufficient for dimensioning the hull structure.

RulesCalc (LR)

RulesCalc is a software tool for an integrated ship design assessment within the design phase. It can be used for the verification of the compliance against the classification Rules, to track down corresponding Rule failures and to rapidly identify areas of concern and the design modifications that might be required. The software covers all ship types in the Rules and Regulations for the Classification of Ships of LR, as well as LNG and LPG carriers and bulk carriers for service on the Great Lakes and River St. Lawrence.

The design under examination is entered to the program by the definition of the main ship particulars, the structural and loading data relevant to the service area, material and profile data, pertinent classification data, general structural arrangement, framing system and bulkhead data. The structural parameters (geometry, materials, thickness of plates, profiles of stiffeners, transverse frames, etc.) for ship transverse sections are entered through pertinent GUIs. The section is then checked against the rule requirements for global strength, under the action of the longitudinal bending and shear forces and for the local strength of panel strakes and stiffeners, under the action of the local loads, corresponding to the point of section considered and the relevant space usage. Local scantling checks on transverse sections, bulkheads, floors, pillars, vehicle decks and ice strengthening, as required by the ship type and service conditions are then carried out. Buckling stresses calculation, weld analysis and fatigue check of the connections can also be performed. Any rule failure can easily be checked, resulting in corresponding structural amendments to the design. After these modifications, the design is ready for the stage of the plan approval process.

RulesCalc can be used as a standalone system or in conjunction with other design software packages, including NAPA, TRIBON and Lloyd's Register ShipRight SDA. The interface can, for example, export data from a RulesCalc project file to ShipRight SDA, for FEM analysis. This set of tools allows the data transfer by extracting data from user’s preferred software design tool and converting it to the required Lloyd's Register format. This format is a Ship Structure eXchange (*.ssx) file, which is an XML based file that adheres to the specification required by Lloyd's Register. The same format is also used for exporting data from RulesCalc.

ShipRight (LR)

ShipRight is Lloyd's Register's finite element model (FEM)-based design assessment tool for structural and fatigue assessment of ship structures against the Lloyd's Register ShipRight SDA (Structural Design

Assessment) procedures for container ships, Membrane Tank LNG ships and Ore Carriers. It provides complete, end-to-end, assessment of structures against LR's procedures.

The software allows importing data from other finite element model tools, view results clearly and targeting failure regions quickly. The end goal of the assessment process is to ensure that the final design of the hull will be durable for its entire operating life. It is a modular software suite designed for ships and offshore units, specifically; FPSOs, FLNGs, container ships, membrane tank LNG ships, ore carriers and bulk carriers. It provides interface with finite element model tools such as NASTRAN and PATRAN, as well as an easy to use graphic user interface for yield strength and buckling assessments.

### 7.3.3 Marine Design Software Structural Modules

AVEVA

AVEVA Hull Detailed Design™ (www.aveva.com) is a powerful, datacentric application for the design and creation of production information for main hull structures. The application covers the entire process, from hull design to parts manufacture and block assembly, for all types of ship. The application creates drawings, parts lists and all the production information and documents required in the design and building process. A new project starts with the hull form defined in the AVEVA Initial Design™ application, or with a form from an external source.

AVEVA Hull Detailed Design is delivered with an extensive range of customisable intelligent shipbuilding standards for brackets, stiffeners, notches, cutouts and holes. These standards automatically adapt their geometry to the context in which they are used, in accordance with shipbuilding rules. Drawings can be made in two different styles, either with a symbolic representation of stiffeners, seams, notches and drain holes, or with full three-dimensional representation.

Available manufacturing equipment of the shipyard is considered during design, and the design altered to use the equipment to best advantage. Production output of highly accurate cutting and marking information, with allowances for weld shrinkage, can be used to directly drive all numerical controlled production equipment, such as plate-cutting machines and panel lines. In addition, the AVEVA Hull Weld Planning™ application provides the functionality to accurately calculate all the joints and their respective weld traces in any assembly according to company-specific rules. The calculation uses the assembly production breakdown structure, the topology of the hull model and the actual geometry of the parts in the hull model. The results of the calculation can be used to determine weld work content and also as input for robot welding systems.

CAFE

CAFE (www.bvbcafe.com) is an innovative software for simple and rapid generation of ship concepts. As regards, structural design, CAFE includes a geometric modeller for modelling any structural arrangement and structural member of the hull (plates, stiffeners, brackets, etc.). A mesh generator can create finite element meshes which can be forwarded for solution to other general purpose commercial FE codes (e.g. ABAQUS, ANSYS, NASTRAN, etc.). Realistic properties of materials, plates and profiles can be added, modified or replaced from MS Excel database or by user in CAFE interface. The geometric information can be used for calculating section modulus of various cross sections, whereas, in combination with a known weight distribution, can result in the longitudinal distribution of bending moments and shear forces. Other characteristics related to the structural modelling include import of geometry from other CAD software, automatic generation of classification drawings at desired intersection planes and shell plating, as well as rapid and parametric definition of shipbuilding entities, such as stiffened panels, openings, brackets, etc.

FORAN

FORAN Hull Structure (www.marine.sener/foran) provides a complete solution for the definition of the 3D model of the structure, and for the automatic generation of all information required for manufacturing and production. A special module with a user interface is provided for the definition of standards of structure having characteristics like an algorithm to represent corrugated parts, commands for checking the edge preparation of plates and profiles, options for the definition of face bars and an algorithm to represent curved shell and deck plates. Regarding profiles and plates nesting, the NEST module allows the nesting of identical parts assigned to different interim products and keeps information to recognize each individual part. FORAN can insert sets of longitudinal stiffeners from end-to-end on each surface, and chop them at the points of change of scantling. Bulkheads, floors, web frames and beams, stringers, and other structural elements can be easily defined just with one click on a sequence of intersection lines, automatically provided on each working section. The FORAN drafting environment provides tools to create structure class drawings from the 3D model, in the traditional 2D structure style, and to update drawings after changes in the model. It is DXF compatible.

FORAN Hull Structure offers a complete set of automatic fabrication and assembly outputs, configurable to the request of any yard or technical office, regeneration of drawings after changes in the model, customized NC data for shipyard machines, powerful management of penetrations and builds Strategy definition with advanced welding management.

The FORAN Hull Structure standards library is comprised of materials catalogues (gross plates and profiles), geometric standards and a number of configuration parameters controlling the modelling and the output generation processes. The parametric standards encompass brackets, clips, other standard plate parts, openings of different types, profile ends, edge preparations and multi-component building solutions.

MAESTRO

MAESTRO (www.maestromarine.com) is a design, analysis, and evaluation tool specifically tailored for floating structures. At MAESTRO's core is a structural design tool developed to suit the needs of ship designers and naval architects. MAESTRO is organized to rapidly generate a finite element model of an entire ship. Using high-level building blocks (i.e. substructures and modules), MAESTRO can leverage longitudinal uniformity typically found within portions of a ship (e.g. plating thickness or frame size throughout a cargo hold, etc.). Each module has its own local coordinate system, and can be copied, rotated or transformed. Hull girder properties such as inertias, cross-sectional area, neutral axis, and section modulus can be plotted and queried for any section cut within the model. MAESTRO also provides fine meshing capabilities which allow the global model to be automatically refined while maintaining the original scantling properties and loads.

MAESTRO offers numerous ship-based loading patterns (e.g. Basic Loads: Cargo Loads, Liquid Tank Loads; Sea Environment: Hull Girder Loads/Sea Loads/Ship Motion Loads; and Operational Loads: Slamming/Flooding/Docking) to accurately and efficiently produce the necessary load cases. In addition to calculating displacements and stresses using the finite element analysis method, MAESTRO also performs an automatic failure evaluation of the principal structural members.

The Extreme Load Analysis (ELA) module allows the user to calculate hull girder load response RAOs, and provides the necessary short-term and long-term statistical computations to predict extreme values of the maximum loads for a given vessel. Moreover, the Spectral Fatigue Analysis (SFA) module provides the ability to perform global fatigue screening of the vessel and introduces additional functionality to the ELA module to compute Stress and Displacement RAOs, define and associate structural groups to SN curves and Stress Concentration Factors (SCFs), and compute fatigue damage based on the Miner cumulative damage principle. Finally, MAESTRO provides the capability to model corrosion as an additive property associated with a particular load case. The new plate and beam thicknesses are automatically used in the finite element analysis and strength assessment.

The MAESTRO Technology is organized within an open software architecture, with a set of core components, and integration with supporting software modules and interfaces. In addition to its built-in modelling capabilities, MAESTRO can read geometry from FEMAP, Nastran, NAPA Steel, DXF, and polygon mesh (.ply) files. Once a model is loaded into MAESTRO from another source, all of the hull girder properties, ship-based loading, post-processing, and advanced capabilities are available to the user just as if the model had been created in MAESTRO.

MAXSURF

The MAXSURF Structure module (www.maxsurf.net) provides initial definition of structural parts including hull/shell plates, stringers, transverse frames, decks and longitudinal structure for all types of MAXSURF designs. The Structure module is used to define the location of parts on the vessel, generate part geometry and define parts which can be passed to other CAD systems for further detailing. Structure provides the user with a range of interactive graphical tools, which are used to parametrically define parts directly from the MAXSURF NURB surface model. Structure's parametric part definition means that not only do parts match directly to the hull surface, they will also automatically adapt to any change in the hull definition.

An integrated parts list within Structure progressively contains all the parts you define and calculate. Quantities, areas, weights, centres of gravity and cutting lengths are calculated and tabulated. Structure has also particularly comprehensive functions for laying out stringers, or longitudinal stiffeners, on the hull surface, whereas plate forming information can be also displayed.

Structure Features include longitudinal and stringer generation, automated girth spacing, perpendicular or twisted stringers, transverse frame generation, unlimited frame openings, automatic cutout insertion, cut-out and materials database, plate definition and development, shell expansion, developed contour locations, interactive part creation, editable part tables, 3D model rendering, plate strain display, parts database, DXF and IGES export, copy and paste to Excel, export to ShipConstructor.

NAPA

NAPA Steel software (www.napa.fi) is an intelligent system for the structural design of ship hulls. It uses an integrated 3D model from the beginning of the design process and includes a consistent database for multiple design aspects as compartments are part of the same model. It achieves significant time savings by creating finite element mesh from the structure model and includes fast and consistent scantling analysis with the most common class rule check software. Rapid and flexible model variations provide possibilities for optimization and studying multiple design alternatives. Automatic generation of drawings from the NAPA Steel model prevent typical inconsistencies between drawings while the model is frequently changing. Moreover, integration with outfitting design systems enable starting 3D outfitting design months earlier in the design process with higher quality information, whereas export to production design systems enables smooth transition and increased efficiency.

NAPA Steel key features include numeric outputs (weight and centre of gravity, bill of materials, welding lengths and painting areas), generating data for production planning and cost estimation, section modulus and radius of gyration, generation of drawings and visualizations for plan approval, data exchange with classification societies' systems for scantling analysis and FEM, export of the 3D structural model to outfitting and production design systems, automatic idealization and generation of FEM mesh, export to FEM solvers such as NASTRAN and ANSYS, as well as IGES and DXF interfaces for linking to a wide variety of general CAD systems such as AutoCAD.

The 3D NAPA Steel model has interfaces to the most common class society's structural rule check software. Ship geometry, compartments and structural scantlings can be exported with dedicated interfaces. Information is always extracted automatically from 3D NAPA model, which gives full compatibility with NAPA drawings and weight check.

Current interfaces support Bureau Veritas, ClassNK, DNV-GL, Lloyd's Register and Korean Register software. ClassNK PrimeShip Hull and DNV GL Poseidon interfaces are full 3D interfaces integrated with associated FEM solvers and concept models. With the results back functionality they can provide full service including yielding, buckling and fatigue post processing.

SHIPCONSTRUCTOR

ShipConstructor (www.ssi-corporate.com) is an AutoCAD based software product line created for design, engineering and construction in the shipbuilding industry. ShipConstructor Hull Structure Suites contain a mix of the hull / structure specific ShipConstructor products, as well as general products to facilitate reporting, collaboration and administration. The ShipConstructor Hull Structure Suite Standard Edition is targeted at smaller organizations with simple workflows within hull / structure disciplines of a project. The ShipConstructor Hull Structure Suite Premium Edition adds additional products which make it ideal for small to medium sized organizations that perform hull / structure modelling, design, and construction at a higher level of complexity. This edition also includes WorkShare which makes it an ideal choice for small to medium size organizations who are working on ShipConstructor projects with other organizations.

The basic features of ShipConstructor Hull Structure Suite includes definition of internal plate structure, definition of internal profiles and extrusions, automatic generation of part names from build strategy and other data, automatic addition of stiffener cut-outs to intersecting parts, automatic addition of required bevel information, definition of planking sections, automatic creation of associative marking for piece-marks, part orientation, stiffeners, bevels, faceplates and more, creation of 2D Workshop and Class Approval drawings, creation of 3D Assembly drawings from all disciplines and creation of 2D profile plots and sketches.

### 7.3.4 Recent EU research projects about structural modelling

ADAM4EVE

ADAM4EVE – Adaptive and smart materials and structures for more efficient vessels – was a joint research project funded under the Sustainable Surface Transport priority within the 7th Framework Programme for Research and Development of the European Commission (www.adam4eve-project.eu). The project focused on the development and assessment of applications of adaptive and smart materials and structures in the shipbuilding industry. The project was initiated and coordinated by Center of Maritime Technologies e.V. A set of fifteen smart design solutions was developed that help to provide optimised properties of ship hulls and outfitting systems at varying conditions. Finally, five prototypes were built in model or large scale, and assessed in terms of technical properties, safety issues, and economic and ecologic impact as well. Each of the prototypes was designed for a specific vessel type and a particular operation scenario.

IMPROVE

The main objective of the IMPROVE Strep project (Design of improved and competitive products using an integrated decision support system for ship production and operation, www.anast-eu.ulg.ac.be) was to develop three new ship generations in an integrated multiple criteria decision making environment by using the advanced design synthesis and analysis techniques at the earliest stage of the design process, which innovatively considers structure, production, operational aspects, performance, and safety criteria on a concurrent basis. The product types focused on this project are new generations of LNG gas carriers and chemical tankers, and an innovative concept of a large Ro-Pax vessel. The specific objectives of the project were to: a) develop improved generic ship designs based upon multiple criteria mathematical models, b) improve and apply rational models for estimation of the design characteristics (capacity, production costs, maintenance costs, availability, safety, reliability and robustness of ship structure) in the early design phase, c) use and reformulate basic models of multiple criteria ship design, and include them into an integrated decision support system for ship production and operation.

MOVE IT!

The MoVe IT! project (Modernisation of Vessels for Inland waterway freight Transport, www.moveit-fp7.eu) was executed within the European 7th framework package. It started in 2011 and finished in

2014. The project focussed on exploring and determining viable retrofit solutions for existing inland ships in order to increase environmental and economic performance.

RISPECT

RISPECT (Risk-Based Expert System for Through–Life Ship Structural Inspection and Maintenance and New-Build Ship Structural Design, www.rispect.eu) was an FP7 project that brought the experience based and statistical methods together and developed and demonstrated an improved decision making method, for safe, cost-effective structural inspection, repair and design rule improvement of existing ships. The project set up a methodology, with specified formats/coding systems for ship structure, coating breakdown, corrosion, cracks and structural, reliability and risk analysis results, to enable the acquisition, storing and better use of inspection (and other measured data).

SAFEPEC

SAFEPEC (Innovative risk-based tools for ship safety inspection, www.safepec.eu) is an on-going FP7 project that aims to promote proactive safety and develop a 'unified risk-based framework' built upon the analysis of historical data of casualties, near miss cases, deficiencies and non-conformities that are detected by various types of inspections. Another outcome of the project is a software prototype that enables the interoperability and coherent interpretation of those data sources; and can contribute to the early detection of failure, either in the ship structure or its equipment. Workshops and other engagement activities will be organised to collect the stakeholder views about the products developed during the project. Based on the feedback obtained along these events, a set of recommendations for proactive ship inspection policy will be elaborated.

## 7.4 System modelling

In the market there are a wide range of products for the development of ships. Depending on its scope of application, it may be of the type:

- **General design software**: These are programs of general design not only related to the naval sector.
    - They allow the creation of any type of 3D element.
    - They usually work with file systems instead of using database. The most well known are: Catia and NX-Siemens being the dominant programs in the aeronautics and automotive sectors.
    - These programs treat naval design as any industrial design discipline.
    - The parts must be created using the individual design, but in a very simple way and you can always use parametric libraries. Subsequently the assembly of these pieces is carried out.
    - As a favourable point we can say that it has no limitations, so any element can be generated.
    - Another important advantage is that they are complemented with very solid PLM tools and with lots of CAE tools.
- **Marine Design Software:** These are programs specifically oriented to the design of naval ships.
    - They are generally based on a topological 3D model in database, with the use of parametric libraries that contain the necessary standards for shipbuilding.
    - They are structured in work modules related to naval design disciplines.

- They are programs that are very closed by a series of parameters, which facilitates the generation of models of ships but it makes the use of elements that do not have contemplated very difficult.
- They are the most widespread tools within the naval sector.

In the following sections main software solutions for systems modelling are introduced.

### 7.4.1 Marine Design Software System Modules

***FORAN Machinery & Outfitting (Naval Software)***

As an integral part of a company's IT infrastructure, FORAN makes it possible to share engineering information with PLM, ERP and MRP systems, FEM tools and other specific CAE applications. FORAN can exchange data in multiple formats, such as DWG, DXF, IGES, STEP, VDA, VRML and XML. FORAN incorporates many advanced CIM features to optimize manufacturing and these can be customized for any production equipment. They include plate marking and cutting; plate bending by roll or line-heating; profile marking, cutting and bending; welding robots; panel lines; pin or plate jigs for curved panels; grinding; painting; dimensional control and pipe cutting and bending.

**FORAN** continues the design process by incorporating all aspects related with equipment, piping, HVAC ducting, auxiliary structures and supports into the same project-centric database already used for the ship hull structure and for the electrical design.

Starting at early design stages, the user can start creating libraries of models to be used even in the general arrangement definition in FORAN. In a very innovative application it is possible to position the main equipment in the 3D model very quickly. After that, the GA drawings can be generated from the 3D model as an automatic output, including equipment. During the basic design stage intelligent P&I diagrams are defined connected with the 3D model. The transition to the detail design stage is smooth, taking advantage of the early position of equipment developed earlier.

A single tool manages in FORAN the equipment layout, piping lines, HVAC ducts, related auxiliary structures and supports with many automated tasks. Finally, all information for production and assembly is generated automatically, including spools, isometrics, drawings and reports. FORAN incorporates a powerful on-line capability for clash detection, and it is integrated with the hull structure to manage the penetrations efficiently.

FORAN has different modules (inside of outfitting) such as:

- FDEFIN module - Outfitting Standards: The FORAN Outfitting standards library comprises a set of technological attributes and built-in geometries so that pipes, fittings and equipment are easily and quickly recreated from the vendor catalogues. Moreover, users can define any kind of 3D model for equipment and fittings by means of geometric macros.

  The pipes and fittings are organized in specifications applied to each system, and contain the complete list of attributes such as material, nominal and secondary diameters, schedule, nominal pressure connection types, and other attributes. On top of that, any type of user attribute can be incorporated.

  The integration between disciplines allows the user to assign electric properties to equipment and fittings for subsequent full electric calculation and wiring using the FORAN Electric modules.

- FSYSD module - Outfitting P&ID: The FORAN application for the pipe and instrumentation diagrams allows the definition of the diagrams as part of the ship design, stored in the same database as the 3D model. A specific 2D environment contains all the needed functionality to handle the basic entities that make up the essential part of the diagrams (equipment, pipes, fittings and instrumentation).

All data included in P&ID´s is available when working in the 3D model, thus guaranteeing the fully correspondence between the diagrams and the product, and therefore facilitating the task of creating the as-built diagrams.

- FPIPE module - Outfitting 3D Model: The FORAN application for the 3D modelling in Outfitting gathers different working environments within the same module, thus allowing the designers to work with equipment, piping, ventilation, cable trays (as space reservation), auxiliary structures and line supports.

  Piping and HVAC ducts can be routed interactively or using user predefined solutions. During routine tasks, FORAN automatically checks the fabricability of the pipes and the compatibility of connections, and calculates bolts, nuts, gaskets and welds.

  As auxiliary structures, users can design any type of foundation, ladder, grating and handrail, plus pipe, duct and cable tray supports from scratch, or they can take advantage of standard, predefined solutions. In the case of the supports, a strong link between the distributor and its support keeps the model consistent after changes in the distributor. All profiles and plates created as part of auxiliary structures and supports can be included in nestings.

  FPIPE has different available option for load 3D model, which are: Equipment (this option includes assemblies and electrical fittings & instruments too), Lines (all kind of lines: pipes, ducts & cable trays, and associated penetrations and supports), HVAC Diagrams (3D ventilation diagrams), Structure (loading it directly from the database), Auxiliary structures (structural outfitting), Supports (to use a more advanced selection mode to load the desired supports), Elements by box (read all entities contained in a box from data base) and Surrounding elements (read surrounding entities from data base)

- ISOM, FBUILDS, FDESIGN - Outfitting Production: The typical outfitting production documents are obtained from FORAN in a highly automated way, especially the pipe spool isometric sketches for fabrication and mounting. Both drawing types are capable of complete customization for symbols, labels, dimensions, boxes and paper formats, and are obtained in a fully automatic way. The fabrication drawings may include complete bending information and can export data to CNC files.

  Similarly to the FORAN Structure, the outfitting entities may be assigned to any building strategy tree. Pipes, HVAC ducts, auxiliary structures, supports and corresponding hot work can be added at any level of structure assembly, thus guaranteeing the pre-outfitting blocks and sections with the consequent savings in cost and delivery times.

***AVEVA (Naval Software)***

AVEVA Outfitting Supports is an add-on module for AVEVA Outfitting. It enables the efficient creation and adjustment, within the 3D ship model, of fully-defined supports of the types used in shipbuilding for piping, HVAC ducts and cable trays. Supports are modelled in an interactive, semi-automatic manner, according to user-defined rules and in the context of the 3D layout of the systems and the supporting plates and stiffeners. Outfitting Supports offers a full range of support standards for each discipline; the most commonly used support types can be modelled in just a few clicks. An extensive catalogue enables predefined parametric components and objects to be quickly selected and positioned within the model, then automatically checked for clashes and for compliance with configurable design rules. Changes made as the design evolves can be highlighted and tracked, making it easier to identify, manage and communicate the changes across the different disciplines.

AVEVA Outfitting Supports enables the user to design supports without altering the previously created pipe, HVAC or cable tray design. It separates pipe, duct or cable tray design from the support design, enabling more fully controlled parallel working.

Powerful interactive modification capabilities enable supports to be modified at any time, for example:

- to flip the support’s orientation.
- to duplicate an existing support a number of times on the same system.

- to move an existing support to a new location by incremental steps.
- to resize an existing support.
- to extend a support's length or height.
- to add or remove a pad at the bottom or the top of an existing support.
- to change the support fittings.
- to connect additional pipes, ducts or cable trays to an existing support.

A number of utilities are provided for quality and consistency checks, measuring, viewing, and so on. Fabrication and erection drawings, complete with annotation, dimensions and detailed material take-off information, are produced fully automatically for all supports in a zone. These drawings are derived directly from the model database, ensuring consistency between design and drawing. Drawing layout and the information to be displayed are fully user-customisable.

***CADMATIC (Naval Software)***

CADMATIC has different modules for system modelling:

- OUTFITTING BASIC DESIGN SUITE: Cadmatic 3D Outfitting Basic Design suite is an integrated, database-driven design module and provides powerful tools for 3D layout -piping-, HVAC-, cable tray- and structural unit design in shaded and coloured views. It produces information for installation and ordering materials. The Outfitting Basic Design suite includes the Diagram module.

  Views can be easily configured to allow the best visualization in every possible situation. Various selections of navigation commands and automated routing functions make the 3D modelling very fast. The online collision control feature alerts the user immediately to clashes during pipe and cable tray routing. The case-based collision control tool applies to any kind of component in the 3D model and enables the user to run separate clash tests at any time. All the collisions are listed and presented via an interactive graphical interface, which makes it easy to fix all the collisions.

  During the design phase the software automatically assigns a lot of information to all objects in the 3D model and takes care of the concurrent engineering in the project via object ownership control.

  Pipe and cable tray routing is specification-driven, this rule- based modelling of pipes and cable trays ensure that the correct materials, sizes and components are used during modelling.

- OUTFITTING DETAIL DESIGN SUITE: The Outfitting Detail Design suite includes all the functionality of 3D modelling of the Basic Design suite. Additionally, the Detail Design suite has a full package of modules for production information: spools and ISOs, duct stools, support design, electrical design and integration with Hull modules.

***SHIPCONSTRUCTOR OUTFITTING (Naval Software)***

The ShipConstructor software product line consists of several task-based applications. These core products can be licensed in a modular fashion or as a complete package as part of a Universal License Therefore, ShipConstructor consists of several program modules, each of which can be purchased separately. Each of these is a product that is integrated into AutoCAD.

Outfitting Products

1. PIPE: Pipe is a complete production design package for pipe systems. Pipe modelling capability is spec-driven, based on a user-defined parametric catalogue of pipe stocks and standards with logical connections between parts in the model. A powerful constraint based modelling system allows intuitive changes to existing piping systems. Pipe spools can be defined which are carried over into production for the creation of spool drawings and inclusion in the build strategy for pre-outfitting.
2. PIPELINK: In the piping world, PCF is a standard format that can be read and written by a large number of applications. These applications include software for the analysis of pipe stress, generation of isometric drawings in formats required by certain segments of the industry, and control of automated pipe bending machines on the shop floor. PipeLink provides the ability to generate

PCF files that can be used to automate these individual tasks using information contained within ShipConstructor.

3. P&ID DesignValidation: P&ID DesignValidation allows for the checking and validation of the ShipConstructor 3D pipe model against 2D schematics generated in standalone P&ID software including AutoCAD P&ID. The validation is performed using neutral formats in order to allow clients more flexibility in the choice of P&ID software.
4. HVAC: HVAC (Heating Ventilation and Air Conditioning) integrates with all of the other ShipConstructor modules and encourages collaboration between departments. HVAC can be based on a parametric catalogue of stocks or can be driven by on-the-fly item creation depending on the client's needs. The software employs the same constraint based modelling engine used in Pipe.
5. ELECTRICAL: Electrical is a 3D modelling and production system for wire-ways, cable trays, supports, cables and transits. It features an associative 3D model connecting allocated space to individual wireways, cable trays, supports and subsequent cables. .
6. EQUIPMENT: The equipment items can be modelled in almost any modelling software, including directly in AutoCAD, and then incorporated into the ShipConstructor database. At this point, HVAC and Pipe connections are added as well as production specific attribute information.
7. PENETRATIONS: Penetrations allow the creation of intelligent penetrations through structural members. The parametric spec-based penetration standards support features such as multi-pipe (and HVAC) penetrations and penetration accessory items.
8. PIPESUPPORTS: PipeSupports offers parametric design of supports based on shipyard standards. Supports are associated with pipe and pipe hangers as well as foundation structure to constrain and automatically adapt to design changes as the project progresses.

### 7.4.2 General Design Software System Modules

***CATIA – (General software)***

CATIA is the most used software in automotive and aeronautical sector, although this software is expanding to naval sector. CATIA has different solutions in the field of Equipment and Systems Solutions. CATIA provides a set of products allowing simultaneous design and integration of electrical, fluid and mechanical systems within a 3D digital mock-up while optimizing space allocation.

- CATIA - PIPING & INSTRUMENTATION DIAGRAMS (PID) provides general diagramming tools to place and locate equipment, and to define and manage piping line definition. CATIA - PID allows when integrated with the CATIA Piping Design (PIP) product automatic parts selection and placement as well as check resulting designs for compliance with the PID diagram. Pipe lines can be re-specified in PID and the 3D Piping Design updated.
- CATIA - PIPING DESIGN (PIP) provides general layout tools for intelligent placement of parts, automatic placement of components such as bends, elbows, tees, and reducers. Specification-driven design is employed where required to ensure compliance with project standards. Function-driven design is used to ensure that the design intent is available for any modification scenario. Integration with a design rules engine allows automation of the design process and ensures that company standards are followed throughout the design process. The product comes with a starter piping parts catalogue based on American National Standard Institute (ANSI).
- CATIA - TUBING DESIGN (TUB) creates and manages physical designs of tubing lines/systems.
- CATIA - HVAC DESIGN (HVA) Product creates and manages physical designs of HVAC systems CATIA HVA provides general layout tools for intelligent placement of parts and automatic placement of components as well as the creation and management of duct lines. The product comes with a starter HVAC parametric parts catalogue.

## 7.5 Life cycle modelling

In terms of life cycle modelling or assessment, the pioneering methodologies can be traced back to before 1992:

- the EPS (Environmental Priority Strategies) methodology based on endpoint modelling expressing results in monetary values,
- Swiss Ecoscarcity (or Ecopoints) based on the distance to target principle,
- the CML 1992 (Dutch guidelines) methodology based on midpoint modelling.

These three methodologies were further developed and widely adopted for todays' LCA assessments in various fields.

Since the early nineties many attempts have been made to harmonise approaches. This is partly to avoid having several methodologies which provide potentially different results (depending on the methodology chosen). This has created confusion and criticism of the use of Life cycle impact assessment (LCIA) and LCA in general.

The ISO 14042 standard on impact assessment published in 1999, now part of ISO 14044, brought some standardization on basic principles. However, this still allows for many different LCIA methods to be ISO compatible.

According to ISO standard 14040 (2006) and 14044(2006), LCA study should be composed by four main parts: Goal and scope definition, Life cycle inventory analysis (LCI), Life cycle impact assessment (LCIA) and Life cycle interpretation. For a life cycle modelling, the basic framework is presented in Figure 17.

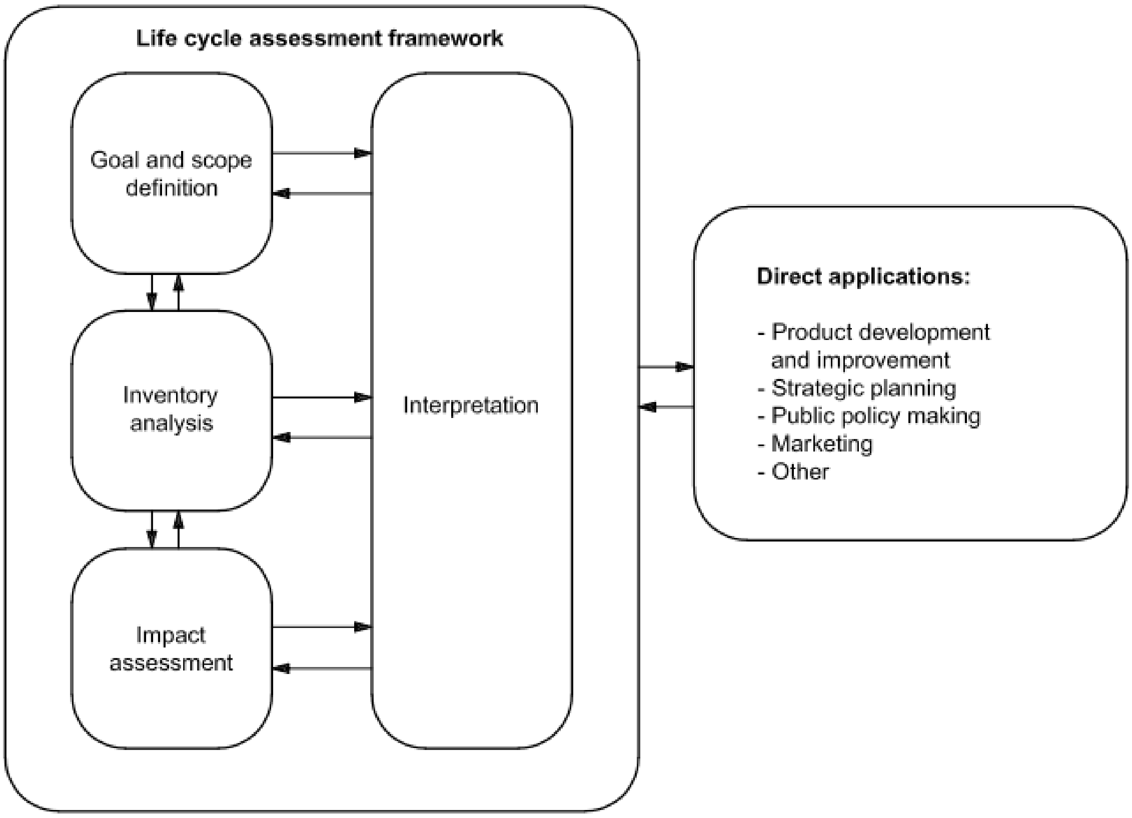



**Figure 17: Stages of an LCA**

### 7.5.1 ISO 14040:2006 / 14044:2006: Definitions

The following definitions and explanations are provided by ISO standards (EN ISO 14040:2006 and EN ISO 14044:2006):

1. Goal of study. To define the goal of an LCA, the following items shall be clarified according to ISO standards:

- the intended application;
- the reasons for carrying out the study;
- the intended audience, i.e. to whom the results of the study are intended to be communicated;
- whether the results are intended to be used in comparative assertions intended to be disclosed to the public;

2. Scope of the study. In order to define the scope of an LCA, the following items shall be considered and clearly described:

- the product system to be studied;
- the functions of the product system or, in the case of comparative studies, the systems;
- the functional unit;
- the system boundary;
- allocation procedures;
- LCIA methodology and types of impacts;
- interpretation to be used;
- data requirements;
- assumptions;
- value choices and optional elements;
- limitations;
- data quality requirements;
- type of critical review, if any;
- type and format of the report required for the study.

In some cases, the goal and scope of the study may be revised due to unforeseen limitations, constraints or as a result of additional information. Such modifications, together with their justification, should be documented.

3. Life cycle inventory analysis (LCI)

LCI is defined in ISO standard as follows: "phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle."

With the definition of the goal and scope of a study, the life cycle inventory phase of an LCA can be initially carried out. While analysing life cycle inventory, the flow in Figure 18 can be applied.

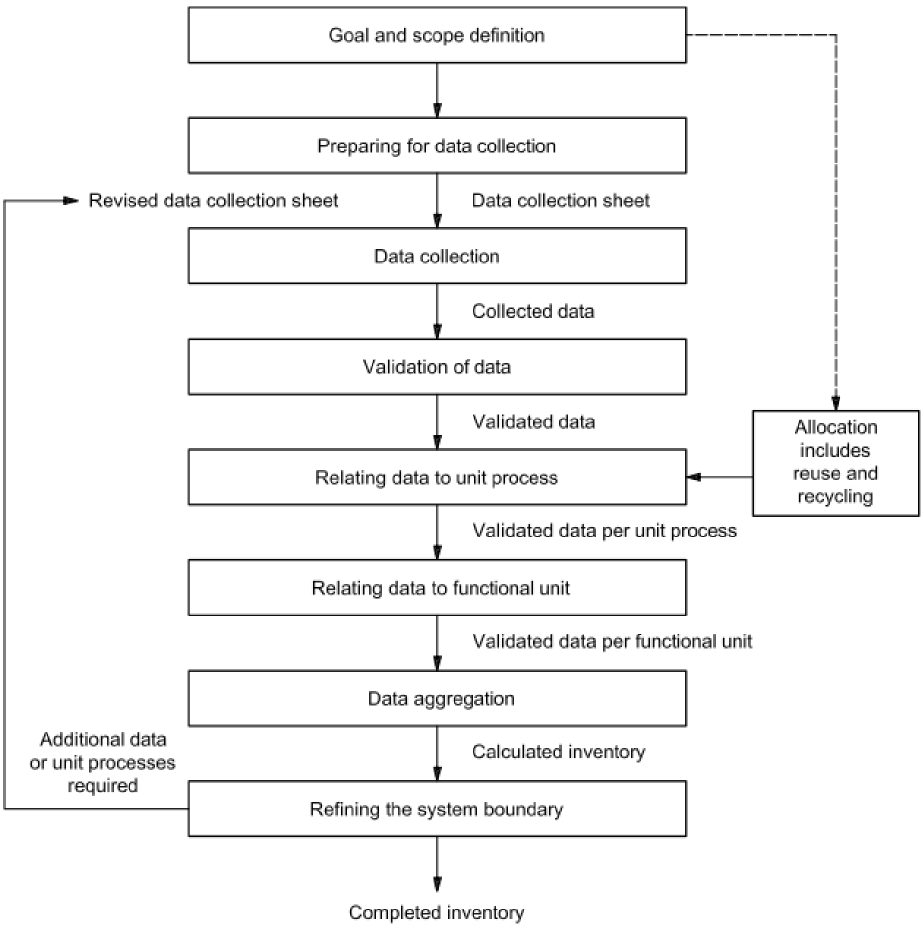



**Figure 18: Simplified procedures for inventory analysis**

4. Life cycle impact assessment (LCIA)

   LCIA is defined in ISO standard as follows: "phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product."

**Table 2. Today's LCIA methodologies (excluding the European Platform on Life Cycle Assessment (LCA) discussed in 7.5.2**

| Methodology | Developed by | Country of origIn |
|---|---|---|
| CML2002 | CML | Netherlands |
| Eoo-indicator 99 | PRé | Netherlands - |
| EDIP97- EDIP2003 | DTU | Denmark |
| EPS 2000 | IVL | Sweden |
| Impact 2002+ | EPFL | Switzerland |
| LIME | AIST | Japan |
| LUCAS | CIRAIG | Canada |

| | | |
|---|---|---|
| ReCiPe | RUN + PRé + CML + RIVM | Netherlands |
| Swiss Ecoscarcity 07 | E2+ ESU-servlces | Switzerland |
| TRACI | USEPA | USA |
| MEEuP | VhK | Netherlands |

To deal with possible omissions and uncertainty of sources, the LCIA phase shall be considered simultaneously with other phases of the LCA. The following considerations shall be made according to ISO standard:

a. whether the quality of the LCI data and results is sufficient to conduct the LCIA in accordance with the study goal and scope definition;
b. whether the system boundary and data cut-off decisions have been sufficiently reviewed to ensure the availability of LCI results necessary to calculate indicator results for the LCIA;
c. whether the environmental relevance of the LCIA results is decreased due to the LCI functional unit calculation, system wide averaging, aggregation and allocation.

The LCIA phase includes the collection of indicator results for the different impact categories, which together represent the LCIA profile for the product system.

The LCIA consists of mandatory and optional elements.

The LCIA phase shall include the following mandatory elements:

- selection of impact categories, category indicators Figure 19 and characterization models;
- assignment of LCI results to the selected impact categories (classification);
- calculation of category indicator results (characterization).

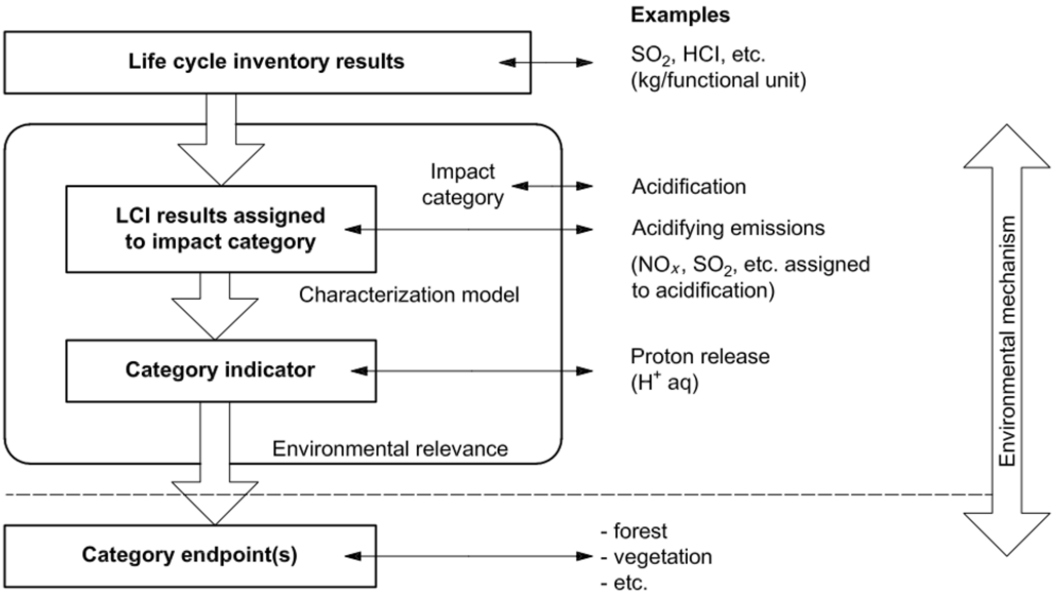



**Figure 19: Concept of category indicators**

5. Life cycle interpretation

The details of life cycle interpretation phase of an LCA are depicted in Figure 20, as follows:

- identification of the significant issues based on the results of the LCI and LCIA phases of LCA;
- an evaluation that considers completeness, sensitivity and consistency checks;
- conclusions, limitations, and recommendations.

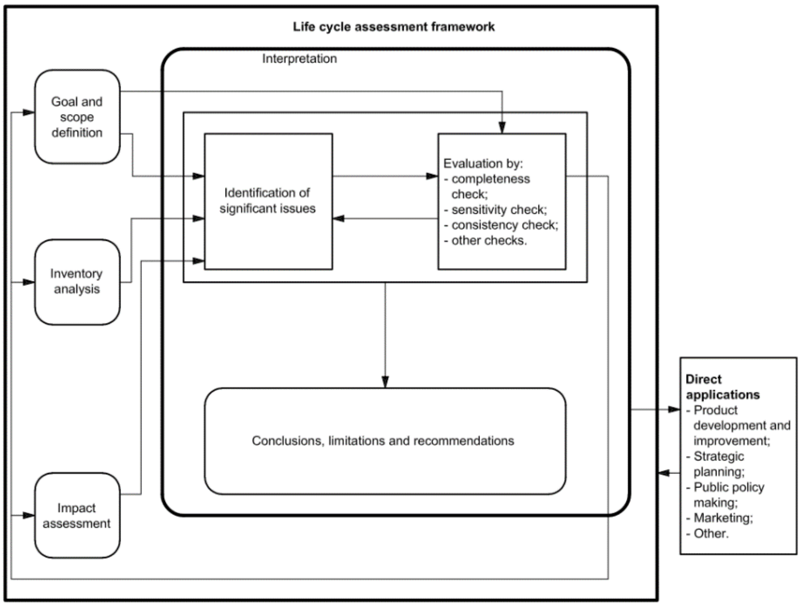



**Figure 20: Relationships between elements within the interpretation phase with the other phases of LCA**

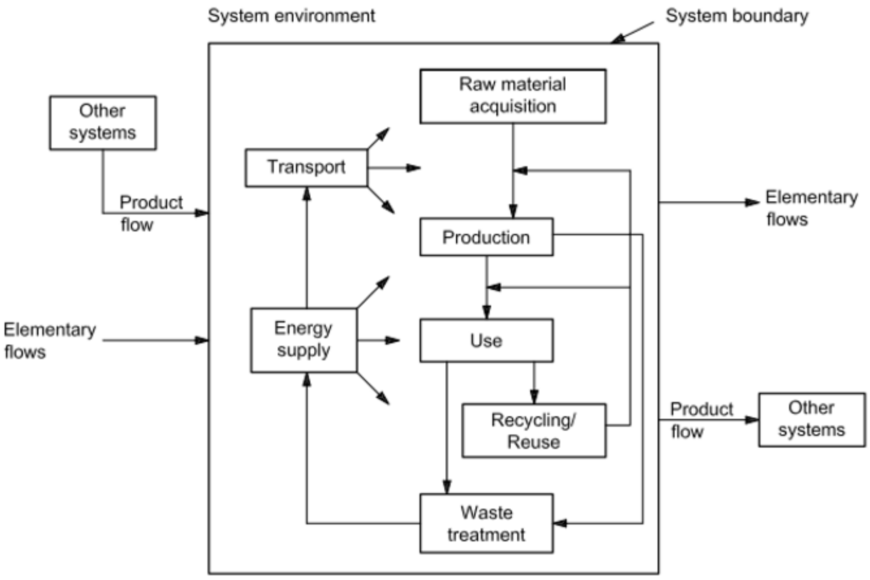



**Figure 21: Example of a product system for LCA**

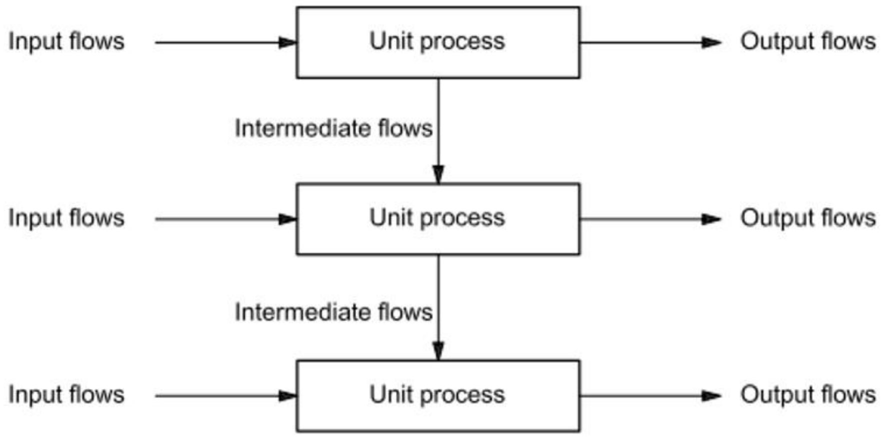



**Figure 22: Example of a set of unit processes within a product system**

### 7.5.2 European Platform on Life Cycle Assessment (LCA)

The European Commission (EC) recognises that Life Cycle Assessments provide the best framework for assessing the potential environmental impacts of products currently available. To this end, the EC provides a platform http://ec.europa.eu/environment/ipp/lca.htm to facilitate communication and exchanges on life-cycle data and launch a co-ordination initiative involving both ongoing data collection efforts in the EU and existing harmonisation initiatives.

The objective is to promote life cycle thinking in business and in policy making in the European Union by focusing on underlying data and methodological needs. The Platform is planned to provide quality assured, life cycle based information on core products and services as well as consensus methodologies.

# 8 Optimal design approach

In the past, optimisation approaches were restricted to mathematical optimisation of well-defined restricted problems. This, associated with the development phase necessary to interface with new domains or tools, restricted the practical interest and effective use of these approaches, even if they are still used for some recurrent problems (for example, shape optimisation of wings-nacelle-pylon in aeronautics.)

However, more recent developments have brought tools allowing a much more flexible and practicable approach in general cases. The purpose of these tools is much larger than pure mathematical optimisation, as they include sets of consistent components which allow to:

- easily configure an optimisation problem (once formalised) and interface with CAD or calculation tools,
- import or generate a large number of designs, relying on the connected tools,
- build approximate models on the basis of available designs, which can be re-used at low cost in the design search,
- analyse relevant design information like trends, correlation between design entities, sensitivities, etc.
- drive the design parameters towards better solutions (optimisation),
- extract best design alternatives,
- help making decision (management of trade-off).

Such tools are to be used, not as a black box providing solutions, but in an interactive way, to provide the maximum number of information which will allow the designer to better understand the problem and make decisions.

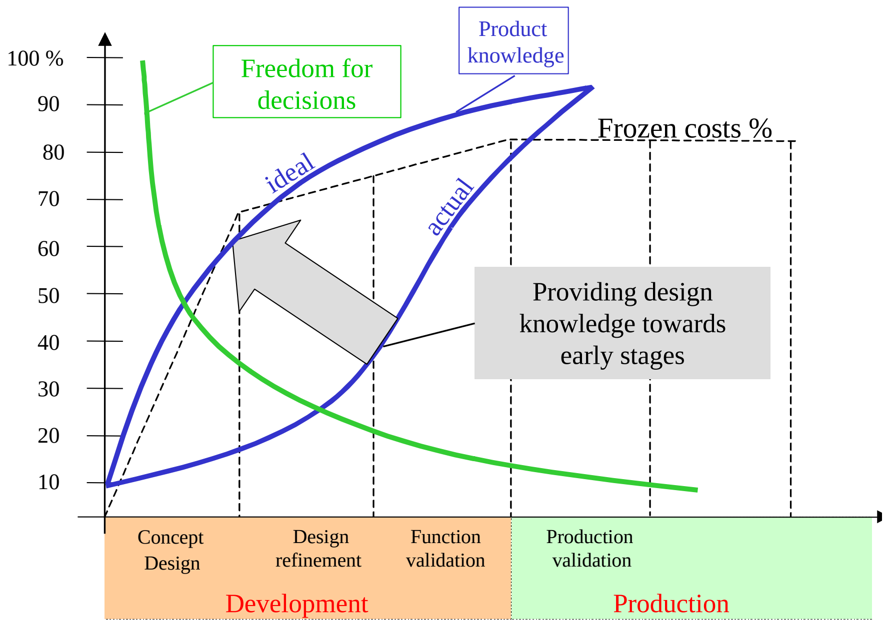
The application of such approach is more or less recent. The most advanced sector is automotive, which uses it on a current basis (ex: AUDI, BMW, CRF, DaimlerChrysler, Denso, Ferrari, FIAT, Ford, GM, Isuzu, Michelin, Nissan, Pirelli, Toyota, Yamaha Motor). The aerospace industry is also using it. In the marine and off-shore sector, some actors already use it on a recurrent basis, however the use of these methods in a complete multi-disciplinary context is still a lit limited.

## 8.1 Optimisation procedures in ship design

The traditional ship design process naturally aims at design optimisation. The involvement in the design process of tools and methodologies specifically focused on design optimisation allows provide much more information on the design trends, at a much earlier design stage, in order for the designer to be able to take relevant early decisions, too avoid losses associated with late modifications or corrections. Figure 23 illustrates the interest of providing early knowledge of the design, in order to take cost engaging decisions when the largest freedom in design is available. [104]

The early availability of knowledge requires being able:

- To formalise the design process in a relevant way, i.e. with the minimum number of most relevant costs or performance drivers and with relevant criteria to judge about the design global performance.
- To generate many alternative designs very early. This requires efficient CAD tools with parameterisation and some automation capabilities.
- To assess these generated designs. This requires efficient and integrated calculation tools, with automation capabilities, in the different concerned areas.
- To extract from the above data the information about design trends, dependencies,
- To isolate best design candidates.
- To make decision towards best trade-off.




Source: FhG/IPK Berlin

**Figure 23: Design process, decision and knowledge availability**

Some tools or methodologies exist, which are able to deal with all the above aspects, except the first one which is highly depending on the domain treated. As regards ship design, the number of functions to be ensured, and the number of components of a ship, makes it difficult if not impossible to formalise the design problem in a global and detailed way. So up to now, the optimal design approach for ship design was used in two extreme types of problems [104]:

- global optimisation of ship at a very early stage, with rough global models involving only main dimensions, global performances calculated with simple tools,
- Optimisation of ship design sub-problems or ship sub-systems (hydrodynamic performance, structural aspects, engine sizing…), the interaction between different domains or disciplines being taken into account outside each optimisation problem.

The current challenge is now to enhance the approach to go towards a global optimisation of a more detailed ship, taking into account most interactions between different design aspects. This will require work at the level of the problem formulation as well as for the optimisation tools. Some work was already undertaken for the latter, see Giassi et al. (2004).

## 8.2 Relevant project examples

### 8.2.1 FANTASTICs

According to [69], the principal objective of FANTASTIC project: "*Functional design and optimisation of ship hull forms"*, (2000 -2003), was to improve ship design by applying parametric shape modelling and state-of-the-art CFD analysis tools to predict ship hull performance. These functional aspects were integrated in an optimisation environment.

The development done in parametric modelling, CFD enhancement, optimal design approaches, and the communication between all these components, made it possible to set up several ship optimisation chains in practical design environments

### 8.2.2 ROROPROB[3]

Since the design of Ro-Ro Passenger vessels continued over the years to be based on the deterministic rules, there was a lack of experience regarding the use of the probabilistic approach and the eventual impact on ship design. This lack of design experience and systematic research, along with the harmonization of the damaged stability regulations on the basis of the probabilistic concept by IMO motivated the set-up of ROROPROB project. "*Probabilistic Rules based optimal design of RORO Passenger ships*." (2000 -2003)

One of the technical and scientific objectives of the project was to develop local and global optimisation techniques for enhanced damage stability characteristics and integrate these within the design methodology.

The most important practical outcome of the project was the development of integrated software tool enabling practical ship design applications which allow finding non-obvious optimised solutions which improve the stability performance and the cargo capacity of the vessel.

The project ROROPROB developed a formalised design methodology for the optimal compartmentation and internal arrangements of passenger Ro-Ro ships, adopting the probabilistic concept of damage stability to address their survivability after damage.

The formalised design methodology coupled with the optimisation procedure for addressing optimally one of the absolutely basic needs of a ship (namely her subdivision), in the form of an integrated computer software is the main result of the ROROPROB project. Its use in practical ship design has been successfully demonstrated by the end users of the project and provided (and will further give) a competitive advantage to the project partners in the future, by supporting the development of cost-effective and safe Ro-Ro designs and creating new opportunities of employment.

[3] http://www.transport-research.info/project/probabilistic-rules-based-optimal-design-ro-ro-passenger-ships

# 9 Object-oriented approach for virtual prototyping in conceptual ship design

Ship designers often struggle with the large amount and variety of information during the conceptual phase. The design resources are considerably complex, since they should handle drawings, analysis and calculations for a wide variety of aspects including stability, hydrodynamic behaviour, structural design, machineries and cargo systems, to name only a few. This complexity spans during the entire lifecycle, from conceptual design to the actual performance in operation and later decommissioning. Therefore, the design elements and their interactions can easily become cumbersome, requiring efficient ways to organize and structure them [31].

For those reasons, it is proposed to use “a design resource supported by objects containing essential data about the ship, as well as basic performance information and links to all relevant design documentation”.

The advantage of this approach is that besides early design, it may also be used during consequent phases as a tool to integrate and maintain the resources through the lifecycle, including virtual prototyping processes.

This tool is a resource aimed at ship design which must offer efficient tools for storage, usage, search and version management, as a way to provide the main organization structure.

With an object-oriented approach, different ships, states and missions may be represented as instantiations of a same prototype class (Figure 24). The tool for virtual prototyping is split in three parts, Entity Model, State Model and Process Model where the tool has different information which can be used for carry out the early design allowing the designer to reproduce the same pattern based on a general description.

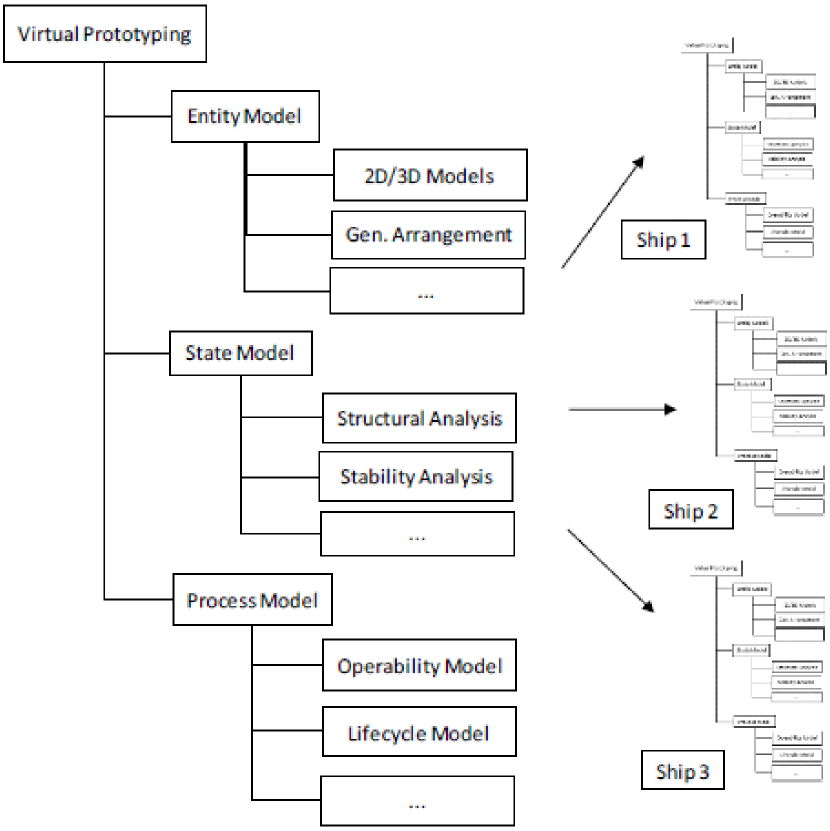



**Figure 24: Ship Virtual Prototype as Instantiated Object [31]**

#### 9.1.1.1 An application example: Shiplab[4]

**SHIPLINES Module**

The main idea behind this design tool is to make the preliminary hull design simple and fast, but it is still necessary to have the user participation during the design process, since an evaluation about the obtained results in each step is important to ensure that the desired results are being reached. If the result of any step is unsatisfactory, the user should refeed the tool, changing some of the input parameters in order to improve the obtained result.

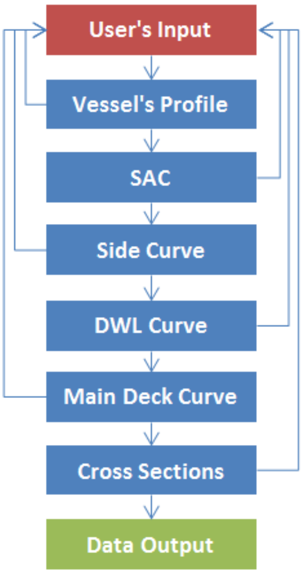



**Figure 25: Methodology Workflow**

**Parametric design module**

The strategy for the parametric design consists of creating a preliminary methodology containing the aspects necessary to describe a vessel based on its operational requirements. The methodology must be flexible enough to incorporate more advanced methods, inputs and outputs, and for this reason is exemplified in its general terms in Figure 26.

The general parametric design toolset should consist of four modules:

i) mission information translated into requirements, connected to field variables (e.g. depth), vessel capabilities (e.g. cargo capacity) and operational attributes (e.g. powering);
ii) Parametric equations are extracted from the parametric study, connecting the mission requirements with expected functionalities of the vessel, as well as these functionalities connected to the vessel main characteristics;
iii) Main design characteristics involve main dimensions (e.g. L, B, D, T), ratios (e.g. B/L, D/B), form coefficients (e.g. CB, CP, CM) and other structural information;
iv) Performance evaluation consists of checking if a vessel with the parameters decided in iii complies with the criteria and expectations.

The last part generates a design description, with the main characteristics and attributes, via an early assessment of key performance indicators (KPIs), such as capital cost and price, space allocation, main equipment, weights and centers, basic stability, powering checks and other attributes able to be benchmarked.

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[4] http://shiplab.hials.org/app/shiplines/

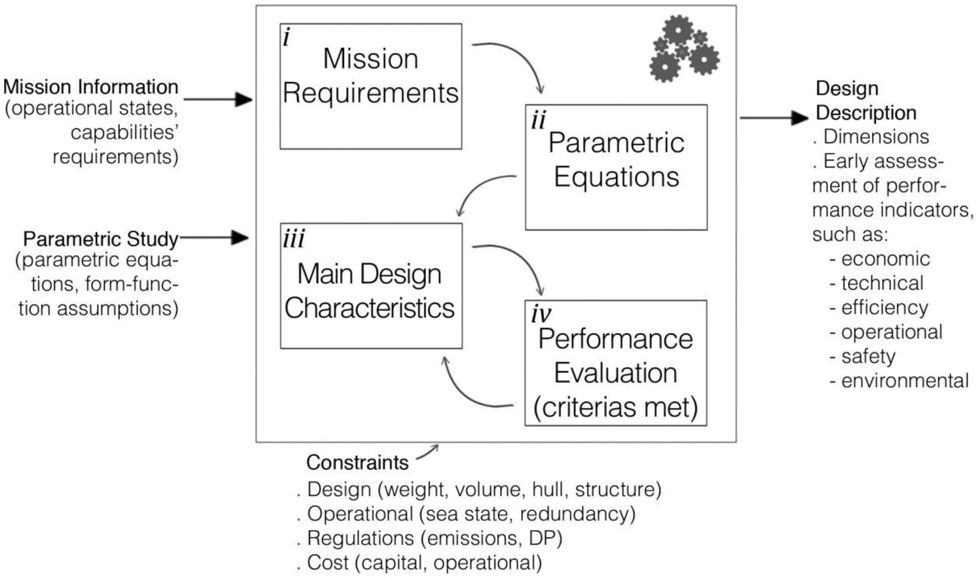
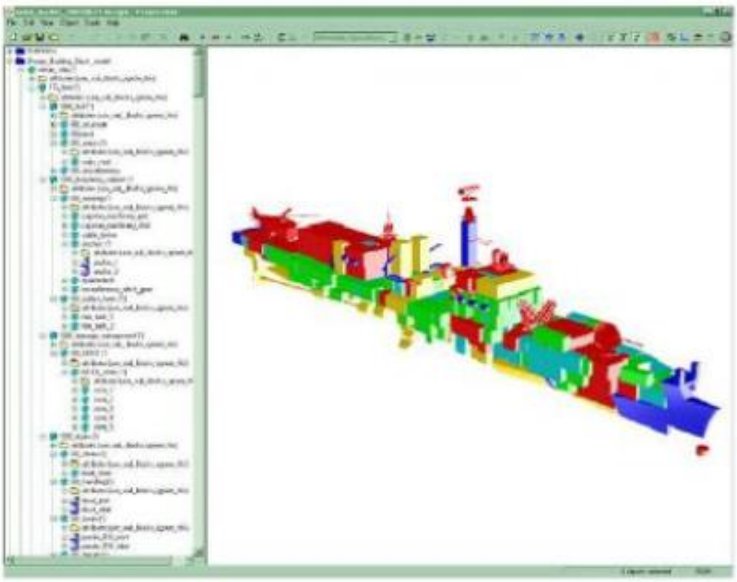



**Figure 26: Parametric Design Methodology**

### 9.1.2 Design Building Block approach and the Library based approach.

#### 9.1.2.1 Design Building Block approach[5]

Building Block methodology is integrated in software denominated Paramarine. Paramarine is an integrated design environment that is based on an object-orientated framework which allows the parametric connection of all aspects of both the product model and the analysis together. In addition to this, development and investigation of a concept design is streamlined by the Early Stage Design (ESD) module This innovative approach is based on UCL's (university College London) Building Block methodology, collating design requirements, product model definition and analysis together to establish the form, function and layout of design.



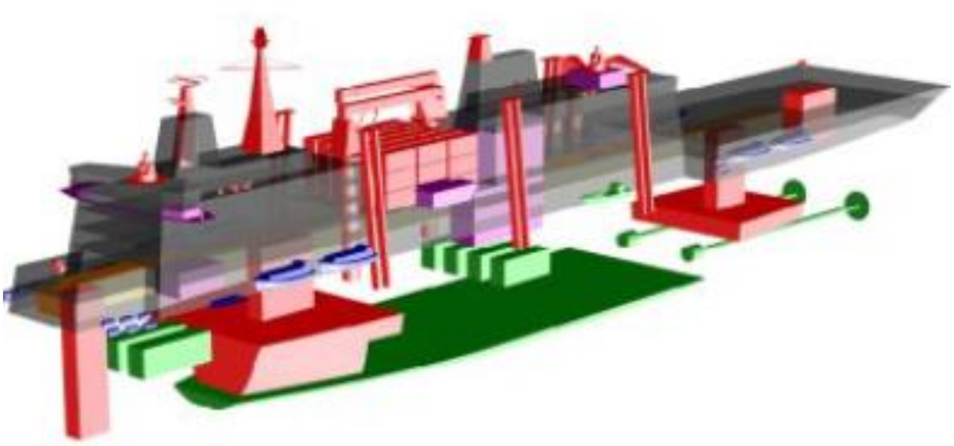
**Source: www.grc.qinetiq.com**

**Figure 27: A frigate represented by its functional Building Blocks.**

[5] Andrews, D.J._2006_Simulation and the design building block approach in the design of ships and other complex systems. doi: 10.1098/rspa.2006.1728

The design is broken down hierarchically in terms of functions (Building Blocks). The building block approach proceeds by refining the top-level functional headings into ever greater detail maintaining a function-based approach throughout

Alongside the refining of the functional definition. The designer can develop a 3D vessel layout and allocate the functional definitions to physical spaces in the ship. It is emphasised that the building block is a functional entity.



**Source: www.grc.qinetiq.com**

**Figure 28: A support vessel design layout**

In the archetypal initial functional breakdown, below the design are the functional areas 'float', 'move', 'fight' and 'infrastructure'. For vessels other than warships, one might substitute functional headings for ‘mission’ or payload for 'fight'. Other desired top level functions such as adaptability, or maintainability can also be used.

This software has different Modules which are:

- Surface Modeler
- Solid Modeler
- Stability Calculator (Launching& docking)
- Stability Criteria - Submarines
- Powering
- Structural Definition (Ships & Submarines)
- Structural Analysis - Submarines
- Submarine Early Stage Design
- Hull Generation
- Design for Production
- Submarine Manoeuvering

The Design Building Block approach provides an integrated model that allows the designer to explore both the configuration and numerical aspects of a design. This model allows the designer to explore innovative design solutions.

### 9.1.2.2 Library based approach.

In comparison with the above, the Library based approach utilises a large library of options to provide the designer with information on acceptable alternatives given a set of requirements or constraints.

# 10 Existing software map

Ship design tasks depend on a large number of supporting software tools. For SHIPLYS it is essential to assess the most commonly used systems and tools. For this reason, a Software Map has been produced, which collects all products identified as relevant by SHIPLYS partners. This map includes an information sheet for each product. It provides details about

- Software sources: commercial, open-source software (from 3rd party or partners)
- Usage status: already used by partners or not yet used, but potentially useful
- Functionalities
  - Early design
    - Drawing generation
    - Surface design, CAD Models
    - System layout (Schematics, …)
    - Analysis (hydrostatics & -dynamics, weight, propulsion, manoeuvring, flow analysis, power balance, …)
    - Simulation (logistics, safety procedures, specific functionality …)
  - Detailed design
    - Structure models
    - Piping, Equipment & Outfitting models
  - Scheduling and Planning
    - Material estimation
    - Material flow
    - Project planning
  - Requirements control
  - Data management

## 10.1 Existing Relevant Products

### 10.1.1 Ship Design Software

The list of existing software for ship design and their capabilities are given in Table 4. The idea is to examine what software solves most of the requirements for the conceptual ship design that are mentioned in the Deliverable D2.1. In selecting the appropriate ship design tool, it should be considered that most of the software are complex and have additional functional characteristics that are irrelevant in the early ship design but that increase their price.

The existing software for ship design are:

- **AVEVA** has different modules. AVEVA's integrated engineering software is used from initial design and specification, through 3D engineering layout to procurement, materials management and project control.
- **CADMATIC** has different possibilities of use. From a CAD/CAM engineering software system for the marine industry, until software is dedicated to 3D modelling of complete industrial projects, through information Management solution.
- **CAFE** - user-oriented software for rapid ship design. Its functionalities are fast modelling capabilities, ship design calculations, 3D ship and equipment models importation, automatic generation of classification drawings, rapid and parametric definition of shipbuilding entities, FE models, automated meshing, FE analysis.
- **Catia –** one of the common CAD-tools used for 2D and 3D design and engineering.

- **CSRS: Common Structural Rules Software** has different modules (5 modules). From *CSR Prescriptive Analysis*, which is a software assesses ship structures, until *CSR FE Analysis,* using finite element analysis to perform direct strength and fatigue assessment of ship structures, via *CSR Stage 1, CSR Spreadsheets and CSR TankCheck Stage 2 & CSR BulkCheck Stage 2.*
- **Delft Ship –** used for 3D hull form modelling; able to perform basic hydrostatic and resistance calculations
- **Foran** – Integrated Shipbuilding CAD/CAM/CAE system that, because of its high-level features, adaptability and customization, can be used to design and build any type of ship or marine structure.
- **Maestro** - design, analysis and evaluation tool for floating structures. Its functionalities are finite element analysis, structural limit state evaluation, structural design tool, linear static analysis, natural frequency analysis, optimization, ship-based loading patterns, possibility to include criteria from classification society.
- **Mars2000** – allows to check the scantling of any transverse sections or any transverse bulkheads all along the ship length.
- **MaxSurf –** used to improve the hull surface fairness and refinement of the hull, the addition of appendages, compartmentation, etc. It offers the capability to calculate basic hydrostatic calculations and perform intact and damage stability (including probabilistic) analysis.
- **NAPA** for Design incorporates state of the art hull surface and 3D model definition with advanced hydrodynamic, stability and structural design software tools, thus enabling the handling of all aspects of eco-efficiency at the early design stages in a single software system.
- **NAUTICUS HULL:** It used for strength assessment of hull structures and offers different tools for efficient hull design and verification according to DNV GL Rules and IACS Common Structural Rules for bulk carriers and oil tankers.
- **NavCad** –used for the design and analysis of virtually any type of monohull or catamaran – from large displacement vessels to fast planning craft. Its features are bare-hull resistance prediction, steady-state propulsion analysis, added resistance, propeller selection, hull-propulsion interaction, vessel acceleration, supplemental analyses.
- **ParaMarine** – a fully integrated Naval Architecture tool. It offers concept design, stability assessment (both damaged and intact), manoeuvring performance, powering and endurance, seakeeping, structural analysis.
- **Pias** – used to create, calculate and analyse ship design. Its features are hull design and lines plan, hydrostatics and intact stability, resistance and propulsion, and damage stability.
- **POSEIDON-** is an integrated software for the strength assessment of ship hull structures**.** Its target is concentrate on designing with efficient dimensioning support.
- **Rapid Ship Evaluation Tool** (BMT) using Computer Algorithms
  The core function of the tool is the population of compartments required to meet user-input capability needs and arrangement of compartments into a feasible design. This task is performed by a bin packing algorithm augmented with a genetic algorithm to search the space of potential solutions. Both of these components are implemented in C++ and the genetic algorithm uses the GAlib library of genetic algorithm components written by Wall [M B Wall, 'Overview of GAlib', http://lancet.mit.edu/ga/, Massachusetts, USA.].
- **Rhino** - 3D surface editor primarily used when working with hull forms. Capable of handling IGES and STEP files amongst many others.
- **RULESCALC** RulesCalc helps improve the efficiency of the initial design process. ShipLoad operates on the basis of nodes, elements, and materials as used in any standard FE program. It can be used for the verification tod the compliance against the classification rules, to track down

corresponding rule failures and to rapidly identify areas of concern and the design modifications that might be required.

- **SAFEHULL:** Finite Element Analysis software for the design and the evaluation of hull structures for tankers,containers,and bulk carried based on steel vessel rules.
- **SESAM GENIE:** It´s a tool for designing and analysing offshore and maritime structures made of beams and plates – integrating stability, loading, strength assessment and CAD exchange
- **ShipConstructor** – an AutoCAD based software product line created for design, engineering and construction in the shipbuilding industry.
- **SHIPLOAD,** Global FE analysis software Shipload has possibility of select and generate design loads for global FE analysis of ship structures.
- **SHIPRIGHT** ShipRight is Lloyd's Register's design assessment tool for structural and fatigue assessment and forms part of our Classification service offering.
- **SimulationX** – the multiphysics simulation software for analyses and optimizations of ship systems.
- **SolidWorks** – solid modelling CAD and CAE computer program.
- **VERISTAR HULL:** VeriSTAR Hull powered by FEMAP is a powerful finite element tool for building and managing safe and optimum designs. It combines the well-known FEMAP processing tool and the proven NX and MSC Nastran solvers with in-house developed features for fast and efficient modelling and results assessment.

**(Table 3 on the next page.)**

## Table 3. List of ship design tools

This list is indicative of key design tools being considered. There may are other software not included in this list at this stage of the project but will be reflected in the software map that will be updated from time to time.

| | Ship main particulars | Shaft Horsepower | Freeboard | Lightweight | Cargo Capacity | Deadweight | Initial Stability and Seakeeping | CAPEX / OPEX | Mid-ship Section Scantling and Progressive Collapse | Probabilistic Description of Still Water and Wave induced Loads | Probability of structural collapse | Minimize investment cost, operational cost, and probability of structural failure. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **General & Marine 3D CAD tools-** | | | | | | | | | | | | |
| Aveva Marine Hull | **M** | N/A | **M** | **M** | **M** | **M** | N/A | N/A | N/A | | | |
| Fdesign (SENER) | **M** | N/A | **M** | **M** | **M** | **M** | N/A | N/A | N/A | N/A | N/A | N/A |
| Nupas/Cadmatic | M | N/A | **M** | **M** | **M** | **M** | N/A | N/A | N/A | | | |
| Rhino | **M** | N/A | **M** | **M** | **M** | **M** | N/A | N/A | N/A | N/A | N/A | N/A |
| SolidWorks | **M** | N/A | **M** | **M** | **M** | **M** | N/A | N/A | N/A | N/A | N/A | N/A |
| ShipConstructor | **M** | N/A | **M** | **M** | **M** | **M** | N/A | N/A | N/A | N/A | N/A | N/A |
| **Naval Architecture design tools -** | | | | | | | | | | | | |
| Aveva Initial Design | **M** | **A** | **A** | **A** | **A** | **A** | **M** | N/A | | | | |
| CAFE | **M** | N/A | **A** | **A** | **M** | **M** | **A** | N/A | **M** | N/A | N/A | N/A |
| Delft Ship | **M** | N/A | **A** | **A** | **A** | **A** | **A** | N/A | N/A | N/A | N/A | N/A |
| Foran Design | **M** | **A** | **A** | **A** | **A** | **A** | **M** | N/A | **M** | | | |
| MaxSurf | **M** | N/A | **A** | **A** | **A** | **A** | **A** | N/A | **M** | N/A | N/A | N/A |
| Napa | **M** | **A** | **A** | **A** | **A** | **A** | **A** | N/A | **M** | | | |
| NavCad | **M** | **A** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| ParaMarine | **M** | **A** | **A** | **A** | **A** | **A** | **A** | N/A | **M** | N/A | N/A | N/A |
| Pias | **M** | N/A | **A** | **A** | **A** | **A** | **A** | N/A | N/A | **A** | **A** | N/A |
| Rapid Ship Evaluation Tool | **M** | | **A** | **A** | **A** | **A** | **A** | **M** | | | | |
| SimulationX | **M** | **A** | **A** | **A** | **A** | **A** | **A** | **A** | **A** | **A** | **A** | **A** |
| Shipload | **M** | A | **A** | **A** | **A** | **A** | **A** | N/A | N/A | N/A | M | N/A |
| **Tools mainly focussed in structural modelling and scantling verification** | | | | | | | | | | | | |
| CSRS | **M** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | **A** | N/A | M | N/A |
| Maestro | **M** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | **M** | N/A | N/A | N/A |
| Mars2000 | **M** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | **A** | N/A | N/A | N/A |
| Nauticus Hull | **M** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | **A** | | **M** | N/A |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Poseidon | **M** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | **A** | **A** | **A** | **N/A** |
| RulesCalc | **M** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | A | N/A | **M** | N/A |
| Safehull | **M** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | **A** | | | |
| Sesam GeniE | **M** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | **A** | **A** | **A** | N/A |
| Shipright | **M** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | **A** | | | N/A |
| Veristar Hull | **M** | N/A | N/A | N/A | N/A | N/A | N/A | N/A | **A** | | | |
| Others tools: This list is indicative of key design tools being considered. There may are other software not included in this list at this stage of the project but will be reflected in the software map that will be updated from time to time. | | | | | | | | | | | | |

* M – manual; A – automatic; N/A – not applicable

### 10.1.2 Available optimisation tools[6]

Many dedicated tools are available in commercial software tools, like CAD tools or CAE packages like FEM codes for example. These tools are normally very efficient in the context of the domain covered by the package itself.

There are now complete environments dedicated to optimal design and able to deal with any set of analysis tools. One of them is the "**modeFRONTIER environment**" [7]. The capabilities of such a tool cover:

- The easy integration of any analysis tool using text files as inputs/outputs and able to be run in batch mode, and with specific connection with current tools (excel, matlab…). Several calculation chains can be managed, thus allowing multi-disciplinary problems.
- The formulation of the calculation and optimisation process in terms of design variables, outputs, objectives, constraints,
- The import (existing database) or generation (design of experiments techniques) of candidate designs databases,
- The construction and adjustment of mathematical models based on a design database (response surfaces, neural networks…),
- The optimisation functionality, starting from a given set of designs and operating any algorithm within a large range of available algorithms, thus allowing to smoothly adjust the search strategy to the
- Design problem, including multi-criteria multi-objective aspects (pareto search),
- Analysis of designs database to extract maximal information: trends, sensitivities, correlations, statistical characteristics, designs filtering, etc…
- Multi-criteria decision making tools, enabling to sort out a number of candidate designs from a limited set of choices and preferences set up by the designer, within a multi-dimensional design space. This may be performed on any database (imported or generated) where designs are defined through a finite number of attributes within which the designer can show preferences.
- Generation of perturbation and extraction of robustness information as well as performance information (robust design).

***<u>"modeFRONTIER"</u>***

"modeFRONTIER" streamlines the design process with powerful workflows, innovative algorithms and sophisticated post-processing tools allowing the user to perform statistical analysis, data visualization

[6] Document Id. SAFEDOR-D-5.1.2-2005-08-15-GL-decision-making.

[7] http://www.esteco.com/modefrontier

and decision making. Its multidisciplinary design enabling technology, critical to successful new product development today, keeps it at the forefront of engineering technology.

## FRIENDSHIP-Modeler

On the other hand, another tool, **FRIENDSHIP-Modeler**, exists. It features a flexible set of parameters of which some are mandatory, other are optional. The hull generation process is subdivided into three subsequent steps: The creation of longitudinal curves - so called basic curves-, the generation of transverse curves (usually sections) based on information retrieved form longitudinal curves and, finally, the generation of surfaces by interopoling the trasversal curves.

FRIENDSHIP is a ship hull design tool conceived towards parametric modelling. The main aspect that can be relevant are:

- Its ability to generate shape from the entities classically used by ship designers (dimensions, coefficients,…) rather than from CAD entities (points, angles..).
- Its ability to recover existing shapes and generate parametric model from them.
- The robustness of the shape generation during variations, both in term of process and quality of generated shapes.
- Its ability to communicate with other tools.

The counterpart of these aspects is that is based on a wide but not exhaustive list of ship features, and features specific to some ships have to be developed if not already present.

## *LBR5 tool*

LBR5 tool**,** which was developed by the ANAST laboratory of Liège University, with the support of Chantiers de l´Altantique. It is a rationally based **optimisation module** to be used in preliminary design stage, and which allows:

- A 3D analysis of the general behaviour of the structure,
- Taking into account all the relevant limit states of the structure (service limit states and ultimate limit states) thanks to a rational analysis of the structure based on the general solid mechanics theory.
- An optimisation of the sizing/scantling (profile sizes, dimensions and spacing) of the structure components.
- To include the unitary construction cost and the production sequences in the optimisation process, through a production oriented cost objectives function.

## *ASSET*

The Advanced Surface Ship Evaluation Tool  is a family of interactive computer programs for use in the exploratory and feasibility design  phases of naval surfaces ship. The primary purpose of ASSET is to perform the initial prediction of ship physical and performance characteristics based on mission requirements and to do so with sufficient fidelity that the total ship implications of subsystem level design and technology decisions are evident.

To develop a design in ASSET, the designer runs each of the design synthesis modules individually, selecting design methods and criteria and inputting the design characteristics and configuration options appropriate for that discipline. Once this initial input has been completed, the Synthesis process is executed. Synthesis executes this group of modules sequentially in a manner analogous to a design spiral. After each iteration through the design synthesis modules, the ship characteristics are checked for convergence and the iterative process continues until a mathematically coherent and balanced design is achieved.

The design synthesis modules include, hull geometry, hull subdivision, aviation support, deckhouse, hull structure, appendage, resistance, propeller, machinery, auxiliary systems, weight, space. ASSET Analysis Modules allow the designer to evaluate the performance of the current ASSET model while not modifying the design. Analysis modules currently available with ASSET are performance, seakeeping, hydrostatics including damage stability.

***PASS***

Parametric Analysis of Ship Systems (PASS) is a system developed in the USA by the Band, Lavis & Associates company under a Small Business Innovation Research (SBIR) project for the U.S. Navy's Office of Naval Research.

The model emphasises the use of algorithms derived from first-principle physics rather than from empirical data to characterise all major subsystems and their synergistic relationship to the overall ship. This has been achieved in order to ensure that newly emerging technologies can be realistically modelled without being unduly biased by existing trends in ship or ship-subsystem design.

In each case, algorithms are used to characterise subsystems by weight, volume, cost, energy consumption and the interface with other ship systems, as appropriate. The overall objective was to develop a design synthesis tool that recognises current or projected future fleet requirements and operational priorities and permits a realistic assessment to be made of the cost-benefits of emerging technologies. **The model uses an Object-Oriented Architecture** and a Windows-based Graphical User Interface (GUI) to allow for easy use.

Other uses of the model include those in which the impact of changing operational requirements are easily examined and those in which design-to-cost trade-offs are conducted for determining the preferred selection of hull form and subsystem choices.

The design process used is iterative and simulates the conventional ship-design spiral. Modules are currently included for the design of the hull structure, propulsion plant and for the characterisation of the electrical system, auxiliaries and outfit and furnishings and for the assessment of stability and seakeeping for ships. Modules have been developed for ships having both conventional and advanced hull forms including displacement monohulls, semi-displacement monohulls, planing monohulls, semi-SWATH, catamarans and trimarans.

**AVPRO**

AVPRO is a preliminary design software dedicated to the naval architect, developed on bases and principles similar to PASS by Principia Marine [5]. It is used to initiate the first iteration of the design: hull form, mid-ship section, stability, propulsion assessment, general ship arrangement and weights estimates are defined within a short timeframe, albeit in a rough form. AVPRO algorithms are based on first principles as much as practically possible, thus offering a rational design solutions rather than an empirically derived one. This approach offers significant advantages when dealing with innovative designs

### 10.1.3 LCA software available

There are several LCA software available, either commercial or open source. Some of them are as mentioned here:

- ***TEAM tm* ( *http://ecobilan.pwc.fr/fr/boite-a-outils/team.html*)**

  Life-Cycle Assessment software package from the Ecobilan Group. TEAM 5.2 allows the user to build and use a large database and to model any system representing the operations associated with products, processes and activities.

- ***EcoPro***

ECOPRO is a German program running on Windows. While ECOPRO allows for the systematic construction of product life cycles, it enables you to define specific system boundaries.

- ***GaBi*** ***(http://www.gabi-software.com)***

The latest GaBi version is **GaBi 5** a tool for building up life-cycle-balances which provides solutions for different problems regarding cost, environment, social and technical criteria. GaBi 5 gives support with handling with a large amount of data and within modelling of the product life cycle. In addition the software helps optimizing processes and managing the external representation in these fields.

- ***KCL – ECO(http://www.buildup.eu/en/learn/tools/kcl-eco )***

*Life cycle assessment calculation program, KCL-ECO that can handle large systems. KCL-ECO's special features are: graphical user interface, impact assessment using different methods, sensitivity analysis, agglomeration function, graphic processing of results.*

- ***OpenLCA (http://www.openlca.org/ )***

*OpenLCA is a free software for life cycle modelling and it can be connected with many commercial or free database such as GaBi database, ecoinvent and ELCD. The open source of this software is another advantage which can be connected with user-defined code as well.*

- ***SimaPro (https://www.pre-sustainability.com/simapro)***

SimaPro is a full-featured LCA software tool. Complex products with complex life cycles can be compared and analysed. The process databases and the impact assessment databases can be edited and expanded without limitation. The ability to trace the origin of any result has been implemented in a very flexible and powerful way. Special features are: multiple impact assessment methods, multiple process databases, automatic unit conversion. Furthermore, there are powerful tools to analyse take-back and disassembly of products, as well as complex waste treatment and recycling scenario. Free demo!

- ***Umberto (https://www.ifu.com/en/umberto/)***

Umberto® is a versatile and flexible software tool for Life Cycle Assessment (LCA) and Eco-balancing based on the unique method of material flow networks (MFNs). Comprehensive database with predefined transition modules (raw materials, materials, handling processes, waste processing, etc.).

- ***Boustead Model (http://www.ghgprotocol.org/Third-Party-Databases/Boustead-Model)***

The Boustead Model is a computer modeling tool for lifecycle calculations. It contains a core set of industry-derived data files with information on a range of different fuel production and materials processing operations.

- **LCAiT**

LCAiT is a software for life cycle assessment which calculates the environmental performance of products, services, and organisations.

There are many other different types of LCA software but some of them are not assessable so there is little information available, such as: LMS Eco-Inventory tool, Ocko Base, PIA and PEMS. The software tools presented in this deliverable are the most commonly used and more details of the software can be derived based on the given links. For GaBi software as an example, there are many researchers from many different projects using it for LCA analysis.

Gabi was applied by [42] to assess the environmental impact of municipal solid waste (MSW) management in Hangzhou, China with mechanical treatment of waste and incineration incorporated. The results showed that the application of MSW management can reduce up to 33% of global warming potential in the city. [27] conducted a life cycle assessment using Gabi to compare the recovered cotton from recycled garments with cotton from traditional and organic crops. The research illustrated the organic cotton cultivation has a positive impact on environment protection which avoids using pesticides or chemicals but still have some pollution from ginning and dyeing processes just like traditional cultivation. However, the cotton recover process doesn't involve any of these processes (insecticidal, ginning or dyeing process) which means it is a much more environment friendly process. Another LCA on alkaline hydrogen fuel cell is carried out by [117] applied LCA analysis in GaBi aiming to find the impact of using gas atomised sponge nickel instead of cast and crush sponge nickel and platinum. [86] applied LCA method to evaluate the carbon footprint during local visitors' travelling in Brazil. A case study of route from Rio de Janeiro to Sao Paulo was conducted and also as a result of using bio-fuel, the study indicated the most carbon efficient travel mode is overland public transportation.

In ship building industry, LCA is also applied in order to determine the environmental impact and cost investment. [12] investigated the environmental impact of two different hull paintings and three types of ballast water treatment systems with their cost assessment. With LCA model, the impacts from different scenarios were determined which recommended the ship builder and ship owner the best option considering both cost and environment assessments. [56] applied the LCA method and conducted a case study to evaluate the benefit of installation of a hybrid power system on a Ro-Ro vessel. They concluded that the life cycle of a new-build hybrid power system was imperative which would help determine the significant impact on the environment, human beings and natural reserves so that proper decision and consideration can be made.

Researchers have evaluated these software tools based on their characteristics. Evaluation results of some LCA software is presented in the followings tables.

**Table 4. Evaluation results of LCA software for product and process ([22])**

| Characteristics | GaBi | KCL-ECO | LCAiT | PEMS | Sima Pro | TEAM |
|---|---|---|---|---|---|---|
| Functionality | 5 | 4 | 4 | 3 | 2 | 4 |
| Flexibility | 3 | 3 | 3 | 3 | 3 | 4 |
| Database | 4 | 2 | 4 | 3 | 4 | 5 |
| User-friendless | 5 | 4 | 3 | 2 | 2 | 3 |
| Software properties | 3 | 4 | 3 | 3 | 3 | 2 |
| Service | 5 | 4 | 3 | 3 | 3 | 5 |
| Cost | 4 | 2 | 3 | 3 | 5 | 2 |
| Note: The evaluation ranges from 1 (very negative) to 5 (very positive). As this evaluation was based on a subjective evaluation method, to highlight that other individuals may come to different findings | | | | | | |

**Table 5. Comparative evaluation of most interesting software tools for LCA ([22])**

| Characteristics | GaBi | KCL-ECO | LCAiT | PEMS | Sima Pro | TEAM |
|---|---|---|---|---|---|---|
| Graphical Interface | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Data Protection | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Unit Flexibility | ✓ | ✓ | ✓ | | ✓ | ✓ |
| Use of Formulas | ✓ | ✓ | | | | ✓ |
| Uncertainty Analysis | ✓ | ✓ | | ✓ | | ✓ |
| Impact Assessment | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Comparison of Results | ✓ | | | ✓ | ✓ | ✓ |
| Graphical Display of Results | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

**Table 6. Summary of LCA software specifications based on [99]**

| Specification | Boustead's Model | TEAM[tm] | EcoPro 1.3 | GaBi 2.0 | KCL - ECO | LCAiT 2.0[a] | LMS Eco-Inventory | Oeko-Base Windows[TM] | PEMS 3.0 | PIA | SimaPro 3.1 | Sima Tool |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Volume of data | v high | v high | low | high | low | med | Low[b] | low | high | med | high | high |
| UK appropriated data | ✓ ✓ | ✓ ✓ | | ✓ | | ✓ | | | ✓ ✓ | ✓ | ✓ ✓ | ✓ ✓ |
| Windows ™ based | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | |
| Network Capability | g | ✓ | g | g | g | g | ✓ | g | g | ✓ | ✓ | g |
| Impact Assessment | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ c | ✓ | ✓ | ✓ | ✓ |
| Graphical impact ass'mt | Via supplied Excel[TM] Graph Marco | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ c | ✓ | ✓ | ✓ | d |
| Graphical inventory anal' | | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ c | ✓ | | ✓ | d |
| Auto sensitivity analysis | | ✓ | | | ✓ | | | | | | | ✓ |
| On line help | See below[e] | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Flow diagram capability | | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| Restriction inputs' output'[e] | g | No limit | g | g | g | 16 | g | g | 24 | No limit | g | No limit |
| Demo Version | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |

[a] Unluckily this software is no longer available
[b] With the review of BUWAL data in June 1996, the volume of data will increase, as will the available process data
[c] BUWAL 133 (Methodology of "ecological scarcity"
[d] Graphical display of impact analysis and inventory analysis can be achieved via a spreadsheet export file
[e] The Boustead model is not supplied with on line help. However the model is supplied with a comprehensive user manual
[f] Restriction on the number of inputs/outputs into a specific process card etc. This can be remedied by adding dummy cards
[g] Not specified

*Note: As this table is from 1997 – some improvements have been incorporated in the latest version of these software tools.*

### 10.1.4 Operation available tools

**FORESIM (NTUA)**

FORESIM is an in-house developed methodology that can be used for **freight rate forecasting**. This approach was introduced in order to produce freight rate modelling, long and short-term forecasts and prediction error calculation analysis. More specifically, under the scope of modelling the shipping market, an explanatory model was built using Artificial Neural Networks and Monte-Carlo simulation. In this way the shipping market macroeconomic parameters are taken into account and statistical series are processed giving relative predictions/forecasting of the market.

The methodology uses MS Windows platform and the programming sub-modules used are SPSS, NEUROSOLUTIONS and MATHEMATICA. The prediction mechanism can be used for long-term forecasting of the market for LCA as well in the frame of SHIPLYS.

## 10.2 Existing Relevant Project Results

As described in the previous sections, there are results from recent Research and development projects which are relevant for SHIPLYS. Some recent applications in the maritime domain are given below, both from R&D and consulting origin

- SHIPLYS LCT will incorporate several rational decision support approaches that consider not only economic, but also environmental and risk factors. This concept is similar to one of the MAINLINE project main outputs – a lifecycle tool named “MAINLINE LCAT (life cycle assessment tool)”.
- SHIPLYS can build on the work done on the MCDA framework developed for MOSAIC. In MOSAIC, one of the criteria in the mcda framework was to compare between life cycle costs of composite materials being introduced or a new type of propeller and the associated risks; and, between capacity/function and its impact.
- According the ENVISHIPPING methodology, an integrated framework for the analysis of the total environmental footprint of ships was created. The framework considered the ship as a system that may be detailed into sub-systems and further more into system elements - this cut down process was consistent with familiar practices used in shipbuilding operations. The framework structure enabled the identification and examination of all important pollution drivers of the ship (e.g. air emissions, oily and non-oil wastes, ballast water, garbage, noxious substances, etc.) on a life cycle basis. For each one of these system elements the basic features in a context of a life cycle approach were identified and elaborated as (a) inputs, (b) processes, and (c) outputs (in the form of specific pollution drivers).
- Within ECOMARINE, a sustainability and eco-efficiency report was produced applying LCC/LCA and cost-benefit analyses. Construction, installation and operation costs were taken into account as well as different TEG types, engine fuels and loading conditions to produce quantitative LCC results and investment repayment period. Furthermore LCA assessment was carried out based on specific assumptions related to various application opportunities.
- SAFEDOR aimed as well to provide the necessary conceptual and practical developments to facilitate the implementation of risk-based design. In terms of the conceptual developments, the main objective was to consolidate a high-level understanding of risk-based design as a process in the light of current ship design practice.
- Although RiskWISE® focusses on risk assessment (RA) during operation & maintenance (O&M) stage, and API 581 is mainly intended for oil, gas & chemical plant and power plant, the fundamental framework / procedure and supporting theory for RA is relevant to the development of SHIPLYS RA model. In SHIPLYS, the development of the RA module requires a through life perspective. Such risk assessments are particularly important in scenarios where novel concepts

are being proposed or modifications to the original design (such as in retrofitting) are being considered.

- Shape optimisation for hydrodynamic purpose, involving various parametric modelling tools and hydrodynamic codes was addressed in FANTASTIC project.
- Ship structure optimisation: parametric modelling of main ship structural components, optimisation including plates thickness and stiffeners definition for a global mass minimisation and regulatory constraints (ex:LBR5). Use of specific calculation tools or regulatory tools (ex: mars2000, BV).
- Ship internal subdivision optimisation for damage stability purpose: maximisation of damage stability criteria and of cargo space, minimisation of ship displacement (ROROPROB)
- Cost optimisation, based on global rough models involving main ship characteristics, production related cost, operation costs, financial aspects, with return on investment and freight rate as objectives
- Exploitation of ships database to build models in terms of performance and costs, and exploit these models to search for new candidate ships for given specification.
- Cognisance of data available at the European Platform on Life Cycle Assessment (LCA) will be taken to determine if and how such data and functionality can be used in SHIPLYS.

# 11 Conclusions regarding relevance to SHIPLYS

## 11.1 Overall framework

**Figure 29** is an indicative representation of the data required for the initial ship design. The data are arranged as input and output parameters for each task that should be integrated within the SHIPLYS project. This is the preliminary concept that should be taken further in D3.2.

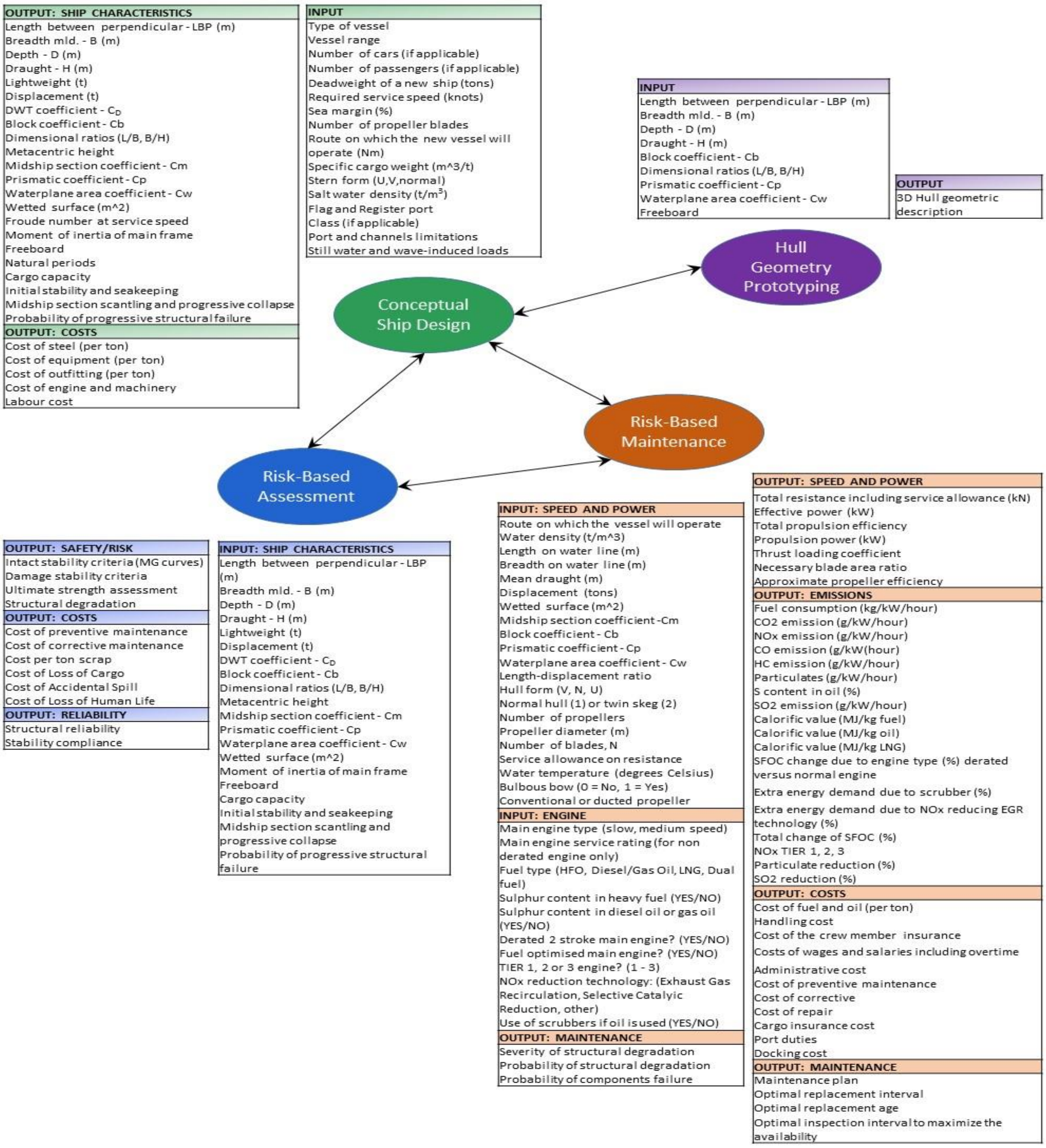



**Figure 29: Indicative list of Input-output parameters**

## 11.2 Models and data requirements

The intended use of the mentioned ISO 10303 activity models in SHIPLYS is to provide the underlying model to be used as guidance in work flow control.

The ISO activity models can be considered to provide a well elaborated starting point for the definition of a detailed process flow model to be applied in the envisioned SHIPLYS design tools and the surrounding framework.

In addition, the software based modelling approach can be used to create a machine-readable representation which is an important feature for use in SHIPLYS. Since the publishing date of the relevant parts of ISO 10303 some modifications have surely become necessary, not least due to the wider availability of new or improved computational methods.

While the standards ISO 10303 and ISO 15384 doubtlessly provide a broad foundation for creating a full-blown data model for SHIPLYS they nevertheless do not cover all aspects relevant to the project. The following areas will require further data model development:

- Production data
- Shipyard facilities (a lightweight shipyard production asset model)
- Processes and Resource definitions
- Analytical Data and Computation Supervision
- Operational Data (Life Cycle)

### 11.2.1 Challenges for use of optimisation in ship design

As indicated in [104], the main challenge for the use of optimal design approaches in ship design lies in the formulation of the ship design problem, in a way to address a sufficient level of details in a way manageable by the optimisation tools.

The ship is a complex system involving many disciplines and functions, and made of very numerous components. As optimisation is basically relying on the capability to make the design vary through a set of free variables, the main difficulty is to have a consistent description of the whole design and of its variations, through a restricted number of driving parameters. This obviously requires some work on the ship description, and the management of the interactions of the master parameters with the ship description, for a given level of details. This "parameterisation" problem is the key one. Some solutions to this problem might be provided by the integrated naval architecture packages (like for example Paramarine, which is a design and analysis package for surface and subsurface marine vehicles and systems) which theoretically enable a consistent associative description of the ship components. Anyway, some more reflection must be led with ship designers on this topic to get efficient solutions.

The tool **Paramarine** is so named because of the parametric relationship of data throughout the design as it develops. Paramarine uses object orientation, the design being held in a hierarchical design "tree" structure of functional objects that apply to specific geometry or analysis categories." In this way, it should be well adapted to the generation of consistent design variants and to their analysis, within an optimisation / decision making approach.

A secondary challenge concerns the availability and integration of models to be used to assess ship performance in the various involved disciplines, as well as costs. It appears that not all disciplines can rely on well validated tools (ex: model tests are still necessary for the assessment of some performances…), some of these tools are expensive in manpower and/or computing resources, and with incompletely controlled accuracy, which make them difficult to be involved into an optimisation process, especially when looking for a short design stage. So the challenge is to have available a set of assessment tools, consistent with the wished design level in terms of accuracy and required resources, and covering the whole range of domains involved in performance and costs assessment.

***Note on decision making:***

The above approach is strictly related with optimisation, requiring parametric variations capabilities. It is important to notice that the use of decision making tools to help the designer to make choice don't necessarily require such automatic parametric variations, and can be used for an objective selection of trade-off, from designers preferences, within a set of alternative designs, wherever these designs come from (parametric variations, manual variations, existing databases, etc…). This can be important for problems where no automation can be envisaged for parametric variations.

## 11.3 Synthesis of decision-making

Decision-making in ship design is not new. Indeed, balancing design options and continuous refinement of the design are central to the classical design spiral. In this sense, multi-objective optimisation is also not new in ship design. What is new, however, is the integration of LCC tools to enhance efficiency of design and decision-making.

Only a central an all-encompassing product data model can ensure data consistency and integrity.

Current decision-making with relation to safety at IMO and classification societies employs cost effectiveness as central decision-making criterion. It is well rooted and used within the ALARP principle. However, only design changes can be assessed.

## 11.4 Integration Approaches conclusions

The main challenges ahead for ship design are not related to the decision-making itself but related to integration and implementation.

- Central product data model to facilitate effective use of advanced tools and to ensure data consistency and integrity
- Integration of tools to enable sufficiently fast scanning of many design alternatives
- Parametric models for more complete designs or effective decoupling in order to employ optimisation

It is essential to use a database system combined with the existence of a product model oriented to support the early design process. The database should store historical information to be queried when starting a new design.

The product model should provide for some simple modelling capabilities, as required in the early design process. The product model organization should be a breakdown structure with a flexible naming system allowing any type of codification

## 11.5 Environment assessment methods selections

As mentioned in Section 6.2.1, in Eco-REFITEC, a characterization model, CML 2010, was applied to evaluate the environment impact. To extend the knowledge of characterization models, a list of methodologies was presented in Table 2. This list indicates widely used methods in life cycle models. For these methods, it is difficult to say which is better or the best without considering the goal and scope of a LCA study.

For CML 2010 and ReCiPe as examples, both are popular and well developed. The first main difference is the level of results: CML 2010 is focused on mid-point levels and ReCiPe can provide both mid-point and end-point results. To combine with current regulations (EEDI is considered in Eco-REFITEC), mid-point level results are more compatible. Another difference is the target region: CML 2010 is for global used and ReCiPe is designed for European countries. Therefore, to find the suitable characterization model for this project, considerations on goal and scope are necessary.

As this project is to develop a software, the validation will be an important part. As commercial LCA software is available, a suitable software should be selected for the software validation of project. In principle GaBi software is selected as covers all the LCA characteristics in relatively high level. It was also used in the Eco-REFITEC project for LCA modelling and assessment.

SHIPLYS is being developed to provide solutions to three types of Scenarios. Some of these may require top-wlevel (screening) LCA and some (Scenario 1 type, for example) may require more detailed LCA.

It was seen that although significant previous research has calculated the environmental impact of ships' activities using some empirical methodologies (formulas), no specific study exists which aims to directly estimate the ghg emissions of the vessel due to its operation using a life cycle modelling tools.

# 12 Concluding remarks

Work done in this Deliverable draws on work done by individual partners on various EC funded projects, software or relevant approaches developed within their own organisations and experience in the use of or knowledge of relevant third-party off the shelf available software. Where applicable, for example in the use of BIM, experts have been consulted and their work referenced. Cognisance has been taken of relevant work outside the shipping sector with a view to learn from such experience and, where applicable, transfer such technology to the project.

This Deliverable contains a summary of models and approaches considered for their applicability to SHIPLYS concepts. The Deliverable lays the background for D3.2 in which a selection will be made from the models considered in D3.1. This involves assessment and identification of, a) existing models to be integrated, and, b) functionality to be developed within the project and integrated within the SHIPLYS software platform.

The aspiration within SHIPLYS is to develop early- design-stage software that is interoperable not only between different 3D and other engineering systems, but also between systems that are used during detailed design and tools used during other life stages of the ship asset.

A well-defined integrated design platform along the lines of PLM can help designers and asset owners to get the most from product value chain. An integrated PLM platform is the one which re-uses and builds up former designs, with a same language among the six PLM elements. Virtual environment allows the designer to really use databases, building up new concepts based on previous information, as well as re-using advanced 3D models across the value chain.

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# Annex A – Design Software Directory

This section contains profile descriptions of the various software components used or proposed to be used within the SHIPLYS context, in alphabetical order.

| **Name** | @Risk™ |
|---|---|
| Version | 4.5 (latest is 7.5) |
| Originator | Palisade |
| Distribution | |
| Functional Scope (keywords) | Monte Carlo Simulations; risk analyses |
| Functional Description | Enables simulations and data fitting |
| Information references (links etc.) | http://www.palisade.com/ |
| | |
| **Commercial Information** | |
| License type | Standalone; Concurrent Network; Enterprise Network |
| Applicable fees | Variable |
| | |
| **Software Technology** | |
| Supported platforms | |
| Interfaces | Works as an add-in to MS Excel |
| Programming language(s) | |
| Documentation | Comes with the product; also available here: http://www.palisade.com/support/manuals.asp |
| | |
| **SHIPLYS relevance** | |
| Used by partners | TWI |
| Information provided by | Ujjwal Bharadwaj - TWI |
| Issues | Requires Excel |
| Comments | The full range of functionality is probably not relevant to SHIPLYS. Typically, a 'risk model' is developed in Excel and @Risk™ works as an add-in. |

| ame | ABAQUS |
|---|---|
| Version | 6.14 2016 |
| Originator | DASSAULT SYSTEMES |
| Distribution | Installer |
| Functional Scope (keywords) | General purpose FEM,CFD,-Heat transfer analysis, weld model simulation<br><br>Tosca structure - topology optimization module<br>Isight – automated exploration of design alternatives, |
| Functional Description | Unified finite element analysis suite |
| Information references (links etc.) | http://www.3ds.com/products-services/simulia/products/abaqus/<br>http://www.3ds.com/products-services/simulia/products/tosca/<br>http://www.3ds.com/products-services/simulia/products/isight-simulia-execution-engine/ |
| | |
| **Commercial Information** | |
| License type | Academic-Research (NTUA)<br>Commercial, flexlm token based on TWI Lan |
| Applicable fees | >60,000GBP/year |
| | |
| **Software Technology** | |
| Supported platforms | Windows x64<br>Linux x64 |
| Interfaces | Most CAD systems |
| Programming language(s) | C/Fortran user subroutines, Python scripting |
| Documentation | Software Documentation included with product |
| | |
| **SHIPLYS relevance** | |
| Used by partners | TWI, NTUA |
| Information provided by | Paul Brown and Jane Allwright, TWI , N.T. Tsouvalis, NTUA |
| Issues | |
| Comments | SHIPLYS is essentially about optimizing ***early design*** based on the certain criteria such as LCCA, Environmental impact and risk assessments. The applicability/ relevance of precision analytical tools such as Abaqus needs to be ascertained. |

SHIPLYS

| Name | ANSYS |
| --- | --- |
| Version | 17 |
| Originator | ANSYS |
| Distribution | Installer |
| Functional Scope (keywords) | Engineering Simulation<br>Finite element analysis<br>CFD<br>Structural Analysis<br>Electronics<br>System Analysis<br>Multiphysics |
| Functional Description | Design, modelling and analysis of various products and systems. Depending on the application, the appropriate software module is selected. |
| Information references (links etc.) | http://www.ansys.com/ |
| | |
| **Commercial Information** | |
| License type | Academic-Research |
| Applicable fees | - |
| | |
| **Software Technology** | |
| Supported platforms | Windows |
| Interfaces | Most CAD systems |
| Programming language(s) | - |
| Documentation | Software Documentation, ANSYS dedicated Books |
| | |
| **SHIPLYS relevance** | |
| Used by partners | NTUA |
| Information provided by | N.T. Tsouvalis, NTUA |
| Issues | |
| Comments | |

| Name | Aquarius – tank scantling assessment due to sloshing loads |
|---|---|
| Version | 2014.0.3 |
| Originator | Lloyd's Register |
| Distribution | Downloadable installer for client machine and server installation |
| Functional Scope (keywords) | CFD analysis<br>Fluid sloshing simulation<br>Scantling strength assessment |
| Functional Description | 2D CFD sloshing simulation for cargo tanks or other large tanks sensitive to sloshing loads. Software includes module to assess the strength of tank plates and stiffeners. |
| Information references (links etc.) | client: http://www.webstore.lr.org/category/21-software.aspx<br>server: http://aquarius.lr-marine-tools.org/index.htm |
| **Commercial Information** | |
| License type | Commercial (Aquarius)<br>Open-Source (OpenFOAM) |
| Applicable fees | £2000 |
| **Software Technology** | |
| Supported platforms | Client: Windows 7<br>Server:<br>- CentOS 6.0, 6.3, 6.5, 7.0<br>- Fedora 20<br>- Red Hat Enterprise 6.0 |
| Interfaces | Visual Studio, Eclipse or any other suitable interface for OpenFOAM. |
| Programming language(s) | C#, C++ |
| Documentation | Product documentation<br>Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | - |
| Information provided by | Norbert Bakkers – Lloyd's Register |
| Issues | |
| Comments | |

| Name | AutoCAD |
|---|---|
| Version | 2014 |
| Originator | Autodesk Inc. |
| Distribution | Downloadable installation file |
| Functional Scope (keywords) | Ship design tool, 3D visualization, 2D drafting, edition |
| Functional Description | Software for Professional 2D & 3D drafting and documentation |
| Information references (links etc.) | www.autodesk.com |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | Subscription fee subject to developer pricing plans if used by third parties |
| | |
| **Software Technology** | |
| Supported platforms | Windows® 8 and Windows® 8.1 Standard, Enterprise, or Professional edition, Windows® 7 Enterprise, Ultimate, Professional, or Home Premium edition, or Windows XP® Professional or Home edition (SP3 or later) operating system |
| Interfaces | Microsoft Windows |
| Programming language(s) | C++ |
| Documentation | Product documentation |
| | |
| **SHIPLYS relevance** | |
| Used by partners | Varna Maritime Ltd. |
| Information provided by | Ilze Atanasova (Varna Maritime Ltd) |
| Issues | |
| Comments | |

| Name | **AVEVA MARINE** |
|---|---|
| Version | 12.0.SP4 |
| Originator | AVEVA |
| Distribution | Downloadable Installer |
| Functional Scope (keywords) | 3D ship design, production planning |
| Functional Description | Hydrodynamics & Hydrostatics<br>Structural Design<br>Outfitting Design<br>Production Planning (Manufacture and Assembly)<br>3D Model Import of Equipment Items |
| Information references (links etc.) | http://www.aveva.com/en/Industry_Sectors/Marine/AVEVA_for_Shipbuilders.aspx |
| | |
| **Commercial Information** | |
| License type | Academic |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7 |
| Interfaces | Can be used as a standalone system and can be combined with various Classes' software like Lloyd's Register's RulesCalc etc. |
| Programming language(s) | |
| Documentation | Software Documentation |
| | |
| **SHIPLYS relevance** | |
| Used by partners | NTUA |
| Information provided by | N.T. Tsouvalis, NTUA |
| Issues | |
| Comments | |

| **Name** | **BMT Smart Fleet / Access** |
| --- | --- |
| Version | Continuous development |
| Originator | BMT Smart (SHIPLYS partner) |
| Distribution | On line tool |
| Functional Scope (keywords) | Data collection, weather data collection, performance measurement, vessel comparison |
| Functional Description | Vessel sensor data display<br>Vessel performance graphs<br>Vessel performance KPI's<br>Vessel performance data driven models<br>Vessel comparison<br>Fleet comparison<br>Weather data collection and display<br>Forecast voyage performance<br>Reports |
| Information references (links etc.) | http://www.bmtsmart.com/ |
| | |
| **Commercial Information** | |
| License type | Normally annual license |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Runs on Amazon Web Services |
| Interfaces | |
| Programming language(s) | Java |
| Documentation | User and technical |
| | |
| **SHIPLYS relevance** | |
| Used by partners | Not currently |
| Information provided by | Ian Sellwood |
| Issues | |
| Comments | |

SHIPLYS

| Name | BMT Smart Vessel |
|---|---|
| Version | Continuous development |
| Originator | BMT Smart (SHIPLYS partner) |
| Distribution | Installer / On hardware |
| Functional Scope (keywords) | Data collection / on board performance |
| Functional Description | On board automatic data collection from sensors<br>On board performance measurement and display<br>Transmittal of sensor data ashore |
| Information references (links etc.) | http://www.bmtsmart.com/ |
| | |
| **Commercial Information** | |
| License type | Normally annual license |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Typically windows 7 but suitable for all windows platforms |
| Interfaces | |
| Programming language(s) | C++ |
| Documentation | User and technical |
| | |
| **SHIPLYS relevance** | |
| Used by partners | Not currently |
| Information provided by | Ian Sellwood |
| Issues | |
| Comments | |

| Name | CAESES |
|---|---|
| Version | 4.1 |
| Originator | FRIENDSHIP SYSTEMS |
| Distribution | Downloadable Installer |
| Functional Scope (keywords) | General Geometric Modeler, 3D Design, Optimization |
| Functional Description | Build variable & simulation-ready geometry that is 100% robust during variation<br>Automate meshing and simulation runs<br>Conduct design studies and shape optimizations |
| Information references (links etc.) | www.caeses.com |
| | |
| **Commercial Information** | |
| License type | Commercial / Academic |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows, Linux |
| Interfaces | SHIPFLOW, FINE™/Marine |
| Programming language(s) | |
| Documentation | Software Documentation |
| | |
| **SHIPLYS relevance** | |
| Used by partners | NTUA |
| Information provided by | N.T. Tsouvalis, NTUA |
| Issues | |
| Comments | |

| Name | CAFE |
| --- | --- |
| Version | 1.0.7.7 |
| Originator | Jointly developed by BVB Ltd and as2con-Alveus Ltd |
| Distribution | Downloadable installer |
| Functional Scope (keywords) | Ship design tool, fast modelling capabilities, ship design calculations, 3D ship and equipment models importation, automatic generation of classification drawings, rapid and parametric definition of shipbuilding entities, FE models, automated meshing, FE analysis |
| Functional Description | User-oriented software for rapid ship design |
| Information references (links etc.) | http://www.bvbcafe.com/ |
| | |
| **Commercial Information** | |
| License type | Commercial (made available to partners for free, but as a subject of separate agreement) |
| Applicable fees | None during project; if customization is necessary some subcontracting fee to third party will be applicable |
| | |
| **Software Technology** | |
| Supported platforms | Windows Server 2008, WS 2012 |
| Interfaces | GUI, OpenGL, |
| Programming language(s) | C#, based on Microsoft .NET framework |
| Documentation | Product documentation, Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | Used by as2con |
| Information provided by | Arijana Milat, Darko Frank (as2con) |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **CATIA** |
| Version | v4,v5, v6 |
| Originator | Dassault Systemes |
| Distribution | |
| Functional Scope (keywords) | CAD system<br><br>2D,3D<br><br>multiple industries |
| Functional Description | Catia is one of the common CAD-tools used for 2D and 3D design and engineering. |
| Information references (links etc.) | http://www.3ds.com/products-services/catia/ |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows, Linux |
| Interfaces | - |
| Programming language(s) | - |
| Documentation | Training, Knowledge Base, Online documentation |
| **SHIPLYS relevance** | |
| Used by partners | None(?), yards and engineering enterprises |
| Information provided by | Konstantin Kreutzer, AES |
| Issues | - |
| Comments | - |

| | |
|---|---|
| **Name** | **Code Aster** |
| Version | - |
| Originator | - |
| Distribution | Download, GPL |
| Functional Scope (keywords) | FEM calculations |
| Functional Description | Can execute many types of calculations based on finite element methods (mech., therm., acoustics, ...) |
| Information references (links etc.) | http://code-aster.org/UPLOAD/DOC/Presentation/plaquette_aster_en.pdf |
| **Commercial Information** | |
| License type | GPL |
| Applicable fees | |
| **Software Technology** | |
| Supported platforms | Linux |
| Interfaces | SalomeMeca (import geometry file) |
| Programming language(s) | - |
| Documentation | Software Doc. |
| **SHIPLYS relevance** | |
| Used by partners | ? |
| Information provided by | K.Kreutzer, AES |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **CSRS Prescriptive Analysis** |
| Version | V2.5 |
| Originator | CSRS (LR/ABS) |
| Distribution | Downloadable installer |
| Functional Scope (keywords) | CSR Prescriptive |
| Functional Description | Rule scantling calculation software in accordance with IACS Common Structural Rules |
| Information references (links etc.) | http://www.commonstructuralrulessoftware.com/products/28-csr-prescriptive-analysis-v25.aspx |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7 |
| Interfaces | Visual Studio |
| Programming language(s) | C#, C++ |
| Documentation | Product documentation<br>Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | - |
| Information provided by | Morgan Le Callet – Lloyd’s Register |
| Issues | |
| Comments | |

| Name | **CSRS FE Analysis** |
|---|---|
| Version | V2.5 |
| Originator | CSRS (LR/ABS) |
| Distribution | Downloadable installer |
| Functional Scope (keywords) | CSR FEA |
| Functional Description | Finite Element Analysis software in accordance with IACS Common Structural Rules |
| Information references (links etc.) | http://www.commonstructuralrulessoftware.com/products/29-csr-fe-analysis-v25.aspx |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7 |
| Interfaces | Visual Studio |
| Programming language(s) | C#, C++ |
| Documentation | Product documentation<br>Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | - |
| Information provided by | Morgan Le Callet – Lloyd's Register |
| Issues | |
| Comments | |

| Name | DraftSight |
| --- | --- |
| Version | 2017 |
| Originator | Dassault Systemes |
| Distribution | Downloadable Installer |
| Functional Scope (keywords) | CAD-system<br><br>2D,3D<br><br>Interoperability (DWG/DXF, PDF...) |
| Functional Description | CAD-system which can be used for generating 2D-plans and 3D-modelling. |
| Information references (links etc.) | http://www.3ds.com/products-services/draftsight-cad-software/ |
| **Commercial Information** | |
| License type | commercial |
| Applicable fees | None during project; |
| **Software Technology** | |
| Supported platforms | Windows, Mac, Linux |
| Interfaces | |
| Programming language(s) | |
| Documentation | Resource Center, Draft Sight Community |
| **SHIPLYS relevance** | |
| Used by partners | Currently none(?), used by stakeholders (Neptun Ship Design,...) |
| Information provided by | Konstantin Kreutzer, AES |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **FATIMA** |
| Version | - |
| Originator | Marin |
| Distribution | |
| Functional Scope (keywords) | Seakeeping resistance/behaviour |
| Functional Description | Linear seakeeping-potential flow code(Rankine sources),roll damping →BUT! takes motion-induced geometry change into account, RAPID output required |
| Information references (links etc.) | http://www.marin.nl/web/file?uuid=878503ab-19e0-4ab5-b499-63c244d0fde9&owner=4cc62623-cf42-4ab3-99ae-f0442e634d30 |
| **Commercial Information** | |
| License type | Professional license |
| Applicable fees | t.b.d. |
| **Software Technology** | |
| Supported platforms | Windows |
| Interfaces | NAPA, CAD (3D Hull Geometry), RAPID |
| Programming language(s) | - |
| Documentation | Software Doc., Support, Papers |
| **SHIPLYS relevance** | |
| Used by partners | ? |
| Information provided by | K.Kreutzer, AES |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **FEMAP** |
| Version | 11.2 |
| Originator | Siemens PLM |
| Distribution | |
| Functional Scope (keywords) | Finite element analysis and modelling, model visualization, digital simulations, CAD-independent, linear statics analysis, buckling, steady-state and transient heat transfer, basic nonlinear analysis |
| Functional Description | Software for advanced engineering finite element analysis |
| Information references (links etc.) | https://www.plm.automation.siemens.com/en_us/products/femap/ |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7, 8, 10 |
| Interfaces | GUI |
| Programming language(s) | NX Nastran Solver for analyses |
| Documentation | User Manual |
| | |
| **SHIPLYS relevance** | |
| Used by partners | Used by as2con |
| Information provided by | Arijana Milat, Darko Frank (as2con) |
| Issues | |
| Comments | as2con has a license for the Femap with NX Nastran Base Module |

| Name | FINE™/Marine |
|---|---|
| Version | v5.1 |
| Originator | NUMECA INTERNATIONAL |
| Distribution | Downloadable Installer |
| Functional Scope (keywords) | CFD |
| Functional Description | Integrated CFD software environment for the simulation of mono-fluid and multi-fluid flows around any kind of ships, boats, yachts or offshore structures, including various types of appendages. |
| Information references (links etc.) | http://www.numeca.com/en/products/finetmmarine |
| | |
| **Commercial Information** | |
| License type | Academic-Research |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows, Linux |
| Interfaces | CAESES |
| Programming language(s) | |
| Documentation | Software Documentation |
| | |
| **SHIPLYS relevance** | |
| Used by partners | NTUA |
| Information provided by | N.T. Tsouvalis, NTUA |
| Issues | |
| Comments | |

| Name | FORAN |
| --- | --- |
| Version | V80 |
| Originator | Developed by SENER |
| Distribution | Downloadable installer |
| Functional Scope (keywords) | Integrated Shipbuilding CAD/CAM/CAE system that, because of its high-level features, adaptability and customization, can be used to design and build any type of ship or marine structure. |
| Functional Description | Single full-ship product model database, suitable from concept design to production.<br><br>Principal functions: Advance surfaces, Surface model, Power prediction, Hydrostatic, General Arrangement, Spaces & Capacities, Launching and Floating, Loading conditions , Damage Stability, Product model, Drawing generation, Hull Structure, Structure 3D model, Building strategy, Outfitting, Electrical, Advance design and drafting .<br><br>FORAN makes it possible to share engineering information with PLM, ERP and MRP systems, FEM tools and other specific CAE applications.<br><br>Easy exchange of data thanks to the off-the shelf database structure, the system architecture & standards and hoc interfaces.<br><br>FORAN can exchange data in multiple formats, such as DWG, DXF, IGES, STEP, VDA, VRML and XML |
| Information references (links etc.) | http://www.marine.sener/en/foran |
| | |
| **Commercial Information** | |
| License type | Commercial (made available to partners through a separate agreement). To be discussed yet |
| Applicable fees | if customization is necessary some subcontracting fee will be applicable |
| | |
| **Software Technology** | |
| Supported platforms | Windows 2008 Server or higher. |
| Interfaces | |
| Programming language(s) | C# |

| | |
|---|---|
| Documentation | Product documentation, Training. |
| | |
| **SHIPLYS relevance** | |
| Used by partners | Used by SOERMAR |
| Information provided by | José Ignacio Zanón, Francisco del Castillo (SOERMAR) |
| Issues | |
| Comments | Note. In the following link you can find tutorials for different software modules and information regarding Platform Requirements https://we.tl/gjFMv7BU1t<br><br>A seminar could be organized by WEBEX where SENER could introduce to the shiplys consortium the FORAN software and capabilities.<br><br>This seminar could last 3 days (2-3 hours each). The cost of the seminar will be aprox. 160 € per hour. |

| Name | FORESIM |
|---|---|
| Version | 2014 |
| Originator | NTUA, In-house developed methodology |
| Distribution | Used in-house only for research purposes and freight rate forecasting. |
| Functional Scope (keywords) | Freight rate modelling, long-term and short-term forecasts, and prediction error calculation. |
| Functional Description | Explanatory model building using Artificial Neural Networks (ANN) and Monte-Carlo simulation in order to model the shipping market. Shipping market macroeconomic parameters, Statistical time series processing, Shipping market forecasting. Not fully automated procedure requiring various individual steps. |
| Information references (links etc.) | http://www.martrans.org |
| | |
| **Commercial Information** | |
| License type | Not for sale |
| Applicable fees | None |
| | |
| **Software Technology** | |
| Supported platforms | MS Windows |
| Interfaces | |
| Programming language(s) | SPSS, NEUROSOLUTIONS, MATHEMATICA |
| Documentation | Product documentation, Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | |
| Information provided by | D. V. Lyridis, NTUA |
| Issues | Only relevant to the project if used for long term forecasting for lifecycle cost assessment. |
| Comments | |

| Name | GKpower |
|---|---|
| Version | V1 |
| Originator | NTUA (SHIPLYS partner) |
| Distribution | Archive, plus installer |
| Functional Scope (keywords) | Preliminary ship propeller calculations, power coefficient calculations |
| Functional Description | Software module for the selection of *Wageningen B-Screw* type propellers, optimizing the efficiency |
| Information references (links etc.) | NTUA-Shipbuilding Technology Laboratory |
| | |
| **Commercial Information** | |
| License type | In house developed software |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows |
| Interfaces | ASCII text files for input and output data |
| Programming language(s) | C++, Matlab libraries |
| Documentation | NTUA-STL GKpower_info.doc |
| | |
| **SHIPLYS relevance** | |
| Used by partners | NTUA |
| Information provided by | G.M. Katsaounis, NTUA |
| Issues | Standalone version (i.e. without Matlab) under development.<br>Graphical user interface under development |
| Comments | |

SHIPLYS

| | |
|---|---|
| **Name** | **HydroE-FD** |
| Version | HydroE-FD beta |
| Originator | Lloyd's Register |
| Distribution | By special request |
| Functional Scope (keywords) | ship motion analysis<br>hydro-elasticity<br>frequency domain<br>springing fatigue analysis |
| Functional Description | This is the flexible body version of Waveload-FD, used for hydro-elastic and fatigue analysis of a ship's hull girder. |
| Information references (links etc.) | http://webstore.lr.org/products/2858-waveload-fd.aspx |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | N/A |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7 |
| Interfaces | Windows |
| Programming language(s) | C#, C++, Fortran |
| Documentation | Product documentation<br>Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | - |
| Information provided by | Norbert Bakkers – Lloyd's Register |
| Issues | |
| Comments | |

| Name | HydroE-TD |
|---|---|
| Version | HydroE-TD beta |
| Originator | Lloyd's Register |
| Distribution | By special request |
| Functional Scope (keywords) | ship motion analysis<br>time domain<br>whipping analysis |
| Functional Description | This is the time domain version for whipping analysis. |
| Information references (links etc.) | http://webstore.lr.org/products/2858-waveload-fd.aspx |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | N/A |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7 |
| Interfaces | Windows |
| Programming language(s) | C#, C++, Fortran |
| Documentation | Product documentation<br>Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | - |
| Information provided by | Norbert Bakkers – Lloyd's Register |
| Issues | |
| Comments | |

| Name | LashRight |
|---|---|
| Version | 2013 |
| Originator | Lloyd's Register |
| Distribution | Downloadable installer |
| Functional Scope (keywords) | LashRight<br>Container securing arrangements |
| Functional Description | LashRight is Lloyd's Register's dedicated container securing software. It calculates the forces acting in lashed and unlashed stacks on deck and validates the results against the requirements contained in Part 3 of Lloyd's Register's Rules and Regulations for the Classification of Ships. |
| Information references (links etc.) | http://webstore.lr.org/category/21-software.aspx?pageindex=1 |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | £1000 |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7 |
| Interfaces | Visual Studio |
| Programming language(s) | C++ |
| Documentation | Product documentation<br>Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | - |
| Information provided by | Morgan Le Callet – Lloyd's Register |
| Issues | |
| Comments | |

| Name | MAESTRO |
|---|---|
| Version | |
| Originator | DRS Advanced Marine Technology Center |
| Distribution | |
| Functional Scope (keywords) | Finite element analysis, structural limit state evaluation, structural design tool, linear static analysis, natural frequency analysis, optimization, ship-based loading patterns, possibility to include criteria from classification society |
| Functional Description | Design, analysis and evaluation tool for floating structures |
| Information references (links etc.) | http://maestromarine.com/ |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7, 8, 10 |
| Interfaces | GUI |
| Programming language(s) | |
| Documentation | User Manual |
| | |
| **SHIPLYS relevance** | |
| Used by partners | |
| Information provided by | Arijana Milat, Darko Frank (as2con) |
| Issues | |
| Comments | as2con doesn't have a license but it can be available for subcontracting during the project if consortium finds it as the best candidate. |

| | |
|---|---|
| **Name** | **MATLAB** |
| Version | R2013b |
| Originator | MathWorks |
| Distribution | |
| Functional Scope (keywords) | Computational mathematics, analysis, matrix manipulation, graphics, data, algorithm implementation |
| Functional Description | Computational mathematics, analysis, matrix manipulation, graphics, data, algorithm implementation |
| Information references (links etc.) | http://uk.mathworks.com/products/matlab/<br>http://uk.mathworks.com/help/matlab/ |
| | |
| **Commercial Information** | |
| License type | flexlm token based licensing on TWI Lan |
| Applicable fees | Approx. £1600 per license, for use in the UK |
| | |
| **Software Technology** | |
| Supported platforms | Windows x64 |
| Interfaces | MATLAB command line.<br>Also able to interface with programs written in other languages, including C, C++, C#, Java, Fortran and Python. |
| Programming language(s) | MATLAB scripting language. Can also interface with programs written in other languages, including C, C++, C#, Java, Fortran and Python. |
| Documentation | http://uk.mathworks.com/help/matlab/ |
| | |
| **SHIPLYS relevance** | |
| Used by partners | TWI |
| Information provided by | Jane Allwright, TWI |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **MAXSURF**<br>**(including Prefit and Hydromax)** |
| Version | 17.02, 20 v8i |
| Originator | FORMSYS (now BENTLEY) |
| Distribution | Downloadable Installer |
| Functional Scope (keywords) | Hull Fairing, Hydrostatics, Intact Stability, Probabilistic Damage Stability, Hydrodynamic property analysis, Motion analysis, Initial Structural analysis |
| Functional Description | **MAXSURF** is used to improve the hull surface fairness and refinement of the hull, the addition of appendages, compartmentation, etc. **Prefit** is the MAXSURF module for the initial 3D hull form design. **Hydromax** is a MAXSURF module that offers the user the capability to calculate basic hydrostatic calculations and perform intact and damage stability (including probabilistic) analysis. |
| Information references (links etc.) | https://www.bentley.com/en/products/brands/maxsurf |
| | |
| **Commercial Information** | |
| License type | License server |
| Applicable fees | 1000 Australian Dollars |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7, 8 |
| Interfaces | |
| Programming language(s) | |
| Documentation | Accompanying Manuals installed during Setup |
| | |
| **SHIPLYS relevance** | |
| Used by partners | NTUA, SU |
| Information provided by | N.T. Tsouvalis, NTUA, SU |
| Issues | |
| Comments | Renewed annually on October |

| Name | modeFRONTIER |
|---|---|
| Version | 2016 |
| Originator | ESTECO |
| Distribution | Downloadable Installer |
| Functional Scope (keywords) | Optimization |
| Functional Description | Multi-objective and multi-disciplinary optimization |
| Information references (links etc.) | http://www.esteco.com/modefrontier |
| | |
| **Commercial Information** | |
| License type | Academic-Research |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows |
| Interfaces | |
| Programming language(s) | |
| Documentation | Available |
| | |
| **SHIPLYS relevance** | |
| Used by partners | NTUA |
| Information provided by | N.T. Tsouvalis, NTUA |
| Issues | |
| Comments | |

| Name | NAPA Design Solutions |
|---|---|
| Version | 2014.3-1, 2016.2-3 |
| Originator | NAPA |
| Distribution | Downloadable Installer |
| Functional Scope (keywords) | Hull form, Hull performance, loading conditions, hydrostatics, stability, Steel structure, Emergency response, Contract design |
| Functional Description | Flexible and efficient design tools for contracting phase through to detailed design phase, enabling rapid design changes and optimization. Primary functions include hull surface editing, hydrostatics and stability calculations. |
| Information references (links etc.) | https://www.napa.fi/Design-Solutions |
| | |
| **Commercial Information** | |
| License type | Academic – Research, Commersial |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7, 8 |
| Interfaces | Can be used as a standalone system and can be combined with various Classes’ software like Lloyd's Register's RulesCalc etc. |
| Programming language(s) | |
| Documentation | Available product documentation, training material |
| | |
| **SHIPLYS relevance** | |
| Used by partners | NTUA ,FERG |
| Information provided by | N.T. Tsouvalis, NTUA, Caj Volbeda (FERG) |
| Issues | |
| Comments | NAPA Oy offers a wide variety of modules for NAPA, not all are accessible by FERG. Main interfaces available to FERG described above. |

| Name | **Nauticus (Hull and Machinery)** |
|---|---|
| Version | Nauticus 2016 |
| Originator | DNV-GL (Third Party) |
| Distribution | Downloadable installer (user ID needed) |
| Functional Scope (keywords) | - Strength assessment of hull structures<br>- Hull design and verification according to DNV GL Rules and IACS rules (CSR BC & OT).<br>- Integrated with Sesam GeniE for FE modelling, post-processing and code check<br>- tools for fatigue, strength and vibration analysis in marine propulsion systems |
| Functional Description | Software for ship structure and marine propulsion analysis and design |
| Information references (links etc.) | https://www.dnvgl.com/software/products/nauticus-products.html |
| | |
| **Commercial Information** | |
| License type | Commercial or educational licenses are available |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows XP, 7, 10 (in test), |
| Interfaces | Graphical user interface (GUI) |
| Programming language(s) | |
| Documentation | User manuals, tutorials and guidance |
| | Trainings sessions can be provided by DNV-GL |
| **SHIPLYS relevance** | |
| Used by partners | TWI has not used this software themselves. |
| Information provided by | Xing Sun, TWI |
| Issues | |
| Comments | It is good to take cognizance of all products in the market that have relevance for SHIPLYS. However, given that we have LR in our consortium, it would be better to first assess what they have that is equivalent to Nauticus. |

| | |
|---|---|
| **Name** | **ng.zine** |
| Version | Beta version |
| Originator | Prototype developed by as2con |
| Distribution | All participants of the design process are joined in Virtual Private Network (VPN) either locally through LAN, WLAN or through Internet |
| Functional Scope (keywords) | Group design of ships, ship design process, communication between different design tools, exchanging parametric data, multi stakeholder approach, shared database, Pareto optimal design solutions |
| Functional Description | software system that enables concurrent group design of complex engineering products |
| Information references (links etc.) | |
| | |
| **Commercial Information** | |
| License type | Prototype, in house development |
| Applicable fees | None; made available to partners during the project |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7, 8, 10, Windows Server 2008, WS 2012 |
| Interfaces | GUI |
| Programming language(s) | Visual Basic |
| Documentation | User manual |
| | |
| **SHIPLYS relevance** | |
| Used by partners | In process of development |
| Information provided by | Arijana Milat, Darko Frank (as2con) |
| Issues | |
| Comments | |

| **Name** | **Pre_weight** |
|---|---|
| Version | V3 |
| Originator | NTUA (SHIPLYS partner) |
| Distribution | Archive, plus installer |
| Functional Scope (keywords) | Preliminary steel weight calculation for midship section |
| Functional Description | Software module for preliminary plate thicknesses and scantlings selection, based on Classification rules, for passenger vessels. |
| Information references (links etc.) | NTUA-Shipbuilding Technology Laboratory |
| | |
| **Commercial Information** | |
| License type | In house developed software |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows |
| Interfaces | ASCII text files for input and output data |
| Programming language(s) | C++, Matlab libraries |
| Documentation | NTUA-STL STL-229-F-06 report |
| | |
| **SHIPLYS relevance** | |
| Used by partners | NTUA |
| Information provided by | G.M. Katsaounis, NTUA |
| Issues | Standalone version (i.e. without Matlab) under development.<br>Graphical user interface under development |
| Comments | |

| | |
|---|---|
| **Name** | **RAPID** |
| Version | - |
| Originator | Marin |
| Distribution | |
| Functional Scope (keywords) | Resistance calculation |
| Functional Description | Non-linear potential flow code |
| Information references (links etc.) | http://www.marin.nl/web/file?uuid=9d7af335-f282-4435-8f2f-731fd48fcd08&owner=4cc62623-cf42-4ab3-99ae-f0442e634d30 |
| **Commercial Information** | |
| License type | Professional license |
| Applicable fees | t.b.d. |
| **Software Technology** | |
| Supported platforms | Windows |
| Interfaces | NAPA, CAD (3D Hull Geometry) |
| Programming language(s) | - |
| Documentation | Software Doc., Support, Papers |
| **SHIPLYS relevance** | |
| Used by partners | TBC |
| Information provided by | K.Kreutzer, AES |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **Rhino & grasshopper** |
| Version | Version 5 SR10 |
| Originator | Lloyd's Register |
| Distribution | Downloadable installer |
| Functional Scope (keywords) | 3D geometry modelling |
| Functional Description | Used to build 3D models of ships from lines plans using the grasshopper facility for fairing |
| Information references (links etc.) | http://www.grasshopper3d.com/ |
| | |
| **Commercial Information** | |
| License type | Commercial<br>(available to Lloyd's Register) |
| Applicable fees | Depending on scope delivered |
| | |
| **Software Technology** | |
| Supported platforms | Linux & Windows |
| Interfaces | |
| Programming language(s) | python |
| Documentation | Product documentation, Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | TBC |
| Information provided by | Constantinos Zegos, Lloyd's Register |
| Issues | |
| Comments | |

| Name | Rhino |
|---|---|
| Version | 5 SR12 |
| Originator | Robert McNeel & Associates |
| Distribution | Downloadable Installer |
| Functional Scope (keywords) | 3D surface modeller |
| Functional Description | 3D surface editor primarily used when working with hull forms. Capable of handling IGES and STEP files amongst many others |
| Information references (links etc.) | https://www.rhino3d.com/ |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | - |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7, 8 |
| Interfaces | - |
| Programming language(s) | - |
| Documentation | Product documentation, training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | FERG |
| Information provided by | Caj Volbeda (FERG) |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **RiskWISE®** |
| Version | 5.0 |
| Originator | TWI Ltd |
| Distribution | Downloadable installer (user ID needed) |
| Functional Scope (keywords) | Risk-based Inspection (RBI)<br>API[1] 581 |
| Functional Description | Quantitative Probability of Failure assessment as per API[1] 581;Semi-quantitative Probability of Failure and Consequence of Failure assessment as per TWI procedures as customized for end-users. Applicable to power plants, pipelines etc. |
| Information references (links etc.) | http://www.twisoftware.com/software/riskwise/ |
| **Commercial Information** | |
| License type | Annual renewable; Perpetual; |
| Applicable fees | £12,000 (annual renewable); £30,000 (perpetual)<br>Price variable depending of other arrangements. |
| **Software Technology** | |
| Supported platforms | Microsoft Windows 7 or above (both x86 and x64 machine) |
| Interfaces | |
| Programming language(s) | C# |
| Documentation | Documentation included with product, extra information may be applicable upon request |
| **SHIPLYS relevance** | |
| Used by partners | TWI |
| Information provided by | Xiaofei Cui, TWI |
| Issues | |
| Comments | RiskWISE® is an API[8] 581 code compliant RBI software for optimising plant inspection and maintenance. It is one of the most established software packages of its kind available.<br>The overriding aim of the software is to provide decision support to asset owners at the Operation and Maintenance (O&M) stage of their plant/ equipment.<br>The approach, that includes a 'systems engineering' perspective, is relevant to decision-making in life cycle management. |

[8] American Petroleum Institute

| | |
|---|---|
| **Name** | **Rapid Ship Evaluation Tool (RSET)** |
| Version | 1.0 |
| Originator | BMT Design & Technology |
| Distribution | Executable .jar file |
| Functional Scope (keywords) | Compartment arrangement, early stage, ship design, design space exploration, cost-capability trade-offs |
| Functional Description | Enables rapid design space exploration for early-stage ship concept design. Performs automated compartment arrangement subject to user-specified constraints (adjacency/proximity/distance, global location and relative location) based on a hull form model (given as input). |
| Information references (links etc.) | https://youtu.be/Wk8W_IA2Rdohttp://www.atlantec-es.com/shipyard-production-simulation.html |
| | |
| **Commercial Information** | |
| License type | - |
| Applicable fees | - |
| | |
| **Software Technology** | |
| Supported platforms | Microsoft Windows |
| Interfaces | - |
| Programming language(s) | Java |
| Documentation | Basic user manual |
| | |
| **SHIPLYS relevance** | |
| Used by partners | BMT Group |
| Information provided by | BMT Group / BMT Design & Technology |
| Issues | - |
| Comments | This application is under development and able to be developed further for the SHIPLYS project to integrate lifecycle costing, ship systems and equipment information, design rules and other relevant input data to allow design optimization, exploration and trade-off. With further development, the output of this software program is intended to be compatible with other design tools including FORAN, AVEVA and Paramarine. |

| Name | **RulesCalc** |
|---|---|
| Version | 2014 |
| Originator | Lloyd's Register |
| Distribution | Downloadable installer |
| Functional Scope (keywords) | Rule calculations<br>RulesCalc<br>RulesCalc Offshore<br>NSR<br>SSC |
| Functional Description | Rule scantling calculation software in accordance with the LR rule sets:<br>Ship Rules<br>Rules for Offshore Units<br>Naval Ship Rules<br>Special Service Craft Rules<br>It enables you to verify Rule compliance, pinpoint Rule failures and identify areas of concern and any design modifications that may be required. Separate software for each rule set. |
| Information references (links etc.) | http://webstore.lr.org/category/21-software.aspx?pageindex=1 |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | RulesCalc £2000, RulesCalc Offshore £4000, NSR £2000, SSC £500 |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7 |
| Interfaces | Visual Studio |
| Programming language(s) | C#, C++ |
| Documentation | Product documentation<br>Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | - |
| Information provided by | Morgan Le Callet – Lloyd's Register |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **SESAM (GeniE and HydroD)** |
| Version | SESAM 2016 |
| Originator | DNV-GL (Third Party) |
| Distribution | Downloadable installer (user ID needed) |
| Functional Scope (keywords) | Hydrostatic and hydrodynamic analysis;<br>Stability analysis<br>FEM software;<br>Concept modelling and automated processes;<br>Static and dynamic structural analysis incorporating environmental load calculation (wind, waves, current). |
| Functional Description | Ship and offshore structural analysis software (initial and detail design stage) |
| Information references (links etc.) | https://www.dnvgl.com/software/products/sesam-products.html |
| | |
| **Commercial Information** | |
| License type | Commercial and educational licenses are available.<br>(TWI does not currently have a license, but have used the software; certain students may have educational license.) |
| Applicable fees | Educational License (£2,500 per year) |
| | Commercial License (Over £100,000 per year) |
| **Software Technology** | |
| Supported platforms | Windows XP, 7, 10 (in test), |
| Interfaces | Graphical user interface (GUI) with command lines |
| Programming language(s) | Java scripts |
| Documentation | User manuals, tutorials and guidance |
| | Trainings sessions can be provided by DNV-GL |
| **SHIPLYS relevance** | |
| Used by partners | Has been used in TWI for research/ consultancy purpose |
| Information provided by | Xing Sun, TWI |
| Issues | |
| Comments | It is good to take cognizance of all products in the market that have relevance for SHIPLYS. However, given that we have LR in our consortium, who own ShipRight$^{TM}$, potentially with enough overlap with SESAM$^{TM}$, it would be better to first assess ShipRight$^{TM}$ and seek LR's views on this matter. |

| Name | ShipConstructor |
|---|---|
| Version | 2015 R2.1.1 |
| Originator | SSI (ShipConstructor Software Inc.) |
| Distribution | Downloadable Installer |
| Functional Scope (keywords) | 3D product models, CAD, draughting, production drawings |
| Functional Description | ShipConstructor is an AutoCAD based software product line created for design, engineering and construction in the shipbuilding industry. ShipConstructor's AutoCAD foundation provides a user environment that is a globally recognized CAD/CAM standard. |
| Information references (links etc.) | http://www.ssi-corporate.com/product-services/shipconstructor |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | - |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7, 8 |
| Interfaces | Hull, Structure, Pipe, HVAC, Electrical, Multi Discipline, Production, Nest & Profile Plots. |
| Programming language(s) | - |
| Documentation | Product documentation |
| | |
| **SHIPLYS relevance** | |
| Used by partners | FERG |
| Information provided by | Caj Volbeda (FERG) |
| Issues | |
| Comments | Wide range of suites available – see link for full list. http://www.ssi-corporate.com/product-services/suites |

| Name | SHIPFLOW |
|---|---|
| Version | 6.2 |
| Originator | FLOWTECH International AB |
| Distribution | Downloadable Installer |
| Functional Scope (keywords) | CFD, Potential flow solver, Viscous flow solver, Time accurate flow solver |
| Functional Description | Complete and powerful environment for pre and post-processing<br>Potential flow and thin boundary layer solvers<br>Viscous flow solver for resistance and propeller hull interaction.<br>Time accurate flow solver for ship motions |
| Information references (links etc.) | http://www.flowtech.se/ |
| | |
| **Commercial Information** | |
| License type | Academic-Research |
| Applicable fees | |
| | |
| **Software Technology** | |
| Supported platforms | Windows, Linux |
| Interfaces | CAESES |
| Programming language(s) | |
| Documentation | Software Documentation |
| | |
| **SHIPLYS relevance** | |
| Used by partners | NTUA |
| Information provided by | N.T. Tsouvalis, NTUA |
| Issues | |
| Comments | |

SHIPLYS

| | |
|---|---|
| **Name** | **SHIPMO** |
| Version | - |
| Originator | Marin |
| Distribution | |
| Functional Scope (keywords) | Seakeeping resistance/behaviour |
| Functional Description | Linear strip-theory method |
| Information references (links etc.) | http://www.marin.nl/web/file?uuid=878503ab-19e0-4ab5-b499-63c244d0fde9&owner=4cc62623-cf42-4ab3-99ae-f0442e634d30 |
| **Commercial Information** | |
| License type | Professional license |
| Applicable fees | t.b.d. |
| **Software Technology** | |
| Supported platforms | Windows |
| Interfaces | Body plan |
| Programming language(s) | - |
| Documentation | Software Doc., Support |
| **SHIPLYS relevance** | |
| Used by partners | ? |
| Information provided by | K.Kreutzer, AES |
| Issues | |
| Comments | |

| Name | ShipRight |
|---|---|
| Version | 2014.2 |
| Originator | Lloyd's Register |
| Distribution | Downloadable installer |
| Functional Scope (keywords) | Ship Design Assessment<br>Structural Design Assessment SDA<br>Fatigue Design Assessment FDA<br>FDA2 FDA3<br>Hatch Cover Assessment |
| Functional Description | Ship Design Assessment software to the requirements of LR's ShipRight procedures for structural and fatigue assessments. Normally used with a FE modeler such as Patran or HyperMesh, and a FE solver such as Nastran. Has built-in FE solver. |
| Information references (links etc.) | http://www.lr.org/en/services/software/shipright.aspx |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | £4000 |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7 |
| Interfaces | Visual Studio |
| Programming language(s) | C#, C++, Fortran |
| Documentation | Product documentation<br>Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | - |
| Information provided by | Morgan Le Callet – Lloyd's Register |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **ShipWeight** |
| Version | 11.71 |
| Originator | BAS engineering AS |
| Distribution | Downloadable installer |
| Functional Scope (keywords) | Weight estimation, management, monitoring<br><br>Weight database<br><br>Reports<br><br>Statistical analysis (regression, historical data) |
| Functional Description | Shipweight estimates, manages and reports all weight issues, from early conceptual design to delivery. |
| Information references (links etc.) | http://shipweight.com/ |
| **Commercial Information** | |
| License type | commercial |
| Applicable fees | - |
| **Software Technology** | |
| Supported platforms | Windows |
| Interfaces | |
| Programming language(s) | |
| Documentation | Video Tutorials, support, Knowledgebase |
| **SHIPLYS relevance** | |
| Used by partners | None yet (but used by other European yards) |
| Information provided by | Konstantin Kreutzer, AES |
| Issues | - |
| Comments | - |

| Name | ShipX |
|---|---|
| Version | |
| Originator | SINTEF-MARINTEK |
| Distribution | Purchase required |
| Functional Scope (keywords) | Hydrodynamic analysis tools |
| Functional Description | Seakeeping calculations;<br>Ship motions illustration;<br>Simulation of maneuvering & station keeping capabilities;<br>Calm water performance prediction;<br>Calculation of speed loss in waves |
| Information references (links etc.) | https://www.sintef.no/en/software/shipx/ |
| | |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | Quote required |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7, x86 |
| Interfaces/Plug-ins | Ship Speed and Powering;<br>Station Keeping; Maneuvering;<br>Vessel Responses;<br>Animation Lab |
| Programming language(s) | |
| Documentation | Product manuals and tutorials |
| | |
| **SHIPLYS relevance** | |
| Used by partners | |
| Information provided by | SU |
| Issues | |
| Comments | Renewed annually on June |

| **Name** | **SOLIDWORKS** |
|---|---|
| Version | 2015 |
| Originator | Comercial |
| Distribution | Downloadable installer |
| Functional Scope (keywords) | Ship design tool, fast modelling capabilities, ship design calculations, 3D ship and equipment models importation, automatic generation of classification drawings, rapid and parametric definition of shipbuilding entities, FE models, automated meshing, FE analysis |
| Functional Description | User-oriented software for rapid ship design |
| Information references (links etc.) | http://www.solidworks.com/http://www.atlantec-es.com/shipyard-production-simulation.html |
| | |
| **Commercial Information** | |
| License type | Commercial (made available to partners for free, but as a subject of separate agreement) |
| Applicable fees | None during project; if customization is necessary some subcontracting fee to third party will be applicable |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7, 8, 10, Vista , XP |
| Interfaces | Microsoft® Windows® |
| Programming language(s) | Microsoft® Visual Basic® for Applications (VBA) |
| Documentation | Product documentation, Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | Used by Astander |
| Information provided by | Laura Herrera (Astander) |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **STAR-CCM+** |
| Version | v10.06 |
| Originator | CD-adapco, SIEMENS |
| Distribution | Downloadable Installer |
| Functional Scope (keywords) | 3D Design, CFD, Hydrodynamics, Sloshing, Solid Mechanics, Fluid Structure Interaction |
| Functional Description | Multidisciplinary engineering simulation |
| Information references (links etc.) | http://mdx.plm.automation.siemens.com/star-ccm-plus |
| | |
| **Commercial Information** | |
| License type | Academic-Research, Commercial (available to Lloyd's Register) |
| Applicable fees | Depending on scope delivered |
| | |
| **Software Technology** | |
| Supported platforms | Windows, Linux |
| Interfaces | |
| Programming language(s) | Mostly Java, some parts use JavaScript |
| Documentation | Product Documentation |
| | |
| **SHIPLYS relevance** | |
| Used by partners | NTUA, LR |
| Information provided by | N.T. Tsouvalis, NTUA, Constantinos Zegos, LR |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **Topgallant® Shipyard Production Simulation (SYPS)** |
| Version | 1.5, 1.6 beta |
| Originator | AES (SHIPLYS partner) |
| Distribution | Downloadable installer, docker images (in preparation) |
| Functional Scope (keywords) | Production simulation,<br>production planning,<br>production scheduling,<br>transport simulation,<br>manufacturing analysis,<br>cost estimation,<br>material management,<br>supply chain management |
| Functional Description | Consists for modules for shipyard modelling, production data processing, scheduling and simulation |
| Information references (links etc.) | http://www.atlantec-es.com/shipyard-production-simulation.html |
| | |
| **Commercial Information** | |
| License type | Commercial<br>(made available to partners during the project) |
| Applicable fees | None during project;<br>special conditions will apply after the project to former partners in SHIPLYS according to CA;<br>otherwise license fees and maintenance contracts apply |
| | |
| **Software Technology** | |
| Supported platforms | Windows 7, 8+, 10 (in test),<br>Windows Server 2008, WS 2012,<br>Linux distributions using 3.x kernels,<br>Solaris |
| Interfaces | TGIS, Topgallant® Development Toolkit |
| Programming language(s) | Mostly Java, some parts use JavaScript, C#, C++ or C |
| Documentation | Product documentation, Training |
| | |
| **SHIPLYS relevance** | |
| Used by partners | Currently none; has been used in EcoREFITEC; |
| Information provided by | Thomas Koch, AES |
| Issues | |
| Comments | |

| | |
|---|---|
| **Name** | **v-shallo** |
| Version | |
| Originator | HSVA |
| Distribution | USB dongle |
| Functional Scope (keywords) | Calculation of wave patterns and calm water resistance.<br><br>3D-potential theory method |
| Functional Description | Calculates wave patterns and calm water resistance with respect to actual hull shape. Neglects other vicious effects than plate friction. |
| Information references (links etc.) | http://www.hsva.de/our-services/software/v-shallo.html |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | - |
| **Software Technology** | |
| Supported platforms | Windows |
| Interfaces | - |
| Programming language(s) | - |
| Documentation | Trainings, documentation texts |
| **SHIPLYS relevance** | |
| Used by partners | None(?), but used by European yards and engineering offices |
| Information provided by | Konstantin Kreutzer, AES |
| Issues | - |
| Comments | - |

| Name | Waveload-FD |
|---|---|
| Version | Waveload-FD 2014, HydroModeller 2014 |
| Originator | Lloyd's Register |
| Distribution | Downloadable installer |
| Functional Scope (keywords) | ship motion analysis<br>rigid body motion<br>full RAO calculations<br>multi-hull multi-vessel interaction<br>time averaged drift force<br>coupled liquid flow in tanks<br>short term statistics<br>zero to moderate ship speed<br>deep and shallow water<br>linear and non-linear viscous damping<br>Morison force and ship motion coupling<br>Effects of mooring lines<br>Mooring and fender system between ships<br>Capable HydroModeller |
| Functional Description | Hydrodynamics software package for calculation of motions, pressures and loads on ships and offshore structures in the seaway. Accurate, reliable and efficient, it has been extensively tested and verified against other software and experimental data. Waveload-FD is a panel-method code based on the three-dimensional Green's function in the frequency domain. |
| Information references (links etc.) | http://webstore.lr.org/products/2858-waveload-fd.aspx |
| **Commercial Information** | |
| License type | Commercial |
| Applicable fees | £20000 |
| **Software Technology** | |
| Supported platforms | Windows 7 |
| Interfaces | Windows |
| Programming language(s) | C#, C++, Fortran |
| Documentation | Product documentation<br>Training |
| **SHIPLYS relevance** | |
| Used by partners | - |
| Information provided by | Norbert Bakkers – Lloyd's Register |
| Issues | |
| Comments | |

# Annex B – Ship Design Process Activities and Flows

## B.1 ISO 10303 Ship AAM – List of Activities

**Table 7: activities defined in Ship Application Protocols of ISO 10303 (-215, -216, -218)**

| Common Name | Aliases | Description |
|---|---|---|
| A0 | Perform ship lifecycle | All of the lifecycle activities associated with a ship. |
| A1 | Specify ship | All activities associated with the production of a detailed specification of the ship prior to a contract being placed. |
| A11 | request a ship | The first activities of a ship owner when intending to order a ship. Having definite ideas regarding appearance and functionality of the ship, the owner expresses these ideas in an inquiry to the shipyard. |
| A12 | Prepare bid | This activity includes all activities of the yard regarding preparation and submission of the offer to the ship owner for the ship to be built. |
| A121 | Evaluate request & schedule bid | This describes the activities of the shipyard when evaluating the inquiry of the ship owner for a new ship. |
| A122 | Create preliminary design | All design activities relevant in a very preliminary stage of ship design in consideration of classification rules, national/international demands, shipyard constraints and owner requirements. The aim of this task is to make a shipyard offer. |
| A1221 | Create preliminary hull form | create preliminary hull form The activity that is the first step of designing a ship. Using parent ships main dimensions and form parameters one or more preliminary hull forms will be generated. |
| A12211 | Estimate main dimensions and parameters | |
| A12212 | Estimate form parameters | Establish preliminary hull form parameters from historical parent ship data and estimated main dimensions |
| A12213 | Do parametric variations | Do parametric variations evaluate alternative hull design solutions created by varying hull moulded form parameters |
| A12214 | Generate initial hull form definition | Establish the primary hull moulded form shape based on the calculated main dimensions, the preliminary hull form, and the performance parameters |
| A122141 | Generate initial fore-body definition | Establish the primary hull moulded form of the fore-body of the ship from the main dimensions, the preliminary hull form, and the performance parameters |

| Common Name | Aliases | Description |
|---|---|---|
| A122142 | Generate initial mid-body definition | Establish the primary hull moulded form of the mid-body of the ship from the main dimensions, the preliminary hull form, and the performance parameters |
| A122143 | Generate initial aft-body definition | Establish the primary hull moulded form of the aft-body of the ship from the main dimensions, the preliminary hull form, and performance parameters considering the number and size of propellers |
| A122144 | Generate inital deck definition | Determine the position and shape of the main weather deck of the ship from the main dimensions, the preliminary hull form, and the performance parameters |
| A122145 | Calculate initial hydrostatic properties | Calculate the theoretical floating portion of the ship based on the ship design parameters |
| A1222 | Create preliminary general arrangements | The activity that produces the preliminary compartmentation plans from the preliminary hull form definition. |
| A12221 | Define compartments | This activity deals with a preliminary establishment of main parameters. Main particulars are length between perpendiculars, breadth, depth, draught, Deadweight, Displacement and block coefficient. Also form parameters will be established like prismatic coefficient, |
| A122211 | Define compartment | arrangement |
| A122212 | Define non-structural | bulkheads |
| A122213 | Define compartment | properties |
| A122214 | Define space product | structure |
| A12222 | Calculate capacities | This activity includes the calculation of capacities of compartments and holds such as underdeck space, bunker space, tanks, machinery room and double bottom peak. |
| A122221 | calculate capacities, holds, bunker space | Calculation of all separate capacities. This could done with the help of integral calculus or approximate formulae. For instance the hold capacity could calculated from sectional areas and the integration over space's length. |
| A122222 | calculate underdeck space | The calculation of all internal volumes. |
| A122223 | calculate tonnage, freeboard | This activity deals with the calculation of tonnage and freeboard. As a result of the freeboard calculation a portion of ship volumes will be defined as reserve volumes. |
| A12223 | Estimate weight | This task is necessary for calculating the lightship weight and consists of the calculation of the hull steel weights, machinery weights and weights of outfitting and accommodation. |

| Common Name | Aliases | Description |
|---|---|---|
| A122231 | evaluate hull steel weights | |
| A122232 | evaluate machinery weights | This activity defines all separate weights belonging to the machinery plant, including auxiliary equipment. |
| A122233 | evaluate weights of outfitting and accommodation | This activity defines all separate weights belonging to the outfitting and accommodation. |
| A122234 | calculate lightship weight | This activity is necessary to summarise all relevant weight components. Together with the deadweight it is relevant for estimating the displacement. |
| A12224 | Calculate stability and trim | This activity deals with stability calculations (intact and damage stability), trim calculations, and calculations of centres of gravity in consideration of loading conditions. |
| A122241 | define loading conditions | This activity deals with the loading conditions and is necessary to ascertain the payload as a function of the available capacities. |
| A122242 | check stability (intact, damage) | This activity includes the calculation of intact stability and damage stability. For the damage stability it is necessary to prove the buoyancy in damage conditions with the help displacement and operation displacement). |
| A122243 | calculate trim | This task involves the calculation of trim due to the weight of the ship and the weight and distribution of cargo. |
| A1223 | Estimate hydrodynamics and powering | The activity that approximates hydrodynamic properties data calculations such as resistance, propulsion, seakeeping and manoeuvrability for the preliminary hull form. |
| A12231 | Estimate resistance and powering | Calculations based on historical data for producing powering and resistance data for the initial preliminary design |
| A122311 | Predict resistance | Estimate the wet-able surface area of the ship for seaway resistance |
| A122312 | Predict propulsion data | Calculate the propulsion requirements of the ship |
| A122313 | Predict propeller performance | Estimate propulsion requirements data to produce a preliminary propeller design |
| A1223131 | specify inital propeller characteristics | the activity which leads to the definition of overall propeller characteristics. |
| A1223132 | create preliminary propeller arrangements | the activity which leads to the definition of the preliminary propeller arrangements in relation to hull. |
| A1223133 | create preliminary blades | the activity which leads to preliminary definition of propeller blades including blade overall size and geometric configuration. |
| A1223134 | create preliminary propeller | the activity of deciding on the preliminary structure |

| Common Name | Aliases | Description |
|---|---|---|
| | components | of a propeller in terms of its major components. |
| A1223135 | *estimate hydrodynamis and powering | the activity which leads to hydrodynamic resistances of a ship and the power needed for ship propulsion. |
| A1223136 | validate inital propeller | the activity of validating the initial propeller design for satisfying the hydrodynamic and powering requirements of the ship. |
| A122314 | Predict brake power and service speed | Estimate the required braking power from the engine and the required power delivered to the propeller for determining the size of the main engine |
| A12232 | Estimate sea-keeping | calculations for the theoretical behaviour of a ship in seaway |
| A12233 | Estimate manoeuvrability | Approximation of the manoeuvrability of the ship and comparison of the model testing results with design requirements |
| A1224 | Create preliminary structure design | The activity that produces the preliminary steel structure design, including the arrangement of the primary structural members. |
| A1225 | Create preliminary machinery design | The activity that produces the preliminary designs for the ship machinery; including the prime mover, shaft system, fuel system, power systems and cargo handling equipment. |
| A12251 | select main engine | the activities which lead to the selection of the main engine by the shipyard. |
| A122511 | specify and select main engine | all activities associated with defining the specification of the main engine and its selection. |
| A122512 | agree on main engine detail specification | the activity which leads to agreement by corresponding organisations on a detailed specification of the main engine. |
| A12252 | design transmission system | the activities which leads to design of the ship main mechanical transmission system. |
| A122521 | select components | the activity which leads to the selection of ship equipment. |
| A122522 | carry out transmission system analysis | the activity of completing various engineering analyses on mechanical transmission systems as part of design and design approval processes. |
| A122523 | agree design | the activity which leads to agreement by corresponding organisations on a design. |
| A12253 | select auxiliary equipment | the activities which lead to the selection of auxiliary equipment. |
| A122531 | specify and select auxiliary equipment | all activities associated with defining the specification of auxiliary equipment and its selection. |

| Common Name | Aliases | Description |
|---|---|---|
| A122532 | agree on auxiliary detail specification | the activity which leads to agreement by corresponding organisations on a detailed specification of the auxiliary equipment. |
| A12254 | design manoeuvring systems | the activities which lead to design of the manoeuvring system by the shipyard for the ship. |
| A122541 | select components:2 | the activity which leads to the selection of ship equipment. |
| A122542 | carry out manoeuvring system analysis | the activity of completing various engineering analyses on the manoeuvring system as part of design and design approval processes. |
| A122543 | agree design:2 | the activity which leads to agreement by corresponding organisations on a design. |
| A12255 | select deck machinery | the activity which leads to the selection of deck machinery. |
| A122551 | specify and select deck machinery | all activities associated with defining the specification of deck machinery and its selection. |
| A122552 | agree on detail specification of deck machinery | the activity which leads to agreement by corresponding organisations on a detailed specification of the deck machinery. |
| A1226 | Create preliminary outfitting design | The activity that produces the preliminary design for the ship?s outfitting, including distributed systems, such as piping and electrical systems. |
| A123 | Decide post-sales & maintenance support | The activity that puts together the maintenance package for the ship. This is part of the tender document and includes the post sales support. |
| A124 | Calculate cost of ship | This activity describes creation of negotiating documents based on technical product data and their estimated manufacturing cost. The results of this activity may contain sale price documents, financing support plan and documents describing funding and possible loans. price documents, financing support plan and documents describing funding and possible loans. |
| A125 | Present offer | The activity concerned with presentation of the offer to build the ship to the prospective ship owner. |
| A13 | Place order | The owner places an order for a ship from the bids that have been submitted. From this a contract is awarded. |
| A2 | Complete and approve ship design | The production and approval of ship design product data, documents and the classification drawings using the preliminary design from the bid preparation, as well as the required rules and regulations. The result of this activity is the approved design and the production and delivery schedule. |

| Common Name | Aliases | Description |
|---|---|---|
| A21 | Finalise and approve general arrangements | |
| A211 | Finalise general arrangements | The activity in which the general arrangements are finalised from the preliminary design. |
| A2111 | finalise compartment definition | The activity which gives the definition of the ship?s compartments. |
| A2112 | finalise capacities calculations | The activity which produces the final volumes and centres results for the final calculation of stability and trim. |
| A2113 | finalise weight estimation | Produces the final weights and centres of gravity for the calculation of the final stability and trim. |
| A2114 | stability and trim calculation | This activity deals with stability calculations (intact and damage stability), trim calculations, and calculations of centres of gravity in consideration of loading conditions. |
| A212 | Approve general arrangements | This is the top level activity for the approval of the general arrangements. It is the entry activity for both the Design Approval Preview and checking against rules and regulations. The ship is not certified by this activity alone. |
| A2121 | perform DAP (Design Approval Preview) | perform DAP (Design Approval Preview) This is the top level activity for the approval preview of ship design. This activity is a feasibility study conducted by a Classification Society, in which the design is checked very roughly to detect critical areas for thorough investigation and conformity checking both as a design comment and to draw attention to specific areas during design approval. The content of this activity may vary with contract specifications and type of ship. |
| A2122 | check design against rules and regulations | This is the top level activity for the approval of the primary design as part of the approval and certification process. The content of this activity is the same for all ships when it comes to conformance with Main Class Rules, but varies when it comes to additional class rules (type of vessel) and register notations. The activities performed are tailored to the rule requirements for general arrangement and global strength. This part of the approval is necessary before the yard can start ordering steel. |
| A21221 | check position bulkheads | The checking of watertight integrity arrangements and stability conditions (intact and damage stability) to meet the relevant regulations given by Load Line conventions and the SOLAS convention. |
| A21222 | check cofferdams and tank content | check cofferdams and tank content This activity checks the necessity for separating tanks from each other by cofferdams based on tank contents. |

| Common Name | Aliases | Description |
|---|---|---|
| A21223 | check internal doors and hatches for WT integrity | check internal doors and hatches for WT integrity This activity checks for compliance with rule requirements with respect to doors and hatches and watertight integrity. |
| A21224 | check arrangements for dangerous cargo | This activity checks for compliance with rule requirements with respect to arrangements for dangerous cargo (fire protection, detection, extinction, extinguisher). |
| A213 | Finalise production planning | This produces outputs relating to the final construction sequence, the material supply and the management of time and people. |
| A22 | Finalise and approve hull form | The activity in which the hull form is finalised from the preliminary design. The result is a final and approved hull form design. |
| A221 | Finalise main dimensions and parameters | Refinement of the model tests, analysis, and usage requirements |
| A222 | Fair hull | Adjustments to the hull moulded form to correct any surface aberrations |
| A223 | Calculate hydrostatic properties | Calculate the theoretical floating portion of the ship based on the ship design parameters |
| A23 | Finalise and approve hydrodynamics and powering | This includes all relevant hydrodynamic calculations such as resistance, propulsion, seakeeping and manoeuvrability. |
| A231 | calculate CFD | calculation of fluid flow around the hull |
| A232 | perform model tests | conduct model testing in a towing tank or model basin |
| A24 | Complete and approve design of ship structure | The completion and approval of the ship structural design. |
| A241 | Design ship structure | Design ship structure (A241) covering the activities of creating a synthesis of the product specification and transforming them into the physical representation of the product. |
| A2411 | Request classification items | collecting the approvable items from the classification society with information about the components and the request for changes . |
| A2412 | Create design of classification items | creating the design of those items required by the classification society. |
| A24121 | Design of transverse structures | dimensioning the midship section, including plates, shell profiles and shell thickness. |
| A241211 | Design transverse bulkheads | Finishing the design by completing the dimensioning of the transverse structure. |
| A241212 | Design collision bulkheads | Designing the collision bulkhead, specially concerning water resistance and strength in the bow area. |

| Common Name | Aliases | Description |
|---|---|---|
| A241213 | Design transverse frames | design frames between transverse bulkheads. NOTE The frames are the transverse members that make up the riblike part of the skeleton of a ship. |
| A24122 | Design longitudinal horizontal structures | dimensioning the midship section, including plates, shell profiles and shell thickness. |
| A24123 | Design Longitudinal vertical structures | supporting the design of vertical structural separations such as bulkheads, cofferdams and vertical shell profiles. |
| A24124 | Layout primary structure | the entry activity for design approval preview and the approval of the primary design. |
| A24125 | Design special areas | design areas of the ship not covered by the longitudinal and vertical structure . EXAMPLE The engine foundations as well as aft and fore body |
| A2413 | Modify for classification | the function concerned with the items of classification found to be not solved properly according to the rules. NOTE The inputs are the design change requests which are modified to be satisfactory for the technical solution. |
| A242 | Approve design of ship structure | Approve design of ship structure (A242) the top level activity for the approbation of ship design. |
| A2421 | Perform design approval preview | This is the top level activity for the approval preview of ship design. This activity is a feasibility study conducted by a Classification Society, in which the design is checked very roughly to detect critical areas for thorough investigation and conformity checking both as a design comment and to draw attention to specific areas during design approval. The content of this activity may vary with contract specifications and type of ship. |
| A2422 | Check desing of general arrangement | Authorities in the country in which the ship is to be registered. For passenger ships the "International Convention for Safety Of Life At Sea (SOLAS)" will normally apply. |
| A2423 | Check design of girder strength | checking the compliance with rule requirements with respect to global strength requirements. NOTE This approval is necessary before the yard can start ordering steel. |
| A2424 | Check global strengh and secondary structures | checking the strength of the whole ship for the approval of the secondary design as part of the approval and certification process . NOTE The content of this activity is the same for all ships when it comes to conformance with main class rules, but varies when it comes to additional class rules (type of vessel) and register notations. |
| A24241 | Check bottom structures | checking the hull structure within the area of the lowest part of the hull, including tanks, ballast area and keel to confirm conformance with the |

| Common Name | Aliases | Description |
|---|---|---|
| | | regulations. |
| A24242 | Check side structures | checking the sufficient material thickness and the fulfillment of the regulation requirements. |
| A24243 | Check deck plans | controlling whether the necessary spaces and volumes of the vessel are correct in volume, size and position. |
| A24244 | Check bulkheads | checking the dimensioning, the correct type and the correct position of the bulkheads. |
| A243 | Elaborate ship structure design | elaborate ship structure design (A243) the function giving detailed information to order parts and to manufacture, and giving the physical outcome of the design. NOTE Among these activities are the subdividing of physical structures and the determination of tasks for manufacturing. |
| A2431 | Make initial assembly definition | the first rough division into assemblies . NOTE This is further developed during production design. |
| A2432 | Check WCoG | checking the weight and center of gravity for the design. |
| A2433 | Manage collision control | |
| A2434 | Make Hull detail design | Covering the design and realization of the steel structure by the use of plates and as stiffening element the profiles . NOTE Therefore in a first step the secondary structure is defined. Finally the structure is coated and in compartmentalization areas an insulation is necessary to be designed. |
| A24341 | Design secondary structure | designing structure details not defined in early design. |
| A243411 | Define plates | setting the layout of individual plates according to the structural hull design. |
| A243412 | Define profiles | setting the position of the profiles according to the structural hull and related design. |
| A243413 | Define brackets | add brackets to early and secondary designs. |
| A24342 | Handle plates | splitting plate parts and add production information. |
| A243421 | Define seams, bevelling and welding | defining the designed features of structured parts for the welding of plates. |
| A243422 | Define holes and penetrations | defining the holes and penetrations according to the other functions of the system that has the connected throughputs. |
| A243423 | Define notches, lag and welding | all design activities which are meant to support the welding process. |
| A243424 | Refine thickness | refining material strength of the plates. NOTE They are found and fixed as working information for the hull design. |
| A24343 | Handle profiles | partition profiles, add production information and |

| Common Name | Aliases | Description |
|---|---|---|
| | | design additional and secondary profiles. |
| A243431 | Partition profiles | defining the resulting length of plate related stiffeners |
| A243432 | Define holes and notches | fixing the dependent holes and notches in their position when defining the profiles in their length and position. |
| A243433 | Define endcuts, beveling and welding | defining the design features required for preparing structural parts for the welding of profiles. |
| A243434 | Define secondary profiles | selecting the detailed length of the individual profiles and their size and cross-section. |
| A24344 | Collect part order information | collecting part ordering information to be used in management information systems (MIS) and estimations. |
| A24345 | Define insulation and sruface treatment | defining the insulation and surface treatment definitions to be used depending on location of structure and functional requirements. |
| A2435 | Make outfitting detail design | |
| A244 | Make production design of ship structure | Make production design of ship structure (A244) the function that contains all activities which perform the material supply, the creation of production information and its documentation and the refined working information. |
| A2441 | Collect and analyse design transfer into drawings | the necessary activities to ensure the material supply for the production of the ship. |
| A2442 | Create production documents | producing the production documents which are needed to describe the features of technical parts and their relationship. |
| A24421 | Prepare production documents for steel structure | the function that performs the segmentation of the steel structure, creating working and assembly information. |
| A24422 | Transform piping and electrical design into production design | a function to transform the conceptual data from design (CA) into material demand and assembling information. |
| A24423 | Work out plans for outfitting and equipment | the function that contains information for the various workforces in scheduling, controlling and coordinating their activities in their specific fields. |
| A2443 | Refine working information | the function that engages with the time scheduling and assignment of dry dock capacities. |
| A24431 | Estimate drydock resources and its divisions | the function that engages with the time scheduling and assignment of dry dock capacities. |
| A24432 | Create production documents | the function that coordinates the proper sequence of the steel structure and outfitting of the structure. |
| A24433 | Prepare outfitting and equipping plans and schedules | work out outfitting and equipping plans. |

| Common Name | Aliases | Description |
|---|---|---|
| A24434 | Coordinate subcontractors tasks | the distribution and coordination of the tasks which are done by the subcontractors. |
| A25 | Complete and approve design of machinery | The selection, arrangement and approval of the power plant in terms of the main engine, associated propulsion system and its auxiliary machinery. |
| A251 | finalise machinery design: 2 | the activities which leads to design of selected machinery such as the propeller which are in the scope of this part of ISO 10303. |
| A2511 | finalise main engine selection | the activity which leads to the selection and ordering of the main engine. |
| A25111 | integrate changes on main engine design | |
| A25112 | approve main engien design | |
| A2512 | finalise transmission system design | the activity which leads to the completion of the ship main mechanical transmission system design. |
| A25121 | finalise selection of components | the activity which leads to the selection of various ship equipment. |
| A25122 | carry out transmission system analysis: 2 | the activity of completing various engineering analyses on mechanical transmission systems as part of design and design approval processes. |
| A25123 | agree final design | the activity which leads to agreement by corresponding organisations on a final design. |
| A2513 | finalise auxiliary equipment selection | the activity which leads to the selection and ordering of auxiliary equipment. |
| A25131 | integrate changes on auxiliary equipment design | the process of including design refinements in the auxiliary equipment design in order to generate the final design. |
| A25132 | approve auxiliary equipment design | the activity which leads to the design approval, by the corresponding organisations, of auxiliary equipment. |
| A2514 | finalise manoeuvring system design | the activity which leads to the design of the manoeuvring system. |
| A25141 | finalise selection of components: 2 | the activity which leads to the selection of various ship equipment. |
| A25142 | carry out manoeuvring system analysis: 2 | the activity of completing various engineering analyses on the manoeuvring system as part of design and design approval processes. |
| A25143 | agree final design:2 | the activity which leads to agreement by corresponding organisations on a final design. |
| A2515 | finalise deck machinery design | the activity which lead to the production of final design for deck machinery. |
| A25151 | integrate changes on deck machinery design | the process of including design refinements in the deck machinery design in order to generate the |

| Common Name | Aliases | Description |
|---|---|---|
| | | final design. |
| A25152 | approve deck machinery design | the activity which leads to the design approval, by the corresponding organisations, of deck machinery. |
| A252 | approve design of ship machinery | the activity which leads to the design approval, by the corresponding organisations, of ship machinery. The design approval relates to the machinery equipment and systems. The ship certification is not complete with this activity and would need equipment manufacturing surveys, tests and installation surveys as well. |
| A2521 | perform design approval | the activity which is mainly carried out by the classification society in approving the design of certain equipment and systems. |
| A2522 | check design against rules and regulations | the activity by class society to ensure that equipment and machinery conform to rules and regulations. |
| A25221 | check main engine | the activity of checking the specification and design of the main engine against the rules. |
| A25222 | check boilers | the activity of checking the boiler specifications against the rules. |
| A25223 | check manoeuvring system | the activity of checking the specification and design of the manoeuvring system against the rules. |
| A25224 | check shafting and propeller | the activity of checking the specification and design of main shafts and propeller against the rules. |
| A25225 | check deck machinery | the activity of checking the deck machinery specifications and design against the rules. |
| A253 | *finalise production planning | the activities which lead to a production plan. |
| A254 | finalise maintenance planning | the activity which leads to preparation of a machinery maintenance plan. |
| A26 | Complete and approve design of outfitting and distribution systems | The selection and approval of the necessary outfitting equipment. The selection is based mainly on former designs and in accordance with the requirements. It also contains the |
| A3 | Produce and inspect a ship | This activity includes high-level activities such as produce, monitor and inspect ship production. Inspect, means the controlling of all activities throughout the whole production life cycle of a ship. |
| A31 | produce steel Sub-sections | Construct and join structural steel members that when assembled and certified make up a modular unit NOTE Their production is controlled by the schedule, contract, the approved design, any manufacturing restrictions, and the classification society. The results are the steel sub-sections, which are assembled into modular units for |

| Common Name | Aliases | Description |
|---|---|---|
| | | completing the ship. |
| A32 | produce modular build units | fabricate steel subsections and erected into large detached certified units that when assembled or attached will make up the completed ship |
| A33 | assemble ship | The production stage of the ship that assembles the modular units and the additional parts |
| A331 | *assemble steel sub-sections | the activity of assembling the ship steel sub-sections |
| A332 | *install modular build units | the activity which leads to the installation of modular build units. |
| A333 | install equipment | the activity which leads to the installation of the equipment. |
| A3331 | deliver machinery | the activity which leads to the delivery of the ship machinery to the shipyard |
| A3332 | install machinery | the activity which leads to the installation of the machinery. |
| A3333 | deliver auxiliary equipment | the activity which leads to the delivery of the ship equipment to the shipyard. |
| A3334 | install auxiliery equipment | the activity which leads to the installation of the auxiliary equipment. |
| A334 | *install modular machinery systems | the activity which leads to the installation of modular machinery systems. |
| A34 | test ship | inspect and evaluate the actual ship against the design specifications, rules and regulations, and contract requirements |
| A341 | test structures | The steel structures are inspected and evaluated against the design specifications, rules and regulations, and contract requirements NOTE The output is the test result documentation. |
| A342 | test systems | The ship‘s systems including outfitting, machinery, and mission systems are inspected, put into service, and evaluated against the design specifications, rules and regulations, and contract requirements |
| A343 | conduct contractor sea trials | The sea trials to test if the built ship meets the contract requirements |
| A344 | conduct acceptance trials | The final trials for delivery the ship |
| A35 | produce and approve reference documents | Compose and assemble technical documentation authorized for the ship using production information |
| A4 | Operate and maintain a ship | The activity that describes the running and maintenance of the ship during its service lifetime. |
| A41 | Operate a ship | provides feedback into other activities based on running the ship. |

| Common Name | Aliases | Description |
|---|---|---|
| A42 | Maintain a ship | The maintenance activities during the operation phase of a ship NOTE It is based on the existence of a planned maintenance system (PMS) for preventive maintenance on board, at the harbor base and at a yard. Preventative maintenance includes planned regular inspections, lubricating, cleaning, replacement of parts and may be scheduled by calendar date, usage condition. A planned maintenance system contains schedule, procedures, and a listing of required materials, skill, tools and test equipment. Correctivmaintenance (repair) will be applied in case of a failure of a system or component. It may be predictable but is obviously not scheduled. Generally after discovering the failure a failure analysis and a specific corrective maintenance plan, inclusive a repair procedure will be made. Execution of the maintenance is followed by inspection, testing, inspection and approval by an organization authorized for the specific maintenance. |
| A421 | Maintain on board | the execution of the maintenance task on-board ship at sea. |
| A422 | Maintain at base | the execution of the maintenance task at base (port). |
| A423 | Maintain at yard | the execution of the maintenance task at shipyard. |
| A43 | Statutory and class survey | preparative and executive tasks to perform a survey with focus on the statutory survey to meet the requirements of the class certificate. |
| A5 | Decommission and disassemble | All activities relating to the last stage of the ship?s lifecycle. It consists of the decommissioning and dismantling of the ship. |

## B.2 ISO 10303 Ship AAM – List of Flows (Inputs, Controls, Outputs)

### Table 8: List of Flows within the ISO Ship Activity Model

| Common Name | Description |
|---|---|
| (special areas) structural design | the design of the hull structure not including longitudinal and vertical structure. |
| Inf. about wcog | the information about weights and centres of gravity. |
| Loading conditions | Quantities of cargo, ballast water, and consumables identified for each space or compartment that are used as a basis for design |
| alarm | the document or report resulting by operating a ship that warns the maintenance personnel which problem the ship has. |
| approved design | The approved design is the final design to be submitted as an offer. |
| approved primary design | the approved fundamental and principal structural design. NOTE - It is a result from the approve design of ship structure activity by a classification society. [#A244C\ |
| arrangement relationships | *** |
| arrangements | part of approved design The arrangements of the ship are the ship?s compartments and spaces. Any description of arrangements will include associated definitions of purpose for the compartment or space. |
| assembled steel sub-sections | *** |
| assembly definition | the rough division into assemblies. |
| auxiliary equipment | an equipment that supports one or more main systems or equipment. |
| auxiliary equipment design | *** |
| availability, reliability and maintainability information | The information about the components that is required to install them in the ship and is required for planned maintenance. |
| base material data | - |
| basic hull parameters | Principal dimensions and proportions based on estimations from historical data or from preliminary design development |
| budget | The budget is a plan the careful use of money necessary to control expenditures for all items. |
| building capacities of yard | the production ability available to the yard, usually in tones per |
| building sequences | the sequences of producing a ship, as input for preparing the section plans. |
| building specification | the information which specifies the detailed framework for the construction of the ship |
| building specifications | the information which specifies the detailed framework for the construction of the ship |
| calculated speed/resistance/power | *** |
| capacities for lifting, drydock spaces and produciton lines | the information that results from estimating drydock resources, which includes scheduling and assignment of a dry dock. |

| Common Name | Description |
|---|---|
| certificates | The certificates issued by the Classification Society on completing the ship. |
| class | *** |
| cog and lightship weights | Summarise all centres of gravity and all weight components relevant for lightship weight. |
| collision control results | the results from managing the control for clutches. NOTE The clutches are, both hard and soft, between different design parts, such as pipes, equipment items and cable trays. |
| compartment as designed properties | *** |
| compartment shape representation | *** |
| completed sectional area curve | The curve created by representing the area of each cross- section, as a point on a curve, at specified intervals through the hull for the length of the ship. |
| components | the equipment or components which are part of the ship systems. |
| configuration plan for outfitting | one part of the production documents for steel structures. |
| contract | The contract is the output from the activity which involves placing the order for the ship. The contract is used as a constraint in subsequent activities such as final design and approval and production. |
| cost | The calculated cost of the ship based on the cost of material and labour. |
| critical design areas | The areas requiring thorough investigation and conformity checking identified by the Design Approval Preview. |
| deck machinery | the machinery positioned on the main deck of the ship. |
| deck machinery design | *** |
| design change request | the feedback from approval design of ship structure activity. NOTE It is the necessary change of the primary structural design of being requested. |
| design modifications | Comments and recommendations on the design (red-marking). |
| design schedule | Data that controls the time from the design phase to production. |
| detail design | *** |
| detailed specification | the ship equipment and systems specifications as required for approval by the ship owner. |
| details of flow | This is the results of the Computational Fluid Dynamics (CFD) analysis, which models the flow of fluid along the hull. This is used to estimate resistance of the hull through the water and contributes to estimating the powering requirements for the ship water and contributes to estimating the powering requirements for the ship |
| distribution and outfitting design | The design of the distribution systems ( electrical and piping ) and the outfitting. |
| drawing | the technical representations, outlining figures or plans of the ship structures. NOTE The drawing is the results of detail design and input |

| Common Name | Description |
|---|---|
| | for creating the production documents |
| early design | the design of the ship structures including the primary design and approved primary design. |
| equipment | a part of the enginering systems that carries out a generally self contained function and to a large extent can be treated as a single item for the purpose of design, acquisition or operation. |
| equipment certificates | The certificates issued by the Classification Society on completing the equipment items which will be assembled to create the final product |
| feedback | The outputs from activities which then feed back and modify previous activities in the lifecycle on the current or subsequent ships. |
| final compartment design | Approved design at the completion of the design of the compartment. |
| floodable curves | Used in the activities which define compartments to establish the main bulkhead positions. |
| fore-body definition | The hull moulded form design of the fore-body of the ship |
| freeboard | The freeboard is the distance from the waterline to the upper surface of the freeboard deck at side. |
| fuel consumption | A fuel consumption calculation is used to estimate the needs of capacities for fuel. |
| general arrangements | The final compartment definitions |
| historical data from previous designs | Data held by the shipyard or model basin on previous ship designs and used to estimate the hydrodynamics, powering requirements and sea- keeping. |
| hole definition | the geometrical and topological information of a hole when defining holes and penetrations on a plate. |
| hull design | the design of hull form, results of the hull detail design. |
| hull form parameters | the block coefficient, prismatic coefficient and Froude number that are used during the preliminary design phase to estimate the hydrostatic and hydrodynamic properties of the ship |
| hull form sections | The design of the hull moulded form at planar sections taken along the longitudinal axis of the ship. |
| hull moulded form | The definition of the shape of the hull of the ship, resulting from the addition of the aft-body, mid-body and fore-body definitions, which does not take into account the thickness of the material from which the hull is made. |
| hull moulded form with deck definition | hull moulded form with deck definition the shape of the hull moulded form with the enclosing watertight deck of the ship |
| hull steel weights | These outputs are the results of several calculation and design activities which result in an estimated weight of the steel structure making up the hull. |
| hydrodynamic loads | - |
| hydrodynamics & powering results | The results of calculations and model basin tests. They contain resistance, propulsion, propeller performance, brake power, service speed, sea keeping and manoeuvrability data. |

| Common Name | Description |
| --- | --- |
| hydrostatics | Hydrostatic properties are used in checking of ship's stability. |
| hydrostatics table | Tabular data that describes the hydrostatic properties for the ship that result from calculations at the initial and final design stages |
| initial propeller characteristics | *** |
| inspection information | the information resulting from visual, non-destructive examinations or tests carried out to assess the condition of one or more components of a ship system. |
| installed equipment | *** |
| installed machinery | *** |
| knowledge and experience | - |
| laws, rules and regulations | National laws, statutory regulations and classification society rules that are used to control the design, manufacture, operation, maintenance and scrapping of the ship. |
| list of classification items | the list of those items required by the classification society. EXAMPLE Midship sections, bulkheads, shell profile arrangement and foundations. |
| list of required certificates | The result of placing an order, this is the list supplied by the owner for certificate requirements. |
| loading and stability manual | The loading and stability manual |
| loading conditions | *** |
| loads | a mass, force or weight supported by a ship. |
| longitudinal bulkheads wall | - |
| longitudinal bulkheads walls | the bulkheads walls between transverse frames. |
| machinery | *** |
| machinery design | The design drawings and electronic models of the ship mechanical systems. An output from the final design process. |
| machinery weights | These outputs are the results of several calculation and design activities which result in an estimated weight for all machinery. |
| main cross section, longitudinal profile dimension and plate dimensions | the dimensions of the main hull cross section and longitudinal profiles and plates resulted from the transverse structure design. |
| main dimensions | *** |
| main engine | the selected main engine |
| main engine design | *** |
| maintenance history | the diary of the maintenances of a ship. |
| maintenance report | the report on the maintenance results. |
| manoeuvering system | a system used to perform planned movement or change from the straight steady course and speed of a ship. |
| manoeuvering system design | the design specification and drawings of the ship manoeuvring system. |

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| Common Name | Description |
|---|---|
| manoeuvring results | The estimated zigzagging, planned moves, and turning results based on previous model basin tests or sea trials |
| manoeuvring system | a system used to perform planned movement or change from the straight steady course and speed of a ship. |
| manoeuvring system analysis | *** |
| manuals | *** |
| manufacturing restrictions | A constraint on the ship construction and design processes governed by available technology and shipyard facilities. |
| material allocation ordering | the data describing the necessary material supply for production. |
| material allocation/ordering | The data describing the necessary material supply for production. |
| material data | the data relating to spare parts and consumables for on-board maintenenance. |
| material list | The list of raw materials needed to manufacture the ship. A result of the final design process. |
| mid-body definition | The hull moulded form design of the parallel body portion, that includes the mid-ship section design, of the ship that extends between the aft-body and the fore-body of the ship or the hull moulded form design of the mid-ship section design for ships that have no parallel body portion |
| model basin theory | - |
| modifcations to hul form | Modifications to the hull shape due to feedback from hydrodynamics and powering results and the final design process. |
| modifcations to hull form | Modifications to the hull shape due to feedback from hydrodynamics and powering results and the final design process. |
| modification | a feedback from the modification for classification when designing the ship structure. |
| modifications from machinery | Revisions or adjustments to the hydrodynamics and powering due to feedback from the preliminary machinery design |
| modifications to hull form | Modifications to the hull shape due to feedback from hydrodynamics and powering results and the final design process. |
| modifications to hull parameters | Revisions or adjustments to the main dimensions of the hull that are made during the hull moulded form design process |
| modifications to main dimensions | Revisions or adjustments to the main dimensions of the hull that are made during the hull moulded form design process |
| modular build units | the modular assemblies of ship steel sub-sections, normally produced in the shipyard. These are later on assembled onto the ship. |
| modular machinery systems | the modular assemblies of ship machinery systems, either assembled in or delivered to the shipyard. These are later on assembled onto the ship. |
| modular units | Sub-sections of the ship complete with machinery and outfitting which will be assembled to create the final product |
| moulded forms | *** |

| Common Name | Description |
|---|---|
| noise and vibration level | the equipment and system noise and vibration levels that influence the design of ship systems. |
| non-structural moulded forms | *** |
| offer | These output includes the data necessary to make an unconditional offer to the shipowner. [#A12O\ |
| offer guidelines | The offer guidelines include the data necessary to make an unconditional offer to the ship owner [#A121O\ |
| on-board material data | - |
| operational histories | the diary made during the operation of s ship. |
| operational information | Accumulated information during the operation phase of the ship used for maintenance and in the final scrapping stage. |
| outfitting items | *** |
| outfitting weights | These outputs are the result of several calculation and design activities which result in an estimated weight for all outfitting systems and furnishings. |
| owner | *** |
| owner request, requirements | the requirements document that is submitted to the shipyard by the owner upon the invitation to tender. |
| owner request, requirents | The activity generates these output necessary for other activities. These outputs includes data e. g. functional restrictions, transportation needs . |
| owner, class | *** |
| owner, classification society | *** |
| part ordering information | the information to order the parts. NOTE It is obtained from the hull detail design. After that the plates and profiles have been handled and the parts are collected. |
| payload | This output calculates the payload as a function of the available capacities. |
| planned maintenance system | Data created during the final design process and used during the operation and maintenance of the ship. |
| plate info | the result from the defining plates during the secondary structure design state. NOTE It includes material type, thickness and geometrical form of the plates. |
| power requirements for engine | hydrodynamics and propulsion data used in the selection of the main engine |
| pre layout | The very initial layout of the ship which is produced during the bid evaluation stage and is the basis for the preliminary design. |
| preliminary blades | *** |
| preliminary design | the design that leads to the submission of a bid proposal. |
| preliminary general arrangements | The space arrangement plan from the preliminary design stage |

| Common Name | Description |
|---|---|
| preliminary hull form | The definition of the hull form, as a result of the preliminary design process. Used in the offer documents and for preliminary compartment design, hydrodynamics and powering calculations. |
| preliminary machinery design | The definition of the ship mechanical systems. Used early to estimate the noise, speed and vibration and to estimate the machinery weights. |
| preliminary machinery, structure and outfitting design | The outputs from activities which then feed back and modify previous activities in the lifecycle on the current or subsequent ships. |
| preliminary outfitting design | - |
| preliminary propeller arrangements | *** |
| preliminary propeller components | *** |
| primary design | the fundamental and principal structural design, a result from the design ship structure activity. |
| primary design in special areas | the fundamental and principal design of the ship not covered by the longitudinal and vertical structure. |
| primary design of similar ships | the fundamental structural data of ships in the same category. |
| primary structure | the first result during the design of the classification items with design approval preview. |
| primary structures | *** |
| product component information | These control includes information several product components e.g. technical data of main engine |
| product structure definition | *** |
| production and delivery schedule | The timetable to which the ship is to be manufactured and delivered |
| production information | data describing the manufacturing and construction details of the product. EXAMPLE Dimensions, mechanical properties, materials, workshop information. |
| production schedule | data that controls the time from the production phase to delivery. |
| propeller design | *** |
| propeller theory | the body of knowledge based on the historical experience and abstract ideas of ship propeller performance. |
| quality assurance | The rules applied by an organization within the shipyard that has the task to audit the shipyard organization and applied processes in a manner such that the quality of the resulting product is assured |
| refined design | The final compartment definitions. |
| refined design for classification | the new design which would require the approval of the classification society. |
| regular wave theory | The knowledge and experience related to the motion response of a ship in waves of constant height and period |
| request for other level maintenance | the request for maintenance on another level as a result of a diagnosis activity. |

| Common Name | Description |
|---|---|
| request for production changes | Changes that are requested to the ship design as a result of production experience or difficulties with the realisation of the ship design. |
| resistance and shaft power | The opposition to motion that results in hydrodynamics and powering estimates |
| resistance theory | The principles, theorems, and rules used to predict the resistance of the hull to forward motion in the sea |
| resources allocation | A result of production planning. |
| ressource allocation | the result of the capacity planning. |
| schedule | The schedule is formed as a part of the final design process. It governs the timing of the production phases. |
| scrapping plan | The document used to schedule the time and resources required to dismantle the ship. |
| secondary structure design | the structure detail design not defined in early design, as input for handling the plates and profiles. |
| secondary structures | *** |
| selected components | A subset from the set of all components worldwide. Only components which are selected. |
| shell and longitudinal bulkhead walls | the watertight skin of the ship and the bulkheads walls between transverse frames. |
| ship | *** |
| ship operations | *** |
| ship product model data | The product data of the accumulated throughout its lifecycle. Because scrapping is part of the lifecycle the ship is not an output, only the documented information and knowledge about the ship survives. |
| ship weight modifications | Modifications to ship weight due to the preliminary structure design. This is fed back to modify the preliminary hull form and revise the preliminary general arrangements. |
| short and long term responses | An approximation of sea keeping ability with calculations based on regular waves of a specified height and period |
| specified and selected deck machinery | specifed and selected |
| stability parameter | Parameters including several results of stability calculations. |
| steel sub-sections | sub-sections of the steel structure which are outfitted with the machinery and distribution systems before assembly |
| structural design | design of the ship foundation and framework. EXAMPLE Includes the keel, hull, bulkheads, decks, superstructures, girders, stiffeners, and the like. |
| sub sections | - |
| supplier | *** |
| survey report | the report on the results of inspections of ship machinery, structure or other equipment. |

| Common Name | Description |
|---|---|
| survey status | - |
| technical documentation | In case of maintenance the technical documentation of a system means part of the product description required to perform preventative maintenance, repair and failure analysis of that system. Technical information is an output which includes more detail information about material parts needed for producing the ship/system. |
| technical requirements | The owner's specifications that must be realised by the completed ship. |
| tonnage | Tonnage is a method of volume calculation applied to ships. |
| total resistance | The counteracting forces on the hull due to forward motion |
| towing tank model | A scale model of the ship used in a towing tank for estimating hydrodynamic properties |
| transmission system | a system by which motive power from a prime mover is made available at load and matched to load (e.g. shafting system connecting main engine to propeller, or shafting system connecting auxiliary engine to generator). |
| transmission system analysis | *** |
| transmission system design | the definition of the transmission system design. Includes all the information, normally in drawing form, including those of the selected equipment. |
| transportation need | A constraint which determines the specification for the ship construction. |
| trim | *** |
| updated survey status | the updated status of a survey after carrying a statutory and class survey. |
| volumes and centres | Volumes and centres of holds, bunkers, tanks and compartments. |
| volumes and centres of gravity | *** |
| weights and centres of gravity | Weights and centres of gravity necessary for further calculations. |
| weights and compartmentation | the ship arrangement and weight details. |
| working information | the information for production stage of the ship structures. |
| workload | the total effort required to build the chosen ship design as estimated by the shipyard and assisting consultants. |
| zone definitions | *** |