**DESIGN OF IMPROVED AND COMPETITIVE PRODUCTS USING AN INTEGRATED DECISION SUPPORT SYSTEM FOR SHIP PRODUCTION AND OPERATION**

**AUTHOR/S:** Amrane A.; Warnotte R.; Rigo Philippe

**ABSTRACT:** IMPROVE final publishable activity report: Three Years Report (1st Oct 2006 to 30th September 2009)

This report includes a summary description of the project objectives, contractors involved, work performed and end results, elaborating on the degree to which the objectives were reached.

This report briefly describes the methodologies and approaches used and it presents the main achievements of the project.

It is explained the impact of the project on the shipbuilding industry and maritime research sector. It includes diagrams and figures illustrating the work of the project, the IMPROVE project logo and the reference to the project website.

**RELATED WP & TASKS:** WP1, WP2, WP3, WP4, WP5, WP6, WP7, WP8 and WP9

**PERFORMING ORGANISATION:** ANAST

**DOCUMENT CLASSIFICATION:** (Void)

**CIRCULATION:** All IMPROVE Partners & EU

**DISTRIBUTION:**

<table>
<thead>
<tr>
<th>REV.</th>
<th>DATE</th>
<th>DESCRIPTION</th>
<th>PAGES</th>
<th>CHECKED</th>
<th>APPROVED</th>
</tr>
</thead>
<tbody>
<tr>
<td>V3</td>
<td>16 Oct 2009</td>
<td>First Draft</td>
<td>26</td>
<td>AM.A ; D.D</td>
<td>PhR</td>
</tr>
<tr>
<td>V8</td>
<td>14 Nov 2009</td>
<td>Final</td>
<td>73</td>
<td>AM. A., R.W.</td>
<td>PhR</td>
</tr>
</tbody>
</table>
The information contained in this report is subject to change without notice and should not be construed as a commitment by any members of the IMPROVE Consortium. In the event of any software or algorithms being described in this report, the IMPROVE Consortium assumes no responsibility for the use or inability to use any of its software or algorithms. The information is provided without any warranty of any kind and the IMPROVE Consortium expressly disclaims all implied warranties, including but not limited to the implied warranties of merchantability and fitness for a particular use.

© COPYRIGHT 2007 - The IMPROVE Consortium

This document may not be copied, reproduced, or modified in whole or in part for any purpose without written permission from the IMPROVE Consortium. In addition, to such written permission to copy, acknowledgement of the authors of the document and all applicable portions of the copyright notice must be clearly referenced.

All rights reserved.

IMPROVE Consortium Contacts:

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Name</th>
<th>Phone</th>
<th>e-mail</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNIVERSITY of LIEGE</td>
<td>Rigo Philippe</td>
<td>+32 4 366 93 66</td>
<td><a href="mailto:Ph.rigo@ulg.ac.be">Ph.rigo@ulg.ac.be</a></td>
</tr>
<tr>
<td>STX Yards, S.A.</td>
<td>Claes Lorenz</td>
<td>+ 33 2 51 10 37 77</td>
<td><a href="mailto:Lorenz.claes@stxeurope.com">Lorenz.claes@stxeurope.com</a></td>
</tr>
<tr>
<td>Uljanik Brodogradiliiste, d.d. (Uljanik Shipyard)</td>
<td>Milanovic Milan</td>
<td>+ 385 52 380 687</td>
<td><a href="mailto:milan.milanovic@uljanik.hr">milan.milanovic@uljanik.hr</a></td>
</tr>
<tr>
<td>Stocznia Szczecinska Nowa Sp. z o.o.</td>
<td>Kapuścik Krzysztof</td>
<td>+48 91459 15 01</td>
<td><a href="mailto:kkapusck@ssn.pl">kkapusck@ssn.pl</a></td>
</tr>
<tr>
<td>Atlantica spa di navigazione</td>
<td>Bocchetti Dario</td>
<td>+39 081 49 65 28</td>
<td><a href="mailto:bocchetti.dario@grimaldi.napoli.it">bocchetti.dario@grimaldi.napoli.it</a></td>
</tr>
<tr>
<td>Exmar Marine NV</td>
<td>Van Nuffel Frederik</td>
<td>+32 3 247 56 94</td>
<td><a href="mailto:improve@exmar.be">improve@exmar.be</a></td>
</tr>
<tr>
<td>Tankerska plovidba brodarško dionicko durstvo</td>
<td>Brzic Zvonko</td>
<td>+ 385 23 202 416</td>
<td><a href="mailto:zvonko.brzic@tankerska.hr">zvonko.brzic@tankerska.hr</a></td>
</tr>
<tr>
<td>Bureau Veritas</td>
<td>Mcc Gregor Jon</td>
<td>+ 33 1 42 91 32 01</td>
<td><a href="mailto:jon.mccgregor@bureauveritas.com">jon.mccgregor@bureauveritas.com</a></td>
</tr>
<tr>
<td>Design Naval &amp; Transport</td>
<td>Hage André</td>
<td>+32 4 366 9225</td>
<td><a href="mailto:a.hage@dn-t.be">a.hage@dn-t.be</a></td>
</tr>
<tr>
<td>Ship Design Group</td>
<td>Chirica Ionel</td>
<td>+ 40 236 47 66 72</td>
<td><a href="mailto:ionel.chirica@shipdesigngroup.eu">ionel.chirica@shipdesigngroup.eu</a></td>
</tr>
<tr>
<td>MEC Insenerilahendused</td>
<td>Naar Hendrik</td>
<td>+ 372 53 425 269</td>
<td><a href="mailto:hendrik@mec.ee">hendrik@mec.ee</a></td>
</tr>
<tr>
<td>Helsinki University of Technology</td>
<td>Ehlers Sören</td>
<td>+ 358 9 451 3497</td>
<td><a href="mailto:soeren.ehlers@tkk.fi">soeren.ehlers@tkk.fi</a></td>
</tr>
<tr>
<td>Sveucilište u Zagrebu, Fakultet strojarstva i brodogradnje (University of Zagreb)</td>
<td>Zanic Vedran</td>
<td>+ 385 1 6168122 01</td>
<td><a href="mailto:vedran.zanic@fsb.hr">vedran.zanic@fsb.hr</a></td>
</tr>
<tr>
<td>Universities of Glasgow and Strathclyde</td>
<td>Turan Osman</td>
<td>+44 (0)141548 3211</td>
<td><a href="mailto:o.turan@na-me.ac.uk">o.turan@na-me.ac.uk</a></td>
</tr>
<tr>
<td>Center of Maritime Technologies e.V.</td>
<td>Roland Frank</td>
<td>+ 49 40 691 99 47</td>
<td><a href="mailto:roland@cmt-net.org">roland@cmt-net.org</a></td>
</tr>
<tr>
<td>BALance Technology Consulting GmbH</td>
<td>Lehne Markus</td>
<td>+ 49 421 335 17 17</td>
<td><a href="mailto:markus.lehne@balance-bremen.de">markus.lehne@balance-bremen.de</a></td>
</tr>
<tr>
<td>WEGEMT A European Association of Universities in Marine Technology and Related Sciences</td>
<td>Smyrnakis George</td>
<td>+44 (0)191 2223521</td>
<td><a href="mailto:George.Smyrnakis@newcastle.ac.uk">George.Smyrnakis@newcastle.ac.uk</a></td>
</tr>
</tbody>
</table>
TABLE OF CONTENT

PROJECT EXECUTION p.04

WP2 : PROBLEM DEFINITION & MODEL DEFINITION (lead TKK) p.05
WP3: LOAD & RESPONSE MODULES (lead by UZ) p.07
WP4 : Production and Operational Modules (lead by CMT) p.13
WP5: INTEGRATION (Lead by ULG-ANAST) p.19
WP6 : LNG CONCEPT (Lead by STX and ANAST) p.28
WP7 : ROPAX CONCEPT (Lead Uljanik Shipyard) p.41
WP8 : CHEMICAL TANKER CONCEPT (Lead by SSN, TKK) p.60
WP9: LESSONS LEARNED, RECOMMENDATIONS, EXPLOITATION & DISSEMINATION (Lead by NAME) p.66

DISSEMINATION AND USE p.70
Project execution

This report includes a summary description of the project objectives, contractors involved, work performed and end results, elaborating on the degree to which the objectives were reached.

This report briefly describes the methodologies and approaches used and relates the achievements of the project to the state of-the-art.

It is explained the impact of the project on the shipbuilding industry and maritime research sector. It includes diagrams and figures illustrating the work of the project, the IMPROVE project logo and the reference to the project website.

www.improve-project.eu

IMPROVE press release and translations in Croatian, Dutch, Finnish, French, German, Greek, Italian, Polish and Romanian are available on:

http://www.improve-project.eu/pressrelease.html

Main results and outcomes of IMPROVE were publishzed in Dubrovnik, Croatia on 17-19 September 2009. The conference proceedings
- Dubrovnik final workshop - Vol_I_Conference_Papers.pdf
- Dubrovnik final workshop - Vol_II_PowerPoint_Presentations.pdf
can be freely downloaded from

http://www.anast-eu.ulg.ac.be/proceedings.html
WP2 : PROBLEM DEFINITION & MODEL DEFINITION (lead TKK)

WP 2 serves to establish the goals for the three new products to be viable and to check the results obtained in the course of the project. The naval architectural aspects of the new concept designs of the products are addressed as a part of this WP. Besides, the WP aims to address the following specific objectives:

- Definition of the multi-stakeholder framework in design of ship structures
- Definition of particular interests of stakeholder for the specific application cases
- Definition of design objectives or attributes, variables and constraints
- Identification and selection of methods to solve the structural, production and operation issues affecting design
- Synthesis of needed actions into a framework for integrated procedure for design of ship structures

Meeting these objectives should help in establishing a system to assist designers to take into consideration not only the usual technical requirements but also productivity, production cost, quality control, risk, performance, cost and customer requirements, operation costs, environmental concerns, passenger comfort, maintenance and life-cycle issues.

All members of the project consortium have taken part in this workpackage. The workpackage was led by TKK.

The workpackage was split in two major tasks: T2.1 Problem definition and T2.2. Model definition. The first task dealt with the definition, better to say formulation of the multi-stakeholder design problem for the three products. The second task dealt with the selection and extension of available decision-making and optimization methodologies.

The reason for this structure is the specific nature of the subject that is studied. Basically, it is formed on the rational approach for solving theoretical problems in engineering. The need for definition of a problem in a clear way, demands wide spread investigations. Since the design problem is in its nature a synthesis of a series of analytical actions the definition of a problem is a large task (T2.1).

The same is valid for the solution or the model definition (T2.2). This task is specifically focusing on the different points of view of the problem solutions, namely the design and the shipyard or the production point of view. This allows for the influence of subjectivity in design. Additionally, the problem solution must account for the uncertainties in all these aspects of design, and of course it has to synthesize these specifics into single formal framework. Therefore, one specific subtask will tackle this issue.

Furthermore, the work in these two tasks can be split in two disciplines: in research and review of the previous research, and in the initial concept design of the improved ship concepts.

In the research part of the work, a series of small and targeted case studies, e.g. structural optimization, were performed to test and advance the current methodology in the multi-objective and multi-disciplinary optimization, as well as in design selection. Case studies were based on the parent designs of the observed ships. Besides advancements in methodology, these investigations resulted also in the preliminary advancements of ship structural design, e.g. regarding investigations of tanker crashworthiness, or topology optimization of RO-PAX structure, very-large LNG carrier etc.

An extensive study was performed on the topic of understanding of ship value for the stakeholders – in this case being the yard and the owner. This piece of fundamental research provided means for interview-based assessment of stakeholder preferences for the three products in the ‘design’ stage of the project, i.e. in the workpackages WP 6 to 8.
In the design part of the work, the basic naval architecture of the improved concept for the three products has been assessed. For example, new general arrangements have been attained, new powering systems established, etc. These were made to serve as the basis for the efforts of the ‘design’ workpackages WP 6 to 8, as well as to indicate needs for the computational module development of the workpackages WP 3 and 4, and integrated in WP5.

The work package achieved the following end-results:

1. Tabulated list of stakeholder preferences and benchmark indicators, so called Key Performance Indicators to measure the partial quality of improvements (presented in deliverables D2.1 and D2.2)
2. Definition of the multi-stakeholder and multi-disciplinary structural design problem for every product, including definition of design objectives, variables and constraints (D2.5)
3. Review and implementation of the existing methodology for multi-stakeholder and multi-disciplinary optimization and decision-making (D2.6)
4. Contributions to the theory of ship value considered by the yard and owner (D2.9)
5. Proposal for the plan of integration of computational modules to support design optimization. (D2.6)
6. Definition of new design concepts of the large 220 000 m$^3$ LNG carrier, fuel efficient Mediterranean RO-PAX and large pure chemical tanker with stainless steel tanks based on fundamental studies of naval architecture. (D2.6)

Observing these results it can be easily concluded that the original objectives have been fully met.

The results of this workpackage bear significant contributions to the industry due to definition of new, next-generation, concept designs, specifically for the LNG, RO-PAX and pure chemical tanker market. Furthermore, a proper definition of the multi-stakeholder and multi-disciplinary optimization and decision-making problems can be considered to be the first such definition in the filed of ship structural design.
WP3: LOAD & RESPONSE MODULES (lead by UZ)

Structural limit states & design aspect: Selection of generic toolkits for an improved design of ship structures (RDMM) - (assessment, testing and adjusting of existing tools)

Objectives

The overall objective of WP3 is to develop and validate missing calculation modules that will be integrated with the core design tools (LBR5, OCTOPUS, CONSTRUCT) through WP5. The load and response calculation modules, corresponding to the design problem identified in the task 2-1 and the design methods identified in the task 2-2, form the core of the design feasibility control of the entire IMPROVE approach. These modules must be streamlined to fit the synthesis methods (see D2.7) presented in task 2-2-4 (fast execution for multiple inputs of design parameters). They may also be relaxed to fit tolerances of the concept design stage. Based on results given in D2.6 regarding identification of missing calculations modules WP has been divided into several tasks.

Following deliverables were submitted to EU in the middle of November 2008 (26th months):

- D3.1a: Report on the selected modules to perform stress and strength analysis (lead by UZ, with ANAST)
- D3.1b: Report on the selected modules to assess vibration (lead by SDG, with ANAST)
- D3.2: Report on the selected modules to assess ultimate strength (lead by MEC)
- D3.3: Report on the selected modules to assess fatigue (lead by TKK, with ANAST)
- D3.4: Report on the selected modules to assess design loads (lead by BV)

Short summary of achieved results

Task 3.1a: Analysis of structural behaviour (strength/stress analysis) (UZ, ANAST, DNT)

Through this sub task UZ, ANAST and DNT made extensive developments that included different structural aspects. Deliverable contains three groups of activities (three groups of modules):

A. Development of fast and effective calculation methods for the concept design. It was best achieved through development of efficient equivalent modelling methods/modules capable of simplifying data input and increasing calculation speed, yet maintaining sufficient accuracy for this design phase. Modules developed enable efficient calculations of corrugated bulkheads, cofferdams and double bottoms.

B. Verification and validation of existing response modules, including their improvements. This was performed for 2D and 3D FEM and analytical models.

C. Development and improvements in the optimization methods using developed/improved modules. Additionally feasibility module according to BV Rules criteria was developed.
Module A: EQUIVALENT MODELLING

1). Finite element for modelling of equivalent corrugated bulkhead. Through this sub-task the development and validation of eight-node iso-parametric finite element for corrugated bulkhead was carried out. The element was developed through introduction of anisotropy into plane shell isoperimetric finite element for plane stiffened panels and was incorporated into OCTOPUS modulus for transverse strength calculation.

2). Equivalent modelling of double-hull element. Through this sub-task the development and validation of the double-hull element was performed taking into account the additional stiffness brought by the double-hull web frames as well as the link they constitute between these web frames and the double-hull plating (inner hull and outer hull). The integration of the double-hull element inside the optimization process, involving the (analytical) computation of sensitivities with respect to design variables was achieved.

3). Through this sub-task the development and validation of modelling of cofferdams using LBR-5 software is presented. It enables better coordination’s between longitudinal and transverse structure optimization.

Modules B: VALIDATION AND VERIFICATION

4). Modules for direct calculation of the longitudinal strength have been examined and improved. The comparison between 2D OCTOPUS and generic 3D FE models are carried out on the RoPax structure as an example. Accuracy of stress distribution over ships height in OCTOPUS model found to be satisfactory compared to the 3D FE model for the purpose of concept design phase.

5). Module for the transverse strength calculation has been examined. For validation and verification of presented method the comparison of transverse beams normal stress between 2D OCTOPUS and 3D FE models of RoPax structure for symmetric and asymmetric load case are carried out. Accuracy of stress distribution over transverse beams breadth in OCTOPUS model found to be satisfactory compared to the 3D FE model.

6). Validation of simplified generic 3D FEM models. Simplified way of modelling complex primary structural response of the multi-deck ships (eg. RoPax) have been established using the generic coarse mesh 3D FE models. Especially considerations is given for equivalent modelling of large side openings due to fact that can significantly influenced longitudinal hull girder bending response. Methods for equivalent modelling of side openings are presented and validate with aim that have to be easily incorporate in generic FE models.

Modules C: OPTIMIZATION & ADEQUACY)

7). Development of a multi-structure module in the LBR-5 software. A methodology has been formulated to enable the extension of LBR-5 to a multi structure optimization.

8). Development of a discrete optimization module in the LBR-5 software. An improvement of optimization algorithm was achieved to enable use of discrete variables.

9). Structural safety calculation based on BV structural safety criteria (yielding and buckling), necessary for a structural evaluation was evaluated and programmed. Each criteria is separately encoded into different FORTRAN subroutine (EPAN.dll) and all the subroutines are subsequently added to the library of structural adequacy criteria.

Extensive theoretical models descriptions, validation and verification examples and implementation flowcharts for each chapter are part of this Deliverable. All modules/methodology developed through this task, together with the other modules developed in WP 3 and 4 have been integrated in the WP5 following the scenario defined in D2.7 for the each application case (WP 6 to WP 8). Finally, newly developed modules, integrated in existing design tools (OCTOPUS, LBR-5, CONSTRUCT) have been extensively used in application cases to ensure rational structural design and improvement of vessels designed in the IMPROVE project.
Task 3.1b: Vibration modules at the early design stage (SDG, ANAST)

Through this sub task SDG and ANAST made developments to obtain an approach for vibration assessment in the early design stage. Objective was to provide modules for vibration calculus of the local structures (local panels) and ship hull girder. The frequencies obtained from these modules will be considered as constraints for the optimization problems. Three modules were developed and programmed in standard FORTRAN language:

1. A vibration module to determine the local panel structure vibration. ANAST proposed a methodology to assess vibration on ship structures. Due to several important limitations and some simplifications of the early-stage optimization process characteristics, the methodology supposes to analyze the vibration of local structures (local panels with/without concentrated masses, pillar-deck assemblies eventually) and to realize a sub-critical design (the first natural frequency of the panel must be greater than the most important excitation frequency). An optimization including this type of design must ensure the minimization of the noise and vibration level, the principal stakeholders’ requirements. In this way a numerical tool based on analytical formulation using the equations of the mechanics of a continuous medium has been developed. Also, a new procedure to find instantaneously the first natural frequency of a general stiffened panel and thus to minimize the time calculation has been developed.

2. Empirical formulae for natural frequencies of the panels, function of the panel parameters, have been generated by using the module REGRESS developed by SDG. These formulae are quadratic functions and can be determined based on the numerical calculation on sensitivity analysis of the panel vibrations. These formulae were performed based on the following methodology:
   - the panel is transformed into an orthotropic plate having the stiffness characteristics determined based on the characteristics of the shell and stiffeners;
   - the formulae are determined based on the analytical formulae of the orthotropic plates.

Types of analyzed stiffened panels are in accordance with the usual ship type panels:
   - uniform unidirectional longitudinal stiffeners;
   - uniform unidirectional stiffeners longitudinal and one longitudinal girder.

This module can be used to generate an approximate function of the main variable (i.e. frequency in this task) from a database. The database is obtained by a parametric study of the design variables (discrete study). This function can be used afterwards as a vibration restriction in the optimization process.

3. A global hull girder module to determine the global vibrations of the ship hull based on beam model was developed and written in FORTRAN. The module can be used in the optimizing process, by taking into account the added mass and without these masses. The added masses are determined based on the analytical-experimental methods. The results obtained with this module were compared with the ones obtained with special software (based on beam model-UGAL) and with 3D model using COSMOS/M. These results are good accuracy for the early stage of the ship design.

Deliverable D3.1b contains the theoretical basis and description of the application tests made for the all vibration modules.

Task 3.2: Assessment of ultimate strength at the early design stage (MEC, UZ)

Objective of the task T3.2 was to validate and report the available methods for hull girder ultimate strength assessment. The implementation of task 3.2 should provide bases for selection of relevant tools for ultimate strength assessment in early design stage and in the case of optimization process. The second objective is the description and introduction of the ultimate strength module based on coupled beam approach.

Through this task MEC and UZ made extensive developments to obtain an approach for hull girder ultimate strength assessment in the early design stage.

The main idea of the task 3.2 is to improve ultimate strength modules and make extensive validation for simplified methods used.
Method development

Two simplified methods that can support design optimization process were improved and tested: modified Smith (MS) method and Coupled Beam (CB) method. In the case of optimization process, where large number of designs is considered, these methods offer advantages over finite element analysis which is very time consuming. The modified Smith method is a single cross-section approach developed for single deck ships. The method enables to consider the shear force influence on ultimate strength and with the support of 3D FE-analysis the non-linear strain distribution can be considered as well. The shear flow for shear force influence estimation is calculated with 2D FE-approach. The CB-method was initially developed for ultimate hull girder strength analysis of multi-deck ships. According to the method the ship structure can be described as set of coupled beams attached to each other by distributed springs. Nonlinear beam and coupling equations can be analyzed incrementally and it enables to estimate bending and shear stresses and also hull displacements and deflections. The theory of both approaches is presented. Regarding ultimate strength of structural members (panels, girders, etc.) the formulation based on IACS Common Structural Rules (using load-end shortening curves) and implemented in both methods (MS and CB) have been examined.

Also the formulae for ultimate strength of structural members (girders, frames, etc.), implemented in design tools (MAESTRO/OCTOPUS, LBR-5, CONSTRUCT) were identified and considered sufficient for structural design process of all three products.

Validation, results and time effectiveness

The task is concentrated on Chemical tanker (single deck model) and RoPax ship (multi-deck model). Two non-linear FE-models of ship hull girders were created in order to get the validation data. The important issue has been the definition of possible loading conditions in case of Ultimate event. The very extensive and time-consuming FE non-linear analysis has been accomplished for both ships. For multi-deck ship three non-linear FE model variants were examined. Also the CB-method and modified Smith method were applied for all models. The extensive comparisons of results were performed; limitations and accuracy of simplified methods were discussed.

The validation analysis revealed that in case of single deck ship the accuracy of the MS-method compared to FE-approach is 3% and CB-method is smaller reaching to 10% compared to FE-results. For multi-deck ships the accuracy is changed drastically. In hogging the difference between the FE and CB results is between 2% and 6%. In sagging the difference is more drastic by changing from 18-45%. For MS-method the difference between FE-results is between 2-21% for hogging between 0.1-4% for sagging. Some new interesting phenomena regarding influence of longitudinal bulkhead in ultimate hull girder of multi-deck ships is identified and discussed and it can be basics for further investigation.

The MS-approach is very fast. In case of single deck ships the cross-section analysis can be calculated with few seconds where the CB-method does the job between 2 to 10 minutes depending from the load step size. So, the use of MS-approach inside the optimization loop can be more feasible then the CB-approach. CB could be used only outside the optimization loop for the final set of design variants.

A detailed description of ultimate strength module based on coupled beam (CB) approach is given as well. The input and output file formats for the module are given and also guidelines are reported for the input file preparation.
Task 3.3: Rational models to assess fatigue at the early design stage (TKK, SDG, ANAST)

At present there is no common and simplified approach for fatigue assessment which can fulfil requirements of early fatigue design. Task 3.3 aimed to develop an approach for fatigue assessment in an early design stage, which is suitable for optimisation purposes and product development in WP 6, 7 and 8. The approach takes into account rational issues by accounting for the definition of various structural details within the existing design tools like.

Through this sub task TKK, ANAST and SDG made extensive developments to obtain an approach for fatigue assessment in the early fatigue design stage. The approach is coded to obtain the Fatigue Module suitable for the implementation into the Improve tool package (WP5), and different product development in WP 6, 7, 8. The deliverables of Task 3.3 are the coded programme of the Fatigue Module and the technical report, which contains four parts of activities:

- Determination of fatigue-critical connections and details
- Development of fatigue approach for the early design stage
- Implementation of the approach for existing design tools
- Validation of the approach

Determination of fatigue-critical connections and details (Chapter 2)

Based on a scientific and engineering approach fatigue-critical structural details and important characteristics of the ships are assessed. The scientific approach is based on damage statistics of fatigue failures in ship structures, and aims to identify critical structural details and corresponding loading modes. This review is concentrated especially on tankers, and is extended to cover Ropax and LNG ships based on an engineering approach. The engineering approach is based on pre-existing know-how and knowledge. The study is focused on special features of different ship types which are further developed in the Improve project. The main results of this study are the identification of generic and ship-type-depended features in fatigue assessment. This is the basis for the development of the fatigue approach for early design stage.

Development of fatigue approach for the early design stage (Chapter 3, Appendix A)

Based on the identified fatigue-critical structural details and main features for fatigue assessment the approach for the early design stage is developed. To overcome the challenges due to limited information in the early design stage, generic structural elements and predefined fatigue-critical details are used. This allows the development of a common approach for different ship types and allows its applicability for optimisation purposes. This chapter describe also the applied theories and calculation methods in the approach.

Implementation of the approach for existing design tool (Chapter 4, Appendix B)

The linkage of the developed approach to existing design tools, which is applied for product development in WP 6, 7 and 8 has been presented. The approach is programmed as a Fatigue Module for easy implementation. The input and output data of the module is developed and described being suitable for the Improve tool package done in WP5. Application of the Fatigue Module with existing design tools is described. The given procedure took into account the aspect of structural optimisation, data transforming and ship-type-depended features.

Validation of the approach (Chapter 5)

Preliminary validation of the proposed approach is carried out. A selected case structure of tanker and Ropax is applied to evaluate the local nominal stress in the fatigue-critical details. The validation is based on the comparison of the results of the Fatigue Module and the finite element analysis. The accuracy of the fatigue approach and calculation time is discussed.

Future work (Chapter 6, Appendix C)

Validation and implementation of the approach is left for WP 5, 6, 7 and 8 as agreed with the steering committee in Hamburg and Helsinki meetings. This validation is focused on the hot-spot and notch stress level, and it is based on the results of FE-analysis of typical structural details carried out by TKK and SDG.
**Task 3.4: Rational models to assess, at the early design stage, design loads (hydrodynamic loads, sloshing, …) and accidental loads (crashworthiness) (BV, TKK, NAME, ANAST)**

The objective of Task 3.4 is to deliver the “missing load assessment tools” identified in WP2, in a format compatible with response modules developed in other tasks of WP3 and with the project optimisation framework.

The results of Task T3.4:

- End-user requirements related to missing load assessment tools have first been reviewed.
- The conclusion of this review was that two load models were to be developed for connection with the optimization framework, namely:
  - Sloshing loads for LNG carriers (model to be developed by BV)
  - Wave loads for ROPAX vessels (model to be developed by NAME with assistance from UZ)
- In addition, other developments were considered necessary and have been included in the scope of the task, namely:
  - Crashworthiness analysis methodology for the Chemical Tanker (TKK)
  - LNG carrier related developments (ANAST, BV):
    - Definition of loading cases for cofferdam
    - Automatic cofferdam geometry and loading data transfer from MARS to LRB5
    - Investigation of global shear effect on cofferdam modeling
    - Validation of the existing LRB5 loading cases for tank structure
- Deliverable D3.4 describes these developments:
  - Chapters 2 and 3 concern the LNG carrier sloshing load module and the ROPAX wave load models respectively. For each model, end-user requirements, development methodology, verification/validation analyses, delivered module programming and user manual are described.
  - Chapter 4 presents the other developments related to LNG carrier and to Chemical Tanker crashworthiness.
- The above planned activities have been successfully performed:
  - A sloshing load module has been delivered by BV. This module covers tank capacities between 125 000 m$^3$ and 180 000 m$^3$. Additional dedicated calculations on the exact 220 000m$^3$ tank and ship designed in WP6 have been performed within task 9.1 since no recent experimental data is available and no test campaign is planned within Improve project for such a large capacity.
  - A wave load module for ROPAX vessels has been delivered by NAME. Different methods for long term analysis are proposed by the module. Preliminary comparisons of the results from both methods with BV load rules have been performed.
  - Both modules have been transferred to WP5 and integrated in the optimization framework.
  - The other LNG carrier related developments have been performed and have been integrated in the optimization framework.
  - The methodology for calculating the Chemical Tanker hull’s capacity to absorb collision energy before being breached has been defined, and the corresponding calculation chain has been assembled.
WP4 : Production and Operational Modules (lead by CMT)

The overall objective of this work package is to assess the production and operational phase. Regarding these phases an investigation was done regarding the application of simplified and advanced existing tools. Therefore existing generic toolkits were selected, compared, tested and adjusted with point of view of ship owner and shipyards.

Furthermore the WP tasks purchased on the following aspects:

- The provision of various modules for the Decision-Tool with respect to the different aspects of the production and operation phase.
- The aim for optimized and advanced tools which support the production and operational matters, through the ability to estimate and assess various solutions under significant boundary conditions
- Evaluation of the full life-cycle regarding production, design and construction aspects
- Estimation and evaluation of advantages and costs of the development and construction of new and advanced vessels with consideration of construction, outfitting and operational phases.
- To assess the economical and ecological risks at an early stage increases the competitiveness of ship owner and shipyard (70 % of the costs getting defined already in the design phases)
- To assess the life-cycle cost and to implement it in the IMPROVE decision support system
- To decrease the boundary conditions already during the design phase through the early estimation of risks and reasonable solutions regarding constructional and operational aspects

The challenges of the work package (WP4) were to:

- Keep the high performance of the optimisation loop due to the low response time of the cost calculation modules
- Keep sufficient detail in simulation modelling of production problems (sequences, transport, human resources, space allocation, etc.)
- Introduce robustness into design process as practical measure

The main achievements which were implemented during the project are:

- Module of Life cycle cost / earning of production and maintenance/ repair (Task 4.1 lead by NAME)
- Module with detailed Discrete Event Simulation (DES) for production and scheduling (Task 4.2 and 4.3 lead by ANAST and CMT)
- Module for design robustness of the structural solution related to various fabrication and operation parameters (Task 4.4 lead by UZ)

Task 4.1 Rational models to assess operational and maintenance costs linked with the structural design variables (life-cycle cost including maintenance, painting, recycling, etc.)

A data collection from the operators for the ship operation was done. Also the maintenance cost model was finalized. It is a generalized life-cycle maintenance cost model which can be used for the assessment and integrated optimisation of the three subject vessels. With a graphical user interface the maintenance module could be parameterized.

This life cycle cost module has been implemented. It contains 5 sub-modules: the production and material cost, the cost of periodic maintenance, the fuel consumption, the operational revenues and the dismantling revenues. A corrosion model according to the new Common Structural Rules (CSR) for tanker ships that modifies the behaviour of the LCC module has also been implemented.

This basic module is able to compute the material cost (as a function of weight), the labour cost and the LCC using a simplified methodology. The advantage of this module is to find a result as fast as possible. This module is already integrated into the design optimization loop of LBR5, OCTOPUS and CONSTRUCT. In order to link the objective function to the design variables, the unitary costs of raw materials, the productivity rates for welding, cutting, assembling must be specified by the user as well as the lightweight and the deadweight of the ship. These unitary costs vary according to the type and
the size of the structure, the manufacturing technology (manual welding, robots, etc.), the experience and facilities of the construction site, the country, etc.

The related deliverables:
- D4.1a Maintenance/Repair database and
- D4.1b The Generalised Life-Cycle Maintenance Cost/Earning Model

Are finished and published.

**Task 4.2 Preparation of simulation (development of data structure, database definition and preparation of data)**

and

**Task 4.3 Model for Production scheduling & cost assessment (Simulation model)**

ANAST and CMT developed the data concept for the simulation and calculation database which is supporting data for the cost and budget calculation with the cost module as well as for the simulation process. Based on this concept a data structure for the database was created (Entity-Relation-Model). The databases were created in MS Access.

Example tables were created to support the data collection on the shipyard. An introduction into simulation and a presentation of the data requirements on the shipyards started the data collection. The feedback from the shipyard was used to improve the concept, fill the database and adapt it to the special requirements in the selected assembly process. An extension of the data concept considering also optimisation in the production process will proof the concept for the future.

The budget assessment module was enhanced to provide a first analytical cost calculation of the production cost. Based on all welding data as the welding length, welding position as well as the welding throat or plate thickness a first assessment of the production cost will be done. It will be detailed and evaluated by using the simulation model.

One approach was to support the generation of technological possible ship assembly sequences. A first test done by software code (VBA) in MS Access doesn’t succeed. Therefore a second solution programmed in JAVA was developed which proper fit to the requirements of the simulation process as well with the optimization concept.

A concept and model for the simulation was developed, which shows the connection and necessary interfaces between the different parts. In the beginning the data interface to the database via ODBC was established. This will guarantee the data transfer from the database into the simulation model as well in the opposite direction for the simulation results. Furthermore the requirements of the simulation...
modules were defined. It considers the selected manufacturing areas which will be consider in the simulation. Test models were created to testify first principles of the simulation. After getting the feedback from the test models the modelling of final simulation models were started.

Final simulation models are realized in Plant Simulation and contain resources like assembly areas, transport facilities (cranes, heavy and fork lifter, etc.) workshops, controls etc. Controls are used to manage the assembly process as well as to coordinate processes like transport. The models are implemented into the application processes in WP6 and WP7 to do the production cost assessment.
For each application cases the calculation of production times and cost can evaluate the different design.

The analytical budget and cost assessment tool will give a first estimation of the production cost. Inside of the IMPROVE optimisation loop its supports the evaluation of a new design. Afterwards a more detailed evaluation in the simulation model was established to provide additional information regarding manufacturing.

Task 4.2 and 4.3 were interacting with WP6 and WP7 to support the final assessment of the different designs of the various ships. The adaption of the simulation models and as well of the input data takes more time than expected. Especially new requirements were implemented in the simulation models, e.g. assembly constraints, transport rules, packaging, different assembly areas. Further the data collection and preparation shows some gaps for the available production data. The block splitting and sequencing in case of STX and the section splitting in case of ULJANIKA was supported by the shipyards but it was difficult to end in reliable data which could used in the simulation. Additional work was necessary to prepare the product data for the simulation. This implies a sequence generator as well as the integration of the optimization tool OptiView and ISSOP.

The related deliverable:
- D4.2 & 4.3 Data preparation and development of the selected modules to assess the fabrication costs and simulate the production

is finished and published.

**Task 4.4 Design robustness of the structural solution related to various fabrication and operational parameters**

UZ made extensive literature survey regarding robust design, design of experiment (DoE) and Taguchi's experimental design. Based on that investigation the methods to be implemented for the robust design calculations were selected. UZ developed methodology to be implemented through generic computational robustness module (IC4RD.dll) and made computational module development-programming in standard FORTRAN language. The integration aspects of the robustness module inside of the IMPROVE platform and link between other IMPROVE modules (e.g. maintenance-T4.1) were taking care of. UZ enabled few possibilities (modes) for imbedding of the design robustness attribute into the design problem formulation based on the modules developed in tasks 4.1 - 4.3, as well as regarding safety aspects, and their particular characteristics. Verification and validation of robustness module are finalized.
The related deliverable:
- D4.4 Design robustness of the structural solution related to various fabrication and operational parameters

is finished.

Results and conclusions

From the work carried out in the Life cycle module, the following are main contributions:
- The developed life-cycle maintenance/repair cost model is robust enough to be used within the IMPROVE's integrated search platform.
- The developed method can efficiently help designers, ship owners and production engineers to make rational decisions during early design phases.
- Although the model is able to calculate generalized life-cycle maintenance cost, it can also be used for what-if scenario analyses with respect to other parameters of the model, such as unit price of steel replacement per kg, price of fuel oil, and so on.
- This model can further be improved with the inclusion of other life-cycle cost elements to be able to find the (significant) cost drivers of the vessels.

The examination of the effect of additional steel weight on the original design in order to minimize the steel repairs throughout the life cycle of a ship proved to be feasible under certain assumptions.

Considering the usage of the production simulation and assessment we can conclude: The lead time, the production cost (Transport cost + Labour cost + Surface utilization cost) as well as the space allocation and the workload are measured and compared for each ship alternative as the result of the project.

Main trends of the results regarding the STX model are that significant lead time and cost can be saved after the scantling optimization of the amidships section of the ship. The main factors acting on the cost reduction is the diminution of the plate thickness as well as the diminution of the stiffener welding length. However, the results shows also that much more can be saved if we reorganize or improve also the production process, e.g. another block splitting, sequencing and key resources like cranes.

Similar findings have also been obtained for the ULJANIK model. In the same way, the reduction of plate thicknesses and stiffener welding length lead to the diminution of the lead time and cost. Nevertheless, in this model, a key additional point is the limited space for production. We highlighted that the organizational improvements of the allocation of the assemblies may effect heavily the lead time and cost.

The use of simulation-based design and virtual reality technologies facilitates higher efficiency in terms of work strategy planning, and offers, as a result, significant productivity gains.

Different aspects also partially investigated during this project are promising:
- The optimization of the erection sequence
- The combination of production simulation and space allocation optimization (Integration of OptiView and Simulation models)
- The optimization inside of the ship production process using simulation and optimization tools

Experimentation with robustness attributes is bringing a new dimension to the selection of preferred design, enabling balancing of the original attribute and its (in)sensitivity to uncontrollable parameters. In that respect, design optimization for robustness is recognized in IMPROVE as practical measure (sea measure Fig. 4.4) that can save the designer's/yard's effort on control of the parameters variation.
Fig. 4.4 - Pareto frontier with respect to RoPax weight, production cost and safety measure.

Robustness level with respect to production cost parameters (material and labor costs, etc.) is marked in color (best robustness is marked ‘1’ – violet, worst is in blue color (see legend).

It have to be underlined again that robustness measure calculations are much simpler and faster compared to e.g. Ps calculations, as described above, and with accuracy acceptable in concept design phase.

The 3 modules implemented during this project:
- the life cycle cost/earning of production and maintenance/repair,
- the detailed Discrete Event Simulation (DES) for production and scheduling,
- and the design robustness of the structural solution related to various fabrication and operational parameters, helped to support and prove the effectiveness of the three scantling optimization software’s (LBR5, OCTOPUS and CONSTRUCT).

The importance of considering simultaneously the LCC, the production aspect and the robustness of the design solutions has been demonstrated in this work package and the IMPROVE project.
WP5: INTEGRATION (Lead by ULG-ANAST)

As opposed to many other projects (VR-SHIP, VIRTUE, INTERSHIP, LOG-BASED), IMPROVE was not primarily aimed at setting up a generic integration platform. Instead, a pragmatic approach to let the tools used in the different workpackages communicate with each other easily was the goal of the integration workpackage. Only in cases where the simple communication was not feasible, a more complex environment was set up as described in the workplan.

The integration team was coordinated by ANAST and composed of BALANCE and USCS (subsidiary company of ULJANIK shipyard), 2 experienced software developers that led the two major sub-tasks of WP5. These high experienced partners guaranteed the coherence of the implementation of the various software with the IMPROVE decision support system. They were assisted by UZ and TKK to integrate the new IMPROVE modules and by CMT for the production simulation module (modules and tools selected in WP 2 and developed in WPs 3 and 4).

The integration was based upon existing solutions in order to avoid development work to an as large extent as possible. Available interfaces and file exchange formats were adapted according to the exchange needs (specified in Task 5.1). In order to avoid the necessity of a large number of interfaces, a central database hub was used as the centre for the inter-module communication (Task 5.2). A design desktop should be developed as part of Task 5.3 to support the engineer in testing and using the IMPROVE tools.

The development work after the project should be limited to mature the prototype and to optimise its performance with limited effort. Therefore it was of major importance that the results would be applicable to the project partners’ requirements but also had to be transferable to European companies outside the consortium as part of the exploitation activities. This means that a neutral approach should be used rather than a company-specific solution.

The objectives mentioned were realised to a large extent. The integration environment was defined and implemented. By specifying an IMPROVE database and a set of interfaces to the components involved, a powerful environment could be developed that covers all aspects of integration as described by the requirements of the IMPROVE partners.

Methodologies

Keeping in mind that the goal of IMPROVE is the development of innovative products, implementation of software tools was restricted to a minimum. Focus was on a pragmatic integration of available tools and the support for collaboration throughout the covered design activities to allow effective usage of the design resources also through reduction of design time. To achieve this, a three level integration approach was employed.

In a first level, integration was carried out through a pragmatic integration. This level consists of a pragmatic integration of the new modules developed in WP 3 and WP 4 with the core optimization tools. It was up to each module developer to create a Dynamic Link Library (DLL) that would be invoked by LBR-5, OCTOPUS/MAESTRO and CONSTRUCT by means of an application programming interface (API). This simple environment could be set up within weeks and allowed all partners to evaluate the actual information exchange requirements between different applications. The outcome of this phase was analysed for each exchange relation. In this level, no interface or design desktop was built. The existing environment of the core optimisation tools was used. By asking the partners for feedback, the requirements towards the database as well as for the interfaces to the algorithms could be collected which then served as input for the following steps. By using this pragmatic approach it could be ensured that the different modules could already be tested while simultaneously collecting the information requirements for the more complex integration steps.

The second level of integration defined and implemented an IMPROVE shared module database. It was expected that other and/or upgraded modules would candidate for integration in the optimisation platforms (LBR5, OCTOPUS and CONSTRUCT). To avoid repetitive manipulation and updating of both the candidate modules for integration and the optimisation core module the shared database as developed. The plan was to introduce all information that might be exchanged into this database, thus supporting the exchange between these different applications. Each application could access this common database using a common data format and could develop an import/export tool from this shared module database to its optimization software.

The development started by setting up an exchange process that was based on the exchange of XML files that contain the results actually needed for the subsequent step. The approach does not require an interface for the applications involved but the capability to write or read data files (from a central
Since all applications were able to provide this functionality, no changes were needed to these background tools. However, none of them used the IMPROVE database format as native means of data exchange which raised the need to develop converters from the proprietary formats into the IMPROVE XML format and vice versa. Only small amounts of data were to be exchanged since the idea of the IMPROVE database was to support the optimisation process, not to exchange entire designs. Therefore such an exchange could be realised with reduced effort. Again, each exchange activity was analysed with respect to efficiency and correctness as foundation for the final step, the implementation of the integrated toolbox and the design desktop.

The IMPROVE Design desktop and the IMPROVE demonstrator were implemented in the last development step. The goal of the Design desktop was a unified interface to the different IMPROVE tools and the database. It should enable external applications to make use of the developments without dealing with software related issues such as the use of different compilers, programming languages and libraries needed. Furthermore a user interface had to be implemented to directly use the algorithms and to edit the database content.

Realisation was carried out in two steps. A local implementation that runs all components on the same computer was developed first, consisting of:

- The IMPROVE database as developed in step 2
- Applications to convert proprietary formats of external tools into the IMPROVE XML database format
- A unique, C-based interface to access the database, the converters, and the different IMPROVE algorithms
- A Java interface which has the same purpose
- A user interface that enables the user to view and edit the database content and to run the algorithms manually

The second phase of Level 3 should be carried out using an integration environment that allows the communication of different applications even when being located at different sites. While the local environment was a mandatory development, the network environment only needed to be realised as a prototype application.

**Results and conclusion**

The IMPROVE toolbox is a dynamic library that is linked to a number of IMPROVE modules and controls their operation. A Graphical User Interface can be used to interactively use the toolbox while other application can directly call the DLL functions. Together with the database and some auxiliary functionality they are the IMPROVE Design Desktop.

Two different types of integration exist:

- Direct linking by integrating a DLL
- Calling an executable and exchange data via files

The Design Desktop registers an algorithm module and provides the user interface to launch it. All information required by the respective algorithm that is not available via the database has to be inserted manually, e.g. the name of the design in question. Typically the integration environment is used as follows:

1. The user calls the user interface either by launching it independently or by running it from within another application. During the start parameters can be passed such as the name of the database to be connected to and the name of the design to be processed. This model is then opened; the parameters are stored in internal variables and shown in the GUI if it has been activated.

2. Once the integration toolbox has opened the user can select the optimization algorithms to be run and the constraints to be considered. Selecting the algorithms is possible either interactively or by passing it on the command line.
3. When launching the optimization process in a first step all required data is fetched from the database. If data is missing to run certain algorithms these have to be typed in if no sensible default values exist.

4. The optimizations are started and data is stored in the database. If user interaction is required during the optimization dialogues are shown as required.

The figure below shows the architecture using the Design Desktop. It shows that the existing tools (LBR-5, OCTOPUS/MAESTRO, CONSTRUCT) are only communicating with the database (for exchanging the optimization data) and the Design Desktop (for launching and controlling the algorithms). Therefore the adding or removing of algorithms does not lead to large changes in these applications as the only necessary activity will be adding or removing of the data exchange and the launching code.

Since the interfacing of the algorithms with the integration toolbox follows a standardized method (adding a GUI, setting parameters, launching the algorithm), such an extension is well-documented and can be performed without affecting the existing parts of the integration environment.

![Figure 5-1: Global system architecture of the IMPROVE Integration Environment Overview](image)

The local integration toolbox only runs on Windows computers. However it has been implemented in Java in order to make sure that the later networking-enabled solution can easily be ported to other operating systems. All IMPROVE algorithms are only available as Windows DLL or executables. Thus there is no need for supporting other environments.

For a strict separation of user interface, functionality and external interfaces, the software has been realized as a multi-layer application that consists of the elements shown in the figure below.
The user or other applications communicate with the software using either the command line interface or the Graphical User Interface (GUI). Both interfaces allow the selection of a model and the algorithm and to pass parameters to the algorithm. All data entered here is passed to the control layer which connects to the database, downloads the selected model, passes the correct parameters to an algorithm, runs the algorithms and returns the calculation results either to the database, to the screen, or to an external output file.

Below the control layer algorithm classes and the database interface are located. While the latter one exchanges data with the IMPROVE database, the algorithm classes provide the interface to the IMPROVE optimization algorithms. Major task is the wrapping of the algorithms which are typically realized either as a DLL or a stand-alone executable in order to offer a standardized API (application programming interface). The wrapper itself is either directly linked to the DLL or calls the executable.

**Database interface**

The database has been developed in Task 5.2. It has been realized as an XML schema and offers the possibility to store all information needed by one or more of the optimization algorithms. One or more models can be stored in a single XML file. The database is neither intended to store entire ship designs nor to replace a full database. The own purpose is to offer a means of exchanging data between external applications and the IMPROVE modules.

Database access is realized using the standard Java classes for handling XML files. First an XML parser is set up and reads the XML file. The parser analyzes the file and extracts the different XML objects, starting with model name and model version. Beginning with this root object, the entire database tree is created and contains all optimization relevant information. The tree can now be used to read the parameters for the algorithms but also to store back the information generated by the optimization tools. In the last step the tree is re-converted into an XML file and stored as new version of the model that can then be read by the external applications.

**Algorithm control**

Although not visible to the user, the algorithm control component is the central part of the Design Desktop software. Depending on the way of launching the application it collects the required information from the command line, the graphical user interface and from the imported model.

The workflow on this component is as follows. In the first step loading of the selected model is initiated and a tree-like data structure is built containing all available configuration values for the algorithms to be run. Next the parameter values provided at runtime (command line arguments or data entered by the user) are analyzed. When launching the algorithm the strategy is to first consider this interactive data and to only fill the fields with the database information that have not been entered by the user. After all parameters have been set the algorithm controller starts the selected algorithm modules one after the other, gets the calculation results and either displays them on the screen or writes them to the standard output. Additionally, they are stored back to the XML model if it is available and accessible for writing.
When adding or removing algorithms, the controller is the major module that has to be changed in order to handle the new algorithm set.

**Graphical User Interface**

Two different types of user interfaces are supported. For interactive configuration and launching of the algorithm modules the Design Desktop provides a graphical user interface (GUI) which supports the selection of the model to be processed and the selection and configuration of the algorithms to be applied to the model. For each algorithm, all parameters can either be read from the database or entered manually. A combination of both approaches is possible as well, e.g. importing some parameters and editing or entering missing information.

In order to integrate the IMPROVE algorithms into a software environment it is also possible to launch the integration toolbox without the GUI and to pass the parameters on the command line. In this case, only a single algorithm is run for each call of the application due to the limitations of the overall command line length in some operating systems.

In both cases, the results are written back into the database. When using the GUI version, the results are also displayed on the screen.

While some of the optimization tasks are carried out automatically as a batch job, there is still the need for launching the algorithms manually via a graphical user interface. The Design Desktop GUI enables the user to select the model to be processed and the algorithms to be applied to the selected design. Each parameter can be set in order to test the algorithm under different circumstances. The results are displayed on the screen and can additionally be saved to the model.

**Interfacing the algorithm DLLs**

Three different implementation approaches are available to integrate existing algorithm implementations into the Design Desktop. Which one can be used depends on the programming language in which the algorithm is implemented. Since the box is written in Java, this is the target language for the integration. Other languages used for module development are Fortran and C/C++.

For the integration three aspects have to be considered: the calling conventions for functions, the name mangling (internal coding of function names) of the linker and the availability of conversion tools. The calling conventions between Fortran and C++ can be easily adapted as Fortran always uses the call by reference method while C++ is able to pass arguments by reference or by value. Opposed to that, Java always passes arguments by value which means that it is not possible to implement a direct mapping from Fortran to Java. Name mangling is another issue, especially when integrating C++ code with code written in another language. In order to overcome this problem, C++ code is treated as C code from the compiler and linker point of view, which means that the naming of symbols can be handled similarly between Fortran and C++.

The Java Native Interface (JNI) offers an easy-to-use solution for the direct integration of C/C++ code into Java applications. It automatically generates code that wraps the C++ functionality into Java classes, enabling the developer to directly call a C++ method from within a Java application. Therefore the following the methods can be applied:

- Integration of code implemented in Java: Direct linkage into the application without any additional measures. This method is not used in IMPROVE as no Java libraries are available.
- Integration of code implemented in C/C++: Writing a Java class that accesses the C++ DLL via JNI. If the C++ code is not available as a library, a wrapper has to be implemented in order to generate the DLL. Such a wrapper is straightforward since it is a 1:1 interface to the existing interface.
- Integration of code implemented in Fortran: Development of a wrapper DLL written in C++ that translates the parameters for the Fortran call and returns the result to the Java code via the JNI interface.

**Integrating stand-alone applications**

Some algorithms are not available as a DLL but as a Windows executable that can be directly started (e.g. the sloshing module). These standalone applications have to be integrated in a different way. Three possibilities exist for calling the application and passing the parameters:

- Passing parameters via the command line
- Providing an input file
- Sending the parameters via standard input
Results can be provided either via an output file or on standard output. Depending on the approach the call of an external application is realized as follows:

1. Preparing the parameters for the application that have been either passed via the command line, the GUI or the imported model
2. If necessary feeding the parameters into an input file for the application
3. If necessary, changing the configuration of the algorithm via configuration files
4. Calling the application with all required parameters
5. Retrieving the calculation results and feeding them back in to the XML model or on the standard output

**Database interface**

The IMPROVE database has been realized as an XML schema. Each XML file might contain one or more models and versions of models. Whenever a model is imported, the entire XML file is parsed and written into a model. Since the IMPROVE data model is not intended to cover the entire ship design process but only the parameters needed for optimization it is expected that the file size will be limited and importing the entire model will not take an unacceptable time.

Implementation-wise the database interface uses the same mechanism as the integration of algorithms realized as C++ code. Therefore the lowest level is a C++ class library that provides the access to the different database objects defined by the XML schema. This C++ library has been generated automatically and contains a number of functions that are not needed in the IMPROVE context. Since it was also required to use the IMPROVE toolbox functions in a C environment (for direct use and for interfacing with Java JNI code), a wrapper was implemented that converts the C++ objects into C compatible functions. This interfaces does not aim at translating the entire C++ class set but to provide easy access to the IMPROVE relevant parts.

On top of this C library a wrapper for the JNI functionality has been established which is again used by a Java class library that provides access to the database functionality for Java applications.

**The IMPROVE Toolbox**

In order to make available the functionality of all IMPROVE modules via a single interface, an integration DLL has been developed that provides the following functionality:

- Direct access to all IMPROVE algorithms
- Read and Write access to the IMPROVE XML database
- Conversion modules from external applications to the database format and vice versa

This library is written in C++ (in C style) and can be linked against all applications that are able to include a C DLL. Additionally, a Java native interface is provided for interfacing with Java applications.

**Viewing and editing the data model tree**

After opening the application and selecting a model, the data content is shown as a tree. By opening the different entries data can be viewed. Clicking on an item selects it for editing. Upon termination of the application the changed data will be written back into the database, generating a new micro version of the database. Alternatively the version number can be adjusted manually by the user.

In order to transfer the model data into the algorithm configuration section, the name of an item has to be activated by a double-click. This action transfers all data items from the selected object into the respective entry fields of the different algorithms (see below).
General configuration and algorithm selection

The „Select algorithm“ tab is used for selecting the algorithms to be run, the model and its version. The model is selected by clicking on „Select Model“. A file dialogue is opened where the user can choose an XML file containing the model in question. To actually import the selected model, the menu item „RunÆImport selected model“ has to be clicked. The model name and the first version found are then shown in the respective text fields. While the model name is fixed, the version can be edited in order to select a different version. Below these fields is a list of the available algorithms which can be selected by checking the box in front of them. Each dialogue field provides a popup help which is shown when moving the mouse pointer onto the particular element.
Algorithm configuration and launching

The “Configure…” tabs contain the configuration pages for the different algorithms. Depending on the module, all parameters can be set individually. The default values are the ones provided by the test applications if available. As soon as a model is imported the information can be overwritten by the parameters set in the GUI. At any time the user might edit the pre-defined values. However, the Design Desktop does not perform any plausibility checks on the entered data except for ensuring that the data type is correct which can lead to error messages of the algorithms in case the values are not plausible.

To start all required algorithms, the menu item „Run → Run selected algorithms“ has to be selected. Now all modules are run one after the other and the results are shown on the screen and stored in the XML model if the user has the right to write into it.

The figures below show the fatigue and module configuration as examples. Figure 5-5 and Figure 5-6 show the parameter dialogues. In Figure 5-7 the algorithm has terminated and the results are shown.
Initially it was planned to not only realise the local version but also the network implementation of the integration environment. However, due to the required effort and licensing issues with the underlying software products it was decided to concentrate on the local version only. This implementation was developed with the network integration in mind to avoid complex adaptations when trying to migrate the system into VIP, RCE or a similar toolkit. The Java interface can directly be used by any of these system and therefore allows to implement the distributed IMPROVE toolkit as part of the IMPROVE interest group after the end of the research project. This means that the WP 5 result fully fulfils the requirements as contained in the description of work.

**Disseminations and use**

The following plans exist to disseminate and use the outcome of WP 5:

- Availability of tools: BALance will set up a download site which will be freely available to IMPROVE partners. Here the results and further developments can be stored and downloaded. Upon request the site will be opened to authorised external partners who will have to pay a license fee to the developers when using IMPROVE results.

- Marketing of IMPROVE tools: As soon as the concept of offering IMPROVE results to the outside world has been finished the website will be updated accordingly to advertise and explain the IMPROVE integration platform.

- Cooperation with industry partners: Cooperation with industry partners will be continued. Interested companies will be introduced to the consortium and if a mutual agreement can be reached will get access to the IMPROVE integration platform.

- Consulting activities: BALance will offer to the IMPROVE partners and to others consulting services in integrating software, especially in the shipbuilding industry but not restricted to it. IMPROVE knowledge will be combined with results from other activities to offer comprehensive knowledge in the integration domain. These services will be advertised on the BALance website.

- Promotion of IMPROVE results: Techniques tested and used during the IMPROVE integration will be promoted in other research projects as well. BALance contributes to a variety of EU, national and industry projects and will use the knowledge acquired in the IMPROVE project to develop integration components in the context of these activities.
WP6 : LNG CONCEPT (Lead by STX and ANAST)

OBJECTIVES
The main objective of this Work Package is the development of a new generation of Gas carriers (LNG).

STX-EUROPE (former Akeryards-St Nazaire and before ALSTOM) have previously designed and built several LNG gas carriers (72 000 m3, 140 000 m3 and 152 500 m3).

Due to the increase of gas demand on the market LNG ships of about 230,000 m³ are now a new standard. 250.000m³ and even bigger ship are under investigation by ship owners. Asian shipyards have already received orders for such large vessels. In Europe (and particularly in STX-EUROPE) preliminary design of 220.000m³ large LNG gas carriers have been performed but not yet optimised in size and in construction design. To be present on this new market and be competitive, it is important for STX-EUROPE to optimise the design of such new product to compete against Asian shipyards that have already been ordered such large vessels.

Due to the labour cost gap between Asian and European yards, it is of utmost importance to develop a product whose global construction and operational cost is competitive. STX-EUROPE has been able to compete on the 150.000m³ market through two major innovations:

- CS1 containment system giving 5% more cargo capacity within the same ship volume,
- Diesel gas generators combined with electric propulsion giving substantial operational cost advantages.

Same technologies is applied to the new 220.000m3 concept; however, in order to add further cost advantages, STX-EUROPE wants to focus on steel construction cost as well as steel protection and maintenance throughout ship’s life.

Two designs are analyzed (Fig. 6.1). The first is named “Standard” design and represents the classic model of an LNG ship. The second is called “Free ballast” design is characterized by an innovative constructive solution adopted in order to allow the navigation without ballast.

![Fig. 6.1- Two designs analyzed: (a) “Standard” design, (b) “Free ballast” design](image_url)
Based on this experience, there are for STX-EUROPE 5 major issues for the development of new LNG structural concept (new Product):

- **TARGET-1**: The optimum size of LNG with 5 tanks: “size a 5-tank max”
- **TARGET-2**: The optimum frame spacing and stiffener spacing for such “5 tank max”
- **TARGET-3**: How to combine reliable fatigue assessment and early design stage?
- **TARGET-4**: The optimum construction block strategy and sequence of production and integration of such production constraints in the early design optimisation
- **TARGET-5**: Crashworthiness study (LS-DINA) to assess impact with tugs (or other ship types).

![Fig. 6.2- External view of the new design - INOVELIS Pod technology and a V-shaped hull](image)

This **NEW “Free ballast” CONCEPT** (Fig. 6.2) is presented by STX-EUROPE SA with a reduced need for ballasts in order to prevent biological invasions of marine organisms transported in ballast water and sediment transfer. Moreover, this permits to save energy and thus money by decreasing the huge amounts of sea water transported almost unnecessarily.

This design concerns:

- LNG with reduced ballast tank (or even without ballast tank)
- Modified hull form (Reduced Cₜ at low draft to increase the draft).
- Propulsion: 2 Pods with small diameter (in nozzle), see Fig. 6.3;
- Simplified hull form (80% is developable), for easy and low cost construction

![Fig. 6.3- INOVELIS Pod technology](image)

The **NEW “Free ballast” design** have almost the same main dimension than the **“Standard” design** (5 tanks [4 prismatic tanks], 220000 m³, LPP = 303m, overall length 317m, etc.) but the innovative idea is to retrieve the ballast during the navigation without gas.

The potential advantages are:

- Environment: avoid moving invasive marine species from region to region
- Economy:
  - Lower fuel Consumption
  - Lower cost (construction)
  - Avoid sediment in ballast

The potential Risks are:

- Slamming in the aft part (when T is minimum, about 7 m)
- Strength and fatigue in the side bilges (which have been reduced)
- The position (vertically) of the manifolds must be adequate (may require ballasting during cargo unloading)
We focus here on the least cost and least weight optimizations by analyzing the influence of the new IMPROVE modules (sloshing, fatigue and multi-structure) on the optimized scantling using LBR-5 code. This optimization is completed by a global one using 3D FEM MAESTRO model, to provide the decision support problem (DSP) rationale for multi-criteria (weight, cost and centre of gravity) based optimization.

Fatigue calculations are done with VeriSTAR software (Bureau FEM software) to validate the fatigue module results. The study is completed by Crashworthiness study and the sloshing direct calculations. The last part is entirely dedicated to the production simulation and the cost assessment modules used for the LNG carrier within the integrated optimization platform of IMPROVE project.

**Deliverables**

Following deliverables were submitted to EU:

- **D6.1**: Detailed and extensive report about the new innovative LNG product (confidential document) – (lead by STX-EUROPE).

- **D6.2**: Report presenting the identified parameters having the larger positive or negative impacts on the optimum solution/RDMM procedure (lead by ANAST).

- **D6.3**: A short version of the detailed report (D6.1 and D6.2) for dissemination version (lead by WEGEMT)

**Work performed**

The following activities were performed:

- Ballast configurations, General Arrangement definition, Capacity Plan, Hull Form definition, Fig. 6.2 and Fig. 6.3 (STX EUROPE);

- Loading calculation, rule still water, Scantlings according to the rules (MARS s/w) and mid-ship section drawing, Fig. 6.1 (STX EUROPE);

- Intact and damage stability calculations. (STX EUROPE);

- Distribution and numbering of grand blocks of the cargo part. (STX EUROPE & ULG);

- Man hour estimation for the cargo part for the following items: Manufacture, forming, prefabrication, prefabrication and assembly (STX EUROPE & ULG);

- Description of the structural optimization analyses for both designs using LBR-5 code by presenting the initial scantling, the load cases, the constraints, the results, and the influence of each new IMPROVE module on optimization results. The “Standard” design versus “Free ballast” design analysis resumes the main differences between the two designs, fig. 6.5, fig. 6.6, fig. 6.7 and fig. 6.8 (ANAST);
- A reliable fatigue analysis is realized for each LNG design in order to give the real fatigue state of the initial scantling and of the optimized scantling at the early stage design. The LBR-5 fatigue assessment is completed by FE simulations using VeriSTAR software, necessary to validate the results of the fatigue module. See fig. 6.9 (ANAST);

- Theory, description and FE results of the crashworthiness study in order to evaluate which level of impact energy can damage the structure and what are the limitations and the safety precautions, fig. 6.10, fig. 6.11 and fig. 6.12 (TKE);

- Global scantling optimization using 3D FE software OCTOPUS/MAESTRO, fig. 6.13, fig. 6.14 and fig. 6.15 (UZ);

- Description of the direct calculations of sloshing,

- fig. 6.16 (BV) and its implementation (ULG);

- Finally a detailed and complex description of the simulation of ship production through the workflow of the production simulation, OptiView analysis, database variables, and experimental scenarios, fig. 6.17 (ANAST and CMT).

fig. 6.5- LBR5 : 3D view of the “Standard” design

fig. 6.6- LBR5 : 3D view of the “Free ballast” design

fig. 6.7- Objective Function Variation (sloshing module activated) - “Standard” design
**fig. 6.8**- Objective Function Variation (sloshing module activated) - “Free ballast” design

**fig. 6.9**- Fatigue analysis: Comparison LBR5 vs. VeriSTAR

**fig. 6.10**- Crashworthiness study: Collision setup for numerical simulation
fig. 6.11- crashworthiness study: Collision scenario

fig. 6.12- crashworthiness study: Vertical position of the contact point

fig. 6.13- Global optimization using 3D FEM MAESTRO model: Optimization and boundary models

Comparison of results - structural mass, t

<table>
<thead>
<tr>
<th>INITIAL STRUCTURE</th>
<th>OPTIMAL STRUCTURE</th>
<th>STANDARDIZED OPTIMAL STRUCTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>3931</td>
<td>3251</td>
<td>3507</td>
</tr>
</tbody>
</table>

fig. 6.14- Global optimization using 3D FEM MAESTRO model: Comparison of structural mass – middle tank and cofferdam structure
Comparison of results - normalized cost

INITIAL STRUCTURE  OPTIMAL STRUCTURE  STANDARDIZED OPTIMAL STRUCTURE

fig. 6.15- Global optimization using 3D FEM MAESTRO model: Comparison of normalized cost

fig. 6.16- Direct calculations of sloshing: Standing & braking waves at high fillings (left), progressive wave at low fillings (right)
fig. 6.17- Simulation of ship production: Erection strategies examples
Interaction with the other Improve work packages

This Workpackage is the outcome and the continuity of the work performed in the WP2 to WP5, including almost all tasks:

- **WP2** "Problem and Model Definition of multi-stakeholder decision making methods", including the sub-tasks T2.1.1 to T2.1.2 related to the requirements from operators, ship-owners and shipyards in order to define the initial inputs in relation to the products to be developed in WPs 6 to 8, and T2.2 related to the model definition;

- **WP3** “Load and response module”, where is included the main work related to the fatigue models (T3.3) and to the sloshing and crashworthiness modules (T3.4) in the early stage design;

- **WP4** “Production and operation module” relates to the rational models to assess operational and maintenance costs, to the preparation for simulation and to the model for production and cost assessment in order;

- The work described on this deliverable strongly interacts with the work done in **WP5** "Integration of the modules", especially with T5.2 “Specification, implementation and evaluation of file exchange process” and T5.3 “Specification and realization of the design desktop”. The integration of the new IMPROVE modules required large information from different design tools which leads to complex exchange processes between a large numbers of design tools.

Results and conclusions

In spite of a worse propeller efficiency of the **NEW “Free ballast” design**, in comparison with a conventional LNG carrier with the same main dimensions, LNG savings (consumed by engines) reach between 0.56% and 10%, corresponding to 0.53 and 9.5 tons of gas per day. Furthermore, the quantity of ballast water transported is more than 80% reduced in the most pessimistic hypothesis. This solution presents other important ecological and economical advantages.

However, **NEW “Free ballast” design** has one main disadvantage. Its 13 meters design draught is bigger than draught restriction in some terminals. Consequently, such a design would be better adapted to smaller ships. Furthermore, smaller ships which usually have shorter routes are more concerned by time and energy wasted for ballast operations. Finally, manifold maximum height for gas transfer is less constraining.

For example, the present design would be perfectly adapted to a relatively small LNG carrier operating in the Mediterranean Sea. Good seaway in this area would permit to avoid ballast use and short trips would not be delayed by ballast operations. Eventually, this innovative design could be adapted to other types of ships.

In the deliverables D6.2, we synthesized the main tendencies of the scantling after LBR-5 analysis and optimization without and with IMPROVE new modules, as well as to explain the main differences in terms of weight and costs between the two designs. The next table presents a qualitative comparison in term of weight and cost between the scantlings before and after optimization, as well as the variation in weight compared to the initial state of the both designs. The objective function was to minimize the production COST (least cost optimization). The global production cost is represented by the material cost, the labour cost and the consumables cost. It is therefore strongly influenced by the quantity of material (weight). The values indicated in the next table are obtained for the half of a single LNG tank (40.5 m of length) without cofferdams.
Table 1 - “Standard” design vs. “Free ballast” design

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>“Standard”</td>
<td>Initial</td>
<td>1 840.44</td>
<td>-</td>
<td>3.16</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Optimized¹</td>
<td>1694.99</td>
<td>7.90 %</td>
<td>3.00</td>
<td>5.16 %</td>
</tr>
<tr>
<td></td>
<td>Optimized²</td>
<td>1714.13</td>
<td>6.86 %</td>
<td>3.02</td>
<td>4.58 %</td>
</tr>
<tr>
<td></td>
<td>Standardized</td>
<td>1709.76</td>
<td>7.10 %</td>
<td>3.06</td>
<td>3.14 %</td>
</tr>
<tr>
<td>“Free ballast”</td>
<td>Initial</td>
<td>1845.70</td>
<td>-</td>
<td>3.13</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Optimized¹</td>
<td>1714.55</td>
<td>7.10 %</td>
<td>3.04</td>
<td>3.06 %</td>
</tr>
<tr>
<td></td>
<td>Optimized²</td>
<td>1744.37</td>
<td>5.49 %</td>
<td>3.05</td>
<td>2.71 %</td>
</tr>
<tr>
<td></td>
<td>Standardized</td>
<td>1724.73</td>
<td>6.55 %</td>
<td>3.07</td>
<td>2.09 %</td>
</tr>
</tbody>
</table>

¹ - with sloshing module; ² - with sloshing and fatigue modules

The gain in cost after standardization is less important for the “Free ballast” design (2.09 %) compared to the “Standard” design (3.14 %). These results can be explained by more severe loading conditions imposed to the “Free ballast” design. However, these facts are quite acceptable considering all advantages of the new LNG “Free ballast” concept.

The least weight optimization (objective function being the minimization of the weight) of the “Standard” design reveals a gain of 15.84 %, but an increase of the cost of 24.68 % (cost after optimization 3.94 M€, 3.16 M€ before optimization). The “Free ballast” design is characterized by a gain of weight of 14.41 % and an increase of the cost of 18.21 % (cost after optimization 3.70 M€, 3.13 M€ before optimization). The gravity centre increase for both designs, i.e. “Standard” design from 15.35 m to 15.87 m, and “Free ballast” design from 15.43 m to 16.6 m.

These large differences in term of cost between “least cost” and “least weight” optimizations can be explained by the strong variation of the scantling.

A last comparison was achieved between the initial and the standardized scantlings in order to find which “cost type” controls the gain of the global cost, keeping in mind that the global cost is constituted by the material cost (proportional to the weight), the labour cost and the consumables cost. In this purpose, we calculate a parameter which is the cost per kilogram (€/kg). Initially, the “Standard” design is characterized by a value of 1.72 €/kg. After standardization, this parameter becomes 1.79 €/kg. Even if this parameter increases, the global cost decreases (3.14%) as the weight strongly decreases (7.10%). The “Free ballast” follow almost the same evolution, from 1.70 €/kg initially to 1.78 €/kg after standardization.

Thus, in LBR-5, the LNG reduction cost is strongly influenced by the decrease of the global weight of the structure. The same variation can be observed for the “Free ballast” design. The above analysis confirms that performing a least cost structural optimization with LBR5 corresponds at the end to a multi-objective optimization, as the production cost and the weight are merged in the objective function.

The VeriSTAR global coarse mesh model shows that both standard and free ballast designs present the same problems: stiffeners buckling and plate buckling by uni-axial or bi-axial compression for plane panel on the cofferdams or bottom areas.

The fine mesh models show that there are no yielding problems on the mid-ship area but there some yielding problems on the intersection of the double bottom and cofferdams and on the cofferdam webs.

For fatigue analysis, different intersections and critical details were studied by very fine mesh in order to evaluate the hot spot stress on the interesting areas.

No fatigue problems on the two designs except a connection of one side longitudinal ordinary stiffener with stiffener of cofferdam on the standard design. This problem can be solved by adding a bracket.
The goal of this study was to calibrate the new Improve fatigue module developed on the WP3, task 3.3. The results of the fatigue module are very acceptable on early design stage.

The OCTOPUS/MAESTRO optimization was performed in order to determine the optimal structural solution of the "Free ballast" LNG carrier design with respect to objective function (minimization of total mass and cost) and safety criteria. The developments were achieved in two major steps.

The first phase, named Concept Design Phase, was identified to the initial exploration of the design space which was done for the initial model $P^0$ within six design cycles. Structural mass and VCG were successfully decreased and safety was increased (Table 2) and solution $O^\text{Concept}$ was generated. Within this first stage, a sensitivity analysis was done in order to inspect the sensitivity of breadth between stiffeners, material type and web frame spacing on the defined design objectives. Sensitivity analysis has shown that by increasing web frame spacing and decreasing breadth between stiffeners is possible to gain additional savings.

The second phase, called Preliminary Design Phase, was performed the standard preliminary design phase optimization. It resulted with the optimal design $O^\text{Preliminary}$ where savings are up to 17%. Complete re-analysis was performed in order to determine strength and safety level of the final standardized design $D^u$ of LNG ship, obtained from the optimal design $O^\text{Preliminary}$. The results of the adequacy analysis were considered satisfactory for the preliminary design phase with respect to BV requirements. Subsequent detail design phase should concentrate on several higher stress areas identified in this phase. A comparison between the results reveals that the proposed standardized design $D^u$ is acceptable from economical point of view, because of 10.8% of savings in structural mass and at least 5% of savings in the cost of structure.

<table>
<thead>
<tr>
<th>Design solution</th>
<th>Structural mass (middle tank)</th>
<th>Mass savings, %</th>
<th>Safety (TNULC)</th>
<th>VCG, mm</th>
<th>Normalized cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial, $P^0$</td>
<td>3931</td>
<td>/</td>
<td>110</td>
<td>16155</td>
<td>1.00</td>
</tr>
<tr>
<td>Optimal, $O^\text{Concept}$</td>
<td>3457</td>
<td>12.0</td>
<td>42</td>
<td>15957</td>
<td>0.87</td>
</tr>
<tr>
<td>Preliminary design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimal, $O^\text{Preliminary}$</td>
<td>3251</td>
<td>17.3</td>
<td>3</td>
<td>15931</td>
<td>0.85</td>
</tr>
<tr>
<td>Standardized, $D^u$</td>
<td>3507</td>
<td>10.8</td>
<td>0</td>
<td>15951</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Total reduction of 17% in design weight for optimal design is rather high, but it also depends on the starting design (since it is the total saving of concept and preliminary design phases). Savings of 12% obtained during concept design phase is also rather high, but it is often achieved with greater changes in prototype parameters (e.g. web frame spacing). Savings of 4 ÷ 7% in weight during the preliminary design phase is standard with respect to the good concept design, as achieved in this example.

Optimal point of the preliminary design phase is a good starting point for standardization, usually compared to the initial Yard design. As demonstrated in the example, UZ standardization has brought savings down to 10.8%, but Yard designers can do it better. Knowledge of the optimal (non-standardized) design scantlings (and its savings in structural weight) is offering the Yard designer an excellent opportunity to perform the refined standardization procedure regarding material quantities and production considerations of particular Yard.

As for LBR-5 results, a comparison between the results reveals that proposed design (standardized scantlings) is offering simultaneously savings in structural mass and cost, increase in safety (due to logical material distribution) and therefore maturity and the potential of the applied approach to design.
A quick comparison between LBR-5 and OCTOPUS/Maestro results of the “Free ballast” design reveals almost gain in weight after standardization, i.e. 9.39 % for LBR-5 and 10.8 % for OCTOPUS/Maestro. These values were calculated taking into account the weight of one tank with the associate cofferdam. On the other hand, the cost’s gain remains inferior for LBR-5 (2.09) compared to OCTOPUS (5%). Moreover, the gravity center variation is different, i.e. in LBR-5 it increased by approximately 50 cm and in OCTOPUS it decreased by approximately 20 cm. These differences are determined by the different conditions take into account by the two codes. According to section XX and section XX, the load cases are disparate (7 load cases in LBR-5 and 17 load cases in OCTOPUS). More than that, the optimization procedure is very different between these two softwares. Nevertheless, this deliverable does not propose to confront LBR-5 and OCTOPUS/Maestro results. We consider that these two codes are complementary codes and must be used together in order to roughly optimize (using LBR-5) and afterwards to optimize and analyze more in detail (using OCTOPUS/Maestro) a ship product.

The simulated crashworthiness scenarios revealed that in collisions at the maximum speed of the striking ship, the outer hull of the struck ship would be penetrated even when its platting thickness is as high as 35 mm. The size of the damage opening increases significantly as the thickness becomes lower. However, with the location of the contact location at the amidships, the most unfavorable scenario is simulated. The energy to be absorbed by structural deformations becomes less when the contact point is at some distance from the amidships. Furthermore, altering the structural configuration could improve the crashworthiness of the side structure. In the current design, the longitudinal stringer just above the collision point presents a hard point in the structure and prevents deformation to spread more evenly. Reduction of the speed of the striking ship reduces the amount of energy available for structural deformations and the outer plating of the struck ship remains intact even in the case of 15 mm platting.

The Bureau Veritas objective was to perform a sloshing pre-feasibility analysis (only for standard fillings) in order to provide quasi-static pressures to be applied on the inner hull structure supporting membrane cargo containment system. Afterwards the was to account these calculi at preliminary design stage, for the additional loads generated by liquid sloshing in the tanks of a STX Europe 220,000 m³ LNGC membrane tank in order to perform its structural optimization (only for standard fillings). The quasi-static pressures denoted the representative design pressures (acting on stiffeners and platings) which are to be taken into account for structural verification according to BUREAU VERITAS Rules.

The sloshing pre-feasibility analysis for STX Europe (limited only to standard fillings) within Improve Project is performed by BUREAU VERITAS within general sloshing assessment procedure, and is limited only to the numerical simulations. The representative sloshing design pressures acting on different inner-hull structural members given in this report are detailed for different relevant locations in the STX Europe 220,000 m³ LNGC membrane tank.

As shown in the production simulation section of this report, a significant reduction of lead time and cost can be expected after the scantling optimization of amidships section in the early design stage of the project. A gain of 3% for the budget, 29% for lead time, 7% for labour cost has been highlighted here while the LBR5 results shows a reduction of the labour cost of (-3.06%). The gains provided by LBR5 with a simplified method are lower than those predicted by the detailed production simulation which puts us on the safety side. The main factor explaining this amount of gain is the overall reduction of plate’s thicknesses which induce a reduction of welding costs.

More can be saved after the improvement of the organization using a new block splitting strategy or optimizing the surface allocation. A new block splitting using blocks with higher dimensions can generate some additional gains especially for the lead time. This gain would be much greater ones the outfitting is considered. The integration of the outfitting inside the simulation is a further potential improvement.

All savings are hardly influenced by constraints and system borders. The strong interaction between the scheduling of steel structure production, pre-outfitting and outfitting has not been taking into account in this simulation. However all the experts are unanimous in saying that this should have a strong influence on the results.
2. Dissemination and exploitation (use)

Final workshop of IMPROVE Project (Dubrovnik, Croatia from 17-18.09.2009):

- LNG Carrier – Ship Owner requirements, markets and technical trends
  F. Van Nuffel - EXMAR

- An innovative LNG Carrier
  L. Claes - STX Europe
  J.-L. Guillaume-Combecave - STX Europe

- LNG carrier- Structural design aspects
  A. Amrane, A. Constantinescu, F. Bair and P. Rigo - ANAST, University of Liege
  V. Zanic, J. Andric, N. Hadzic - University of Zagreb

- LNG carrier – new innovative product
  A. Constantinescu & Ph. Rigo - University of Liege
  J.-L. Guillaume Combecave - STX-Europe

- Use of the New LNG Concept (product) – STX EUROPE is developing new projects used the new concepts

- IMPROVE User Group. Use for the new optimisation tools using the IMPROVE User platform, by the IMPROVE partners but also by new partners. An User Group Agreement has been established and signed by the partners (see also the new WP10 on BAL.PM)
WP7 : ROPAX CONCEPT (Lead Uljanik Shipyard)

OBJECTIVES
This WP7 has as a main objective the development of an innovative 'new generation of large RoPax vessels' by using the IMPROVE RDMM concepts.

ULJANIK Shipyard in the last 5 years has designed several Ro-Ro, Con-Ro and RoPax vessels for different ship-owners. For a long period ULJANIK has strong cooperation with GRIMALDI Group, as respectable ship owner regarding market needs and trends.

In Owner definition: RoPax Vessels are built to combine basically 2 genres of transport: the roll on roll of services (as trailer, semi trailers, cars and special cargo) and the passenger transfer, and of course to take profit out it.

To make the difference in a competitive market the essential aspects are mainly two.

1. Creation of a solid network to guarantee to each client the most flexible and wide range of possibilities. With this vision since the beginning of Improve Project three years ago, Grimaldi Group has extended the initial RoPax fleet of only 5 Vessels into an exponential growth with a huge new building program and controlling two major RoPax operators: Minoan for Greek links and Finnlines for Scandinavian routes.

2. Possession of a young, competitive, environmentally friendly and most efficient fleet. Considering the daily operative cost a RoPax (and nowadays still more with economic crisis) only an extremely high efficiency can allow remaining on the market. Vessel of the future will have to be more and more efficient in terms of fuel consumption and related to the environment (even applying alternative power sources) or with a high flexibility in routes and cargo spaces.

The structural aspect is also essential because to maintain the scheduled itinerary every day no damage and no stop can be planned. So during design phase all the structures have to be dimensioned to avoid and to be resistant to fatigue, cracks and corrosion as much as possible.

A close cooperation between the Shipyard and the Owner during the design phase and during the preparation of the technical specification is a key point to achieve above results.

The development of the new products required a concurrent design, where new product design generations have to be developed in a multiple criteria decision making environment including multiple objective design and multiple attribute design evaluation stages.

Regarding general ship design the targets are:

- Selection of resistance friendly hull form
- Smaller propulsion engine for same speed
- Reduced fuel oil consumption
- Selection of hull form in order to reduce length of engine room (increased cargo space)

For new design, the extensive structural FE analysis will be performed to evaluate global structural feasibility. The arrangement of cargo space without pillars requests sophisticated structural solutions. Reducing height of deck structure is a very demanding task and can result in many benefits regarding general ship design, e.g.:

- Lower VCG (better stability)
- Reduced light ship weight (increased deadweight)
- Smaller Gross Tonnage

The challenge was to improve Rule-based structural design at the early stage of design (concept stage) and to find optimal design solution with the IMPROVE tools and continue the design process in preliminary stage (where more detailed FEM calculations were performed) with the better starting
point/design. The decrease of production cost (optimum sequence of production for ULJANIK environment) was the relevant design objective. In WP7, other challenges that were considered are:
- rational models to assess seakeeping and manoeuvring performances,
- rational models to assess fatigue at the early design stage,
- assessment of ultimate strength at the early design stage,
- rational models to assess vibrations at the early design stage,
- robustness models with respect to uncontrollable environments (seaway, economy).

**Deliverables**
Following deliverables were submitted to EU:
- D7.1 : Detailed and extensive report about the new RoPax product (confidential document - lead by ULJANIK).
- D7.2 : Report presenting the identified parameters having the larger positive or negative impacts on the optimum solution/RDMM procedure (lead by UZ).
- D7.3 : A short version of the detailed report (D7.1) realized for dissemination purposes (in collaboration between the WP leader and WEGEMT).

**METHODOLOGIES, WORK PERFORMED AND ACHIEVED RESULTS**
An innovative RoPax design has resulted from a multi-stakeholder (MS) approach where shipyards and ship-operators were involved and used the decision support environment for the key decisions on the new product.

To maximize the key performance indicators (KPI) for a multi-deck RoPax ship, various aspects of ship structural design were integrated into the novel multi-criteria (MC) optimization process. It is using, besides existing methods and tools, a number of new tools developed within IMPROVE project. The procedure was mainly split into two interconnected levels:

1. general ship design (GD) – optimization and selection Blocks 1-2.
2. ship structural design (SD) – optimization, selection and analysis Blocks 3-9.

The work and results are described in the sequel.

**Task T7.1: Basic Design, Performance, Stability etc. (ULJ, GRIM, UZ, NAME)**

The primary focus was on the general ship design (Naval Architecture calculations: speed, power, damage stability, etc.) performed at ULJANIK and corresponding comparisons of selected propulsion variants. Within set requirements the design considered large variations in seasonal trade (summer 1600pax, winter 100pax). The design was based on a successful existing contemporary ship, used as a prototype (Level I). The optimized design, see Figure 7.2, has significant advantages as compared with reference RoPax ship, such as improved redundancy and simplicity of systems, improved manoeuvrability, optimized seakeeping and maximized comfort.

**Figure 7.2 IMPROVE RoPax design**

Main dimensions of ROPAX concept design are optimized using TRIDENT/SEAKING software (ULJANIK/USCS software) in order to obtain minimal main engine power and sufficient stability. A new application was developed, which finds a best combination of main dimensions in order of minimize resistance. Original hull form was Uljanik's biggest car carrier, which was then transformed into new (level 2) form (see Figure 7.3) with smaller resistance.
**Propulsion** design alternatives were investigated, see Figure 7.4:

- **Variant I**: One slow speed main engine directly coupled to fix pitch propeller with one active rudder with propulsion bulb to increase main propeller efficiency.
- **Variant II**: Two medium speed main engines coupled via gearbox to CP-propeller with two retractable side thrusters.

The main idea of novel propulsion concept is to avoid as much as possible the running of electrically driven thrusters in seagoing condition, i.e. to use it only during manoeuvring in harbour (no tugs) and to have two independent sources of propulsion in order to obtain 100% redundancy notation.

IMPROVE goals regarding achievement in fuel oil consumptions and increased lane meter on tank top (cargo capacity) have been achieved.

In comparison with **Standard** ship, **New** design (Level 2) needs almost 7900 kW less power, weight of machinery is reduced by 450 t, fuel oil consumption is 29% less and finally, propulsion system is more reliable. Index of redundancy is 100% (2 independent engine rooms and 2 independent propulsion systems). Final **IMPROVE** ship (Level 3) has 4 % less lightship weight in comparison with **New** IMPROVE ship (Level 2) and because of this, the required propulsion power and fuel oil consumption are 5 % less (19560 kW instead of 20500 kW). The gain of 5% more trailer lanes (cargo capacity) on tank top is achieved by investigating different positions of longitudinal ballast tank bulkhead and at the same time ballast volume is minimized.

**Seakeeping** performance evaluation has been carried out by NAME. For that purpose 2D strip theory software available at NAME was used to estimate the response of the vessel under various sea states, wave directions and ship’s speed. In general, the vessel is expected to perform satisfactorily up to sea-state 5 in North Atlantic. However, significant motion sickness incidences and motion induced interruptions are expected at higher sea states, especially at the vessel’s bridge and its surroundings. That was one of the reason to choose two deck superstructure variant. The likelihood of propeller emergence and deck wetness are found to be nil. The responses evaluated include ship motions, deck-wetness, motion induced interruption, and motion sickness incidences, see Figure 7.5 for example. Results of seakeeping analysis were taken into account during the selection of preferred topological concept of ship general arrangements.
Figure 7.5: ROPAX Motion Sickness Incidences (MSI)

Manoeuvring analysis of the IMPROVE RoPax vessel has been carried out by NAME based on data supplied by ULJANIK. Empirical methods were used to estimate the missing data necessary for the analysis. The aim of this study was to evaluate the manoeuvring characteristics of the vessel. Simulations were carried out for the loading condition 4 defined in the Trim and Stability booklet. The types of maneuver simulated were based on the guidelines provided in IMO Resolution MSC.137(76) Vessel; these included the following two critical maneuvers: 1) Turning circle and 2) Zig-zag test, see Figure 7.6. The IMPROVE RoPax vessel, under designed layout/sizing of the steering system, was able to meet IMO requirements with very good margins.

Figure 7.6 10/10 Zig-zag Maneuver Test

Topological/geometrical variations of general arrangements concepts The main topological / geometrical design variables, based on Yard Owner requirements, were:

1. Number of superstructure decks. Two variants of superstructure decks (two and three tiers) with constant total area of accommodation decks.
2. Transverse position of longitudinal bulkhead between deck 1 and deck 3. Three different positions were examined that generated three different midship section.

Two variants of superstructure were attached to each of three different geometrical variants of midship section. A total number of six different model variants were formulated, see Figure 7.7, and analyzed by ULJANIK and UZ as a multi-objective design problem.
ULJANIK has calculated preliminary hull scantlings (MARS – BV software) and has designed hull structural drawings (with CADDS/TRIDENT) for that purpose for all variants. For each variant, intact and damage stability calculations were performed. In order to obtain same subdivision index “A” freeboard was increased rather than metacentric height, as the passenger comfort depends on the period of roll and additionally passive anti rolling system can work successfully at MG abt 1.1 m.

GRIMALDI has produced data about oversized cargo. Conclusion was to load oversized cargo on freeboard deck 50 m from stern ramp SB.

In this phase the design procedure has been based on two optimization / selection blocks that are interconnecting general ship design and structural design (defined further in Section Task T7.2):

Block 1: Structural optimization of generic coarse mesh FE structural model (six different models - 0.8 of ship length), see Figure 7.8. Analysis of minimal height of the deck supporting structure (transverses, girders) was performed for all examined variants.

Block 2: Subjective selection of generated designs based on designer/ship-owner preferences has been preformed with respect to various design attributes (damage stability, cargo capacity, cost, etc.).

Based on structural optimization results and additional calculations of ship (stability, cargo handling, etc.) for all variants the designer specified six criteria for the final selection: Parking area, Ship stability, Air draught, Production cost, Passenger comfort and Structural Safety. Designers’ and Owner’s subjective intra-attribute and inter-attribute preferences are demonstrated in Figure 7.9, while AHP method was used for inter-attribute preferences, see Figure 7.10. Optimal variants of all designs are visualized using OCTOPUS Designer DevView Tool, see Figure 7.11. RoPax22 variant (see Figure 7.7) was chosen as the final variant and selection was based on the Parallel axis plot of selected criteria in Figure 7.12.
Cargo handling analysis was performed for all three midship section variants. Achieved gains were:

<table>
<thead>
<tr>
<th>Description</th>
<th>Variant 1</th>
<th>Variant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parking area Dk No2</td>
<td>201.6 m2 x 3000 Euro/m2</td>
<td>= 604800 euro</td>
</tr>
<tr>
<td>Parking area Dk No1</td>
<td>201.6 m2 x 5000 Euro/m2</td>
<td>= 1008000 euro</td>
</tr>
<tr>
<td>Total parking area</td>
<td>403.2 m2</td>
<td>= 1612800 euro</td>
</tr>
</tbody>
</table>

Stability analysis was performed for all examined variants. The objective was to obtain metacentric height < 2.0 m as per stabilizing tank manufacturer requirements and to increase passengers comfort index. Achieved gains were:

<table>
<thead>
<tr>
<th>Description</th>
<th>Variant 1</th>
<th>Variant 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metacentric height</td>
<td>2.70</td>
<td>1.21</td>
</tr>
<tr>
<td>Period of roll (sec)</td>
<td>13.6</td>
<td>20.3</td>
</tr>
</tbody>
</table>

Finally, procedure resulted in optimal structural design of a RoPax with two superstructure decks, optimal parking area on lower decks, VCG position, etc. It was combined with minimization of the ship lightweight and related savings in fuel and other operational costs. Parameters having the larger impacts on the optimum solution have been identified.
Gains in oil consumptions and savings in required power were already specified. Other characteristics of the preferred RoPax 22 variant are:

- 403.2 m² of extra parking area with respect to the starting variant RoPax 30
- No additional ballasting – the vessel sails at lower draught
- 2.5m smaller air draught with respect to RoPax 32
- Reduced weight of wing tank blocks and smaller distance to water line offering improved passenger comfort. Structure inside wing tanks is modified in order to avoid erection of scaffolding for inspection.
- The conceptual phase obtained savings in cargo space weight of approx. 300 tons in Step 1 which influenced general ship design in terms of reduction of required propulsion power.

The preferred topological/geometrical concept has been chosen and served as the starting point for the more detailed structural optimization. The work done for task T7.1 has been reported in Deliverable D7.1.

Task 7.2: Structural design using MC/MS decision making process (ANAST, ULJ, SDG, TKK, UZ)

The novel decision support methodology for the concept and preliminary design of multi-deck ship structures was applied to the structural design of the next generation of the RoPax ship.

Design of complex multi-deck RoPax ship requires:

- Development of a special design procedure due to strong interaction of superstructure / lower hull.
- Application of full-ship 3D FEM models to capture those effects correctly.
- Speed of design calculations should meet requirements of the practical design process.

To gain speed, the optimization process has to follow designer’s data availability and provide fast answers with adjusted models. This ruled out standard optimization procedures as inoperable and required development of a new approach to the decision support problem for the RoPax ship.

Development of novel and efficient multi step procedure was also needed in order to solve the complex topology optimization problem (with interwoven scantling/geometry optimization), as to satisfy design requirements when number of decks, web frames, openings in side structure, etc. are parts of design variables set.

Approach combines three design steps for the fast generation of different design variants regarding topological, geometrical and scantlings variables.

Concept design phase: multi-criteria topology /geometry optimization (STEP 1)

Usage of methodology in general design was given in Section on Task T7.1. Structural aspects (methods, models) and work done are given below:

- **Block 1:** Geometry/Topology exploration. It is based upon the extruded generic 3D FEM MAESTRO models based on geometric/topological variables determined using DOE. Each design variant is further optimized with respect to scantling variables for fair comparison in the Block 2.

- **Block 2:** Subjective Selection of Designs with Preferred Geometry/Topology. It is based on designers preferences and ANOVA analysis. Transformation procedure is used as interface between the geometry/topology and scantlings optimization models. Fractional or full factorial experiments can be performed for subset of topological and geometrical variables coordinated with MODM approach to other variables (scantlings/material). Full factorial was used here.

  The generic ship 3D-FEM MAESTRO models based on macro-elements were developed and analyzed according to BV rules and optimized, see Figure 7.13.
In the context of general design, designer’s selection was performed using appropriate design quality measures among 6 structurally optimized variants, as presented in the previous section. The design objectives used for structural optimization of all design variants were: structural weight, production cost and position of vertical centre of gravity. Beside topological variable (the number of superstructure decks); the geometrical (breadth of lower hold i.e. position of longitudinal bulkhead in cargo space) the set of scantling variables included numerous scantlings of all principal structural elements. Minimum and maximum values for the height of frame web of deck transverses were specified by ULJANIK yard. Minimum scantlings were determined according to BV Rules. (e.g. wheel loads). Four critical load cases (upright and inclined) according to BV Rules were implemented. Optimizations process was successfully performed for three optimization modules (in parallel) and optimum scantling were generated, see Figure 7.14.

Evaluation and comparison between six model variants were made with the following conclusions:
- Total mass of every model is successfully decreased for approximately 200 to 300 t,
- Cost and VCG are successfully decreased while in parallel safety was increase,
- Height of all models was slightly increased (for 450 mm) due to greater height of frame webs.

Effect of superstructure topology on the longitudinal stress distribution has been identified as very important. Due the fact that superstructure with two decks is very long (about 80-90% of ship’s length) it participated in hull global bending with more efficiency then variants with much shorter superstructure on three deck. Comparison of longitudinal stresses for LC2 is given for two variants RoPax 22 and RoPax 30, in Figure 7.15 as an example. Very low participation of superstructure decks was identified for RoPax 30. That affected stress distributions over cross section height and caused higher stresses in Deck 6 (highest lower hull deck) and also increased compression stresses in the bottom plating when compared to RoPax 22 variant. Higher compression stresses led to thicker bottom plating to prevent buckling problems.
Effect of the different positions of longitudinal bulkhead with respect to different midship section variants was also examined. Transverse position of longitudinal bulkhead between deck 1 and deck 3 influenced mainly transverse beams scantlings on deck 2 and 3. Its influence is relative low with respect to the completely examined structural mass. Optimal deck height was found for all examined variants. It is important to emphasize that active constraints in optimization process related to deck structure were mainly minimum allowable stiffened panel scantlings due to wheel load.

Optimal structural scantlings of preferred variants RoPax 22 served as the starting point for multi-criteria optimization in Step 2.

**Concept design phase: multi-criteria scantling optimization (STEP 2)**

Transition from generic model (3D MAESTRO) to zone models (2.5D OCTOPUS)-see Figure 7.16

Optimization Blocks 3 -7, including IMPROVE modules, were executed in STEP 2

- **Block 3**: Initial scantling optimization using gradient SLP optimizer for three characteristic cross sections of RoPax, see Figure 7.16.
- **Block 4**: Extensive scantling optimization with reduced analysis block using initial designs generated in block 3. MADM exploration of the design space was performed and educated generation of Pareto frontier was performed.
- **Block 5**: Subjective selection of certain number of Pareto designs based on multi-stakeholder preferences. Saaty’s inter-attribute preferences and fuzzy membership grade functions for intra-attribute preferences can be defined and applied. Distance Lp-norms can use for selection of appropriate number (20-30) preferred designs. In Rapox application case this block was omitted, although originally planed, due to increased speed of OCTOPUS Analyzer LUSA.
• **Block 6**: Additional calculation of complex design attributes (Hull girder ultimate strength) was done. Complete analysis of the reduced number of the preferred Pareto designs generated in block 4 and selected in block 5 were optimized based on MOPSO (additional FFE based optimizations were not considered necessary).

• **Block 7**: Final selection of preferred designs. Subjective reasoning is performed through DeView modules based on the results of LCC calculation, while generally, different preference formulations in the selection of the final design variants are possible. Designer’s own routines for measuring ship performances were used (eg. resistance).

Refinement of selected design was performed using its `control structures` (bays) of different ship segments. They were modeled, using the computationally very fast OCTOPUS 2.5D FEM models (Figure 7.16) in generation of design alternatives on the Pareto frontier. They were validated using the IMPROVE developed adequacy and quality measures (vibration, fatigue, robustness, safety and production cost). IMPROVE LCC module was used in determination of the optimal combination of different generated substructures, as starting points for the next, preliminary design phase.

The main goal of Step 2 was selection of a preferred design from Yard and Owner’s standpoint. Firstly, it was necessary to create ship designs based on the results from the models representing zones around Frame 129 and 184.

Resultant Pareto frontier at the end of Step 2 was obtained by generating all combinations of Pareto designs from two models, Figure 7.17a-d. For all generated designs, the IMPROVE Life Cycle Cost module was used to calculate Periodic maintenance cost, Fuel Cost, Earning and Dismantling cost. From obtained costs, the costs of the referent ULJANIK shipyard model, was deducted in order to present directly differences between the referent model and each design variant (see Figure 7.17b).
All calculated attributes with their aspiration direction (Minimize or Maximize) are presented in Table 7.3, while those which were used as objectives for Pareto filtering have their type marked bold. After Pareto filtering the resulting Pareto frontier was interactively presented to the ULJANIK shipyard head designer in order to select the final design.

Table 7.3 Design attributes for the final selection and the values obtained for selected RoPax 22

<table>
<thead>
<tr>
<th>No</th>
<th>Description</th>
<th>Type</th>
<th>Acronym</th>
<th>Value (- denotes reduction)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Delta Lightship weight</td>
<td>Min</td>
<td>D_LWT</td>
<td>-493.7 t (aspirated change)</td>
<td>-3.9</td>
</tr>
<tr>
<td>2</td>
<td>Delta production cost</td>
<td>Min</td>
<td>DC_PROD</td>
<td>-6.545E+05 € (aspirated change)</td>
<td>-9.2</td>
</tr>
<tr>
<td>3</td>
<td>Delta Maintenance cost</td>
<td>Min</td>
<td>DC_MAINT</td>
<td>6.930E+05 €</td>
<td>18.1</td>
</tr>
<tr>
<td>4</td>
<td>Delta fuel cost</td>
<td>Min</td>
<td>DC_FUEL</td>
<td>-9.484E+06 € (aspirated change)</td>
<td>-4.1</td>
</tr>
<tr>
<td>5</td>
<td>Delta dismantling</td>
<td>Max</td>
<td>D_DISM</td>
<td>-2.383E+05 €</td>
<td>-4.1</td>
</tr>
<tr>
<td>6</td>
<td>Delta Life cycle cost</td>
<td>Max</td>
<td>D_LCC</td>
<td>9.207E+06 € (aspirated change)</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Based on Pareto designs the ULJANIK shipyard’s head designer had selected the design with the maximal profit for the GRIMALDI ship-owner. Table 7.3 summarizes attribute values for selected design, while Figure 7.18 presents some of safety related calculations, performed by OCTOPUS Analyzer on the selected design.

Concept design phase: LBR5 Concept design process and results

ANAST laboratory (University of Liege) and DN&T carried out strength and least production cost assessments based on scantling optimization of the RoPax design using the LBR-5 software. Among the new modules implemented in LBR-5 code in the framework of IMPROVE, the vibration module (Task 3.1.b) was used as post-analysis of the RoPax optimized scantling.

Figure 7.19 LBR-5 model and results

In LBR-5 cylindrical part of the ship was modeled (Figure 7.19a). According to the RoPax drawings, the cylindrical part has an approximate length of 39.2 m. The transversal section has a vertical
symmetry axis. Then, for symmetry reasons, only half of section is modeled. Six most critical load cases were defined for the RoPax case. These load cases represent actually combinations between the loading conditions and the load cases indicated in BV Rules. Figure 7.19b) presents Lateral pressure distribution for LC 1, while Figure 7.19c) distribution of calculated Von Mises stress in frame web-plate junction for LC1.

The optimization process returned a production cost of $1.42 \times 10^6 \, \varepsilon$, and the gain compared to the initial scantling is approximately 5.33 %, according to Figure 7.20. The Table 7.4 presents a comparison in terms of mass and cost between the initial and optimized (least cost) scantling of the RoPax.

![Figure 7.20 - Initial Design Objective Function Variation](image)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>935.03</td>
<td>-0.15 %</td>
<td>1.50</td>
<td>5.33 %</td>
</tr>
<tr>
<td>Optimized</td>
<td>936.50</td>
<td>-0.15 %</td>
<td>1.42</td>
<td>5.33 %</td>
</tr>
</tbody>
</table>

Optimization results have shown that global production cost is constituted by the material cost (proportional to the weight), the labor cost and the consumables cost. ANAST calculated the parameter expressed by the cost per kilogram (€/kg). For the initial scantling of the RoPax the value is 1.63 €/kg and after optimization this parameter becomes 1.52 €/kg. However, the global weight increase from 935.03 tons to 936.50 tons and do not keep the same evolution as the global cost. Therefore, the RoPax reduction cost is not based on the decrease of the global weight of the structure, characteristic to LNG carrier for example, but is influenced by the reduction of the labor and consumables costs. This fact is very important for the stakeholders since it represents the main objective of the production simulation.

**Stiffened panel vibration (eigenfrequency) analysis and results**

ANAST has performed vibration analyses using LBR5 model. Calculations were realized on the initial and the optimized scantlings. The validation of the results (eigenfrequency values) was done by comparisons with FE solutions.

The vibration module was automated to analyze isolated planar stiffened panels, i.e. stiffened panels having independent boundary conditions from the other neighbour panels. According to the RoPax drawings, 6 (six) stiffened panels of the RoPax were analyzed. These panels are indicated in Figure 7.21 together with resulting eigenfrequencies and first natural frequency visualization for panel 3.

![Figure 7.21 Vibration model with first eigenfrequencies before/after least cost optimization](image)
Conceptual analysis of RoPax Fatigue

TKK has performed preliminary fatigue assessment of RoPax ship in the concept design phase using the ConStruct tool and the IMPROVE Fatigue-module.

Aim of the study was to confirm that the nominal stress levels are correct with respect to fatigue. Thus, the fatigue analysis was based on simplified approach, where fatigue loading included the expected critical case according to the Bureau Veritas Rules. Additionally, the analysis focuses on the section of the main frame (L/2).

Table 7.5 presents calculated critical values of damage sum, corresponding stress and pressure values at $P=10^{-8}$ probability level together with the plot of ship showing fatigue-critical location (contour of damage sum values).

<table>
<thead>
<tr>
<th>Position</th>
<th>B</th>
<th>TP</th>
<th>Stiff</th>
<th>$\Delta S_{xx}$</th>
<th>$\Delta P$</th>
<th>Damage</th>
<th>Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel</td>
<td>m</td>
<td>mm</td>
<td>profile</td>
<td>MPa</td>
<td>kNm</td>
<td>D</td>
<td>years</td>
</tr>
<tr>
<td>D8</td>
<td>3.84</td>
<td>6</td>
<td>HP-120*6</td>
<td>96</td>
<td>2.0</td>
<td>0.4</td>
<td>50</td>
</tr>
<tr>
<td>D7</td>
<td>3.84</td>
<td>6</td>
<td>HP-120*6</td>
<td>82.9</td>
<td>2.0</td>
<td>0.3</td>
<td>67</td>
</tr>
<tr>
<td>D6</td>
<td>3.84</td>
<td>9</td>
<td>HP-140*8</td>
<td>76.5</td>
<td>2.0</td>
<td>0.2</td>
<td>100</td>
</tr>
<tr>
<td>D4</td>
<td>3.84</td>
<td>11.5</td>
<td>HP-260*10</td>
<td>56.8</td>
<td>15.2</td>
<td>0.1</td>
<td>200</td>
</tr>
<tr>
<td>D3</td>
<td>3.84</td>
<td>13</td>
<td>HP<em>240</em>10</td>
<td>38.3</td>
<td>30.3</td>
<td>0.1</td>
<td>200</td>
</tr>
<tr>
<td>D2</td>
<td>3.84</td>
<td>6</td>
<td>HP-100*7</td>
<td>6.4</td>
<td>3.0</td>
<td>0</td>
<td>Inf</td>
</tr>
<tr>
<td>D1</td>
<td>3.84</td>
<td>11</td>
<td>HP-260*10</td>
<td>47.2</td>
<td>40.4</td>
<td>0.2</td>
<td>100</td>
</tr>
<tr>
<td>Bilge</td>
<td>3.12</td>
<td>13</td>
<td>HP-280*11</td>
<td>38.8</td>
<td>110.4</td>
<td>0.8</td>
<td>25</td>
</tr>
<tr>
<td>Bottom</td>
<td>3.84</td>
<td>15</td>
<td>HP-300*11</td>
<td>78.8</td>
<td>59.2</td>
<td>0.4</td>
<td>50</td>
</tr>
</tbody>
</table>

Preliminary Design Phase: Full ship model optimization and analysis (STEP 3)

The full ship 3D FEM models were developed using MAESTRO software to for the preliminary optimization phase and to validate optimal design variants using safety, weight, cost, fatigue and vibrations criteria, see Figure 7.22. Starting points were optimal scantlings from Step-2. All classification documentations (drawings) and load conditions definition were developed by ULJANIK shipyard. Definition of optimization variables and constarins were simmilar to those presented in Step1.

Optimization Blocks 8 -9 were executed in Step 3:

- **Block 8**: Multiobjective MAESTRO optimization using SLP. Full ship 3D FEM model using optimal scantlings for all three ship zones (selected in block 7) was developed. Selective re-optimization of critical or unsatisfactory substructures was performed.

  During performed multi-criteria structural optimization, structural mass and position of VCG were successfully decreased and safety increased (no more unsatisfied constraints). In addition, relative adequacy index is greater for each module (it is equal to unity). In total structural mass was decreased for 78 t, or 2.8% (with respect to the structural mass at the beginning of the design step 3)
and position of VCG for 13.9 cm (w.r.t. the VCG position at the beginning of the design step 3), see Figure 7.23.

Figure 7.23 History of structural mass and total number of unsatisfied constraints

- **Block 9:** Full ship MAESTRO + OCTOPUS analysis of the final design. Model was modified for the new optimal scantlings.

Since quality of loading prediction is basic to structural optimization, direct load calculations made by NAME were also used in addition to the standard procedure. The short term dynamic wave load model developed by NAME is essentially an extension of the guidelines given in Part-B, Chapter-5 of BV rules for ‘Sea Pressure’ design loads. This model employs 3D panel method seakeeping analysis software in the first phase (DNV’s WASIM) to calculate various motions and load related Response Amplitude Operators (RAOs). These RAOs are then combined with the defined sea conditions of interest (phase-II) to calculate design extreme (1% probability of exceeding, user can define other probability levels - see user manual), most probable and RMS responses as required.

Load components (pressure field, accelerations, etc.) have been implemented on the full ship 3D FEM model for the final evaluation of structural scantlings. Equivalent sinusoidal wave (length =L, h_w) is prescribed in MAESTRO and FE model is balanced on a wave (change: trim, heave, heel) in order to achieve equilibrium position (closed shear and moment diagram) and also to have the reaction forces below the Rule requested limit, see Figure 7.24.

Figure 7.24 Obtained outer pressure and shear force distribution in FE model

Detail structural evaluation of the final variant were done w.r.t structural response (stresses, deflection, adequacy), see Figure 7.25.

Vibration calculus of RoPax aft part was performed by SDG using COSMOS software. FE model was developed according to 2D CAD drawings supplied by ULJANIK, see Figure 7.26. The model was clamped in fore part, in the section of the engine room aft bulkhead. The first 150 natural vibrations were determined. The values of the frequencies are very high due to the fact only structure weight was considered.
Conclusions on Design Procedure

During WP7 RoPax ship was successfully optimized within three design steps presented in the sections above. Overall results achieved for each design step are given in Table 7.6 starting with initial solution for RoPax ship – RoPax 30. A comparison of weight and safety for each model is also given.

Design Step 1: Structural optimization resulted with structural mass decrease of 283 t (8.62%) with respect to the initial structural mass of P0 (RoPax 30), denoted as P1 at Table 7.6.

![Figure 7.25 Full-ship model of RoPax ship σx and σy membrane stress- LC2](image)

Design step 2: The starting point of a second design step was P1. Multi-criteria optimization during second design step resulted with structural mass decrease (P2) of 232 t (7.7%) with respect to P1 solution.

Design step 3: Structural optimization resulted with structural mass decrease of 108 t (3.9%) with respect to the structural mass of P2 solution, denoted as P3. At the end of the design sequel, structural scantlings were standardized and final D3 solution was generated. Due to that, a structural mass is slightly higher w.r.t. P3 solution for 37 t (1.12%).

![Figure 7.26. Mode 2 of aft part (general bending)](image)

<table>
<thead>
<tr>
<th>Structural models of RoPax ship</th>
<th>Mass, t</th>
<th>Savings, %</th>
<th>Norm. Cost</th>
<th>VCG, mm</th>
<th>Height, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoPax 30 (reference design denoted P0)</td>
<td>3283</td>
<td>0%</td>
<td>1</td>
<td>13695</td>
<td>31800</td>
</tr>
<tr>
<td>RoPax 22 (selected design variant in 1st design loop)</td>
<td>3313</td>
<td>-</td>
<td>1.01</td>
<td>13378</td>
<td>29100</td>
</tr>
<tr>
<td>Step 1 design (P1)-optimal RoPax 22</td>
<td>3000</td>
<td>8.62</td>
<td>0.91</td>
<td>12906</td>
<td>29550</td>
</tr>
<tr>
<td>Step 2 design (P2)-optimal RoPax 22</td>
<td>2768</td>
<td>7.73</td>
<td>0.84</td>
<td>13290</td>
<td>28100</td>
</tr>
<tr>
<td>Step 3 design (P3)-optimal RoPax 22</td>
<td>2660</td>
<td>3.9</td>
<td>0.80</td>
<td>13134</td>
<td>27380</td>
</tr>
<tr>
<td>Final RoPax 22 design - standardization D3</td>
<td>2690</td>
<td>-1.12</td>
<td>0.81</td>
<td>13151</td>
<td>27325</td>
</tr>
</tbody>
</table>

**TOTAL SAVINGS** | **593** | **18.06%** | **19 %** | **544** | **4475**
Overall savings, from prototype RoPax 30 to standardized design D3 are very challenging 18% in weight, 19% in cost and 4475 mm in ship height. It however proves that the cascade of optimization steps in the novel design procedure produces very satisfactory results. They were further cross-checked with the 3D FEM full-ship analysis of the class required fidelity level.

Decision making implied (a)-the objective optimization procedures (dual SLP and MOGA) combined with (b)-stakeholders’ subjective decision making (selection) on the generated Pareto frontiers. Procedure resulted in optimal structural design of RoPax with two superstructure decks, optimal parking area on lower decks, VCG position, etc., combined with minimization of the ship lightweight and related savings in fuel and other operational costs. The work done for task 7.2 has been reported in Deliverable D7.2.

Task 7.3: Construction Cost & Life Cycle Cost: Impact Assessment in the optimization Process
(ULJ, GRIM, UZ, CMT, ANAST)

Production cost assessment/simulation

The production cost assessment model, which is based on major cost drivers, was used for the generation of new RoPax, and relevant cost ratings, which include material cost, labour cost and operational cost of the facilities used directly in the production of a design alternative, were assessed in this task. Particular focus was on the sequence of production and the welding techniques used to assemble panels altogether and assemble grand blocks (very expensive welds). For the concerned ship simulations runs have included:

- Adaptation of the simulation model to the additional shipyard requirements,
- Adaptation and verification of input data from the shipyard to the simulation requirements,
- Parameterization of the model (to customize the model),
- Validation and verification of the model,
- Simulations run and experiments,
- Transfer of simulation results and data into databases,
- Deliver statistics and key figures for optimization.

The production simulation (lead by CMT) and the cost assessment modules (lead by ANAST) were used for the RoPax carrier within the integrated optimization platform of IMPROVE project. The production cost assessment module has been divided in two sub modules:

- the analytical calculation of the production cost starting from the scantling data of the mid ship section, and
- the assessment method based on a detailed production simulation that validates and improves the analytical function mentioned above.

The main objective of the production simulation of the RoPax carrier was to study the effects of scantling alteration and the section splitting on the production behavior through the production simulation methodology during the overall scantling optimization loop.

Two types of ships design have been considered in the production simulation. The first type of ship was RO/RO Car Truck Carrier (yard 472), which was used to define, adapt and test the model for production simulation. The second type of ship was the RoPax, used in two variants of midship section, differing in lower hold breadth. Two scantlings have been considered. The first one was the initial scantling provided by the shipyard and the second one was the optimized scantling provided after the optimization based on LBR5 software. A complete simulation model has been developed, see Figure 7.27.
The lead time, the production cost (Transport cost + Labour cost + Surface utilization cost) as well as the space allocation and the workload were measured and compared for each ship alternative. The quality of the input data affected significantly the quality of the simulation outcome, therefore some further work on gathering more detailed data could lead to better and more usable results of production simulation. The work done for task 7.3 regarding production simulations has been reported in Deliverable D7.1.

Assessment of Life cycle cost and Robustness

Life-Cycle Cost as well as its components production and maintenance/repair costs (with respect to structure related variables) were used as attributes during concept design stage. It has been proven that changes in scantlings have a considerable impact on a production, maintenance/repair costs due to corrosion, dry-docking cost and dominant cost of ship unavailability (GRIM). It was important to know and assess RoPax LCC and its impact on KPIs at the earliest design phase for evaluation and comparison of alternative designs (SD Steps1-3), identification of cost drivers, maintenance planning, etc.

In the life-cycle cost calculation, using the IMPROVE modules developed by ANAST and NAME, consideration was given only to relevant costs and earnings that are directly or indirectly affected by the design options and their structure related variables. Economy related attributes were: production cost, periodic maintenance cost, fuel oil cost, operational earning and earning of dismantling. It was apparent that more steel weight means more production cost in terms of material and labour costs, and also more dismantling earning. Similarly, less steel weight indicates less fuel consumption.

Since those attributes are dependent on parameters that cannot be controlled (seaway and economy stochastic environments) the robustness (or (in)sensitivity to their changes) is of interest to the RoPax designer. Three problems regarding robustness attributes were identified: (a) production cost, (b) life-cycle cost (modules developed by NAME and ANAST) and (c) panel safety module developed in OCTOPUS. They were inserted into the IMPROVE robustness module developed at UZ. Module was validated on safety measures of the RoPax stiffened panel (Figure 7.28c). Obtained Pareto frontiers for problems ad (a) and (b) are given in Figure 7.28 a, b and used in STEP 2 decision making (Block 7).

Problem of Yard production cost and its robustness implies identification of designs that are less sensitive to changes in material cost (plating, stiffeners, girders, etc.), welding costs, production plan efficiency etc. related to changes in economy environment during production process. According to performed calculation, using IMPROVE modules, ULJ and UZ concluded that designs close to the minimum weight design have significantly better robustness measure related to production cost then designs close to the minimum production cost.

Problem of life-cycle cost is relevant to the ship owner. During the RoPax life-cycle, economic situation (price of fuel, RFR, etc.) is changing and accordingly the ship owner costs and revenues will oscillate. The calculation was performed to find designs that are less sensitive to those changes. Acquired results for RoPax are somewhat similar to the results of robustness analysis for production cost in a sense that designs with minimum obtained weight also have the highest robustness of LCC.

Panel safety analysis was performed to check the robust designs identification. Robustness measures (Taguchi, Suh), proved more efficient than calculation of Probability of success which requires time consuming CALREL (reliability based) runs for given uncontrollable load combinations. These findings were used in formulation of RoPax safety measures.
Conclusion

Challenging goals for RoPax application case, as defined at the beginning of the IMPROVE project, have been fully achieved during this project. Ship-owner profit has been significantly increased due to reduction in fuel consumption (better propulsion and ship hull form, reduced weight, etc.), increase in payload (increased parking area). It is also very important to acknowledge that reduction of fuel consumption has significantly reduced CO\textsubscript{2} emission, thus increasing environmental friendliness and also ensuring that legal requirements related to the pollution would be easier satisfied in the future.

One of the major drivers of those achievements is a novel design methodology that has closely joined two collaborating design systems (general ship design and structural design) as well as basic stakeholders (Owner, Yard, Designers, Regulatory institutions) through formulation of Decision Support Problem for rational decision making. It was successfully tested in the interactive work with stakeholders, revealing their subjective preferences in the OCTOPUS DeView graphic environment and enabling quality decisions. It was found out that the competence of structural subsystem designers is to generate Pareto frontier of non-dominated structural designs. It is then used for higher level decision making multiplying benefits from subsystem gains.

Developed methodology gives EU Yards and Owners a possibility to select competitive design solutions by following the basic IMPROVE paradigm: better ship for the Yard production and more profitable ship for Owner regarding maintenance and operational aspects within Life Cycle Costs. Presented modern RoPax design and its KPI’s were calculated to prove it, as well as to prove the methodology that was driving RoPax design process.
Dissemination and exploitation (use)

All details are given in deliverables regarding Exploitation and Dissemination plans.

Several dissemination activities were performed during the project.

Final workshop of IMPROVE Project (Dubrovnik, Croatia from 17-18.09.2009):

- “RoPax Carrier Ship Owner requirements, markets and future trends”, Dario Bocchetti.
- “New innovative RoPax vessel”, D. Dundara et al.
- “RoPax- Structural design aspects”, V. Zanic et al.

Several conference papers were generated related to WP7:


Further exploitation of results:

- Use of the New RoPax (product) – ULJANI K will used the developed concept for the new projects
- IMPROVE User Group. Use for the new optimisation tools using the IMPROVE User platform, by the IMPROVE partners but also by new partners. An User Group Agreement has been established and signed by the partners (see also the new WP10 on BAL.PM)
**WP8 : CHEMICAL TANKER CONCEPT (Lead by SSN, TKK)**

Work package 8 presents the IMPROVEd chemical tanker concept. This concept is based on the expertise of the Szczecin Shipyard (SSN) with respect to chemical and product tankers. Their choices of improvements are outlined. The purpose of the IMPROVEd design is to lower the amount of duplex steel due to its significant influence on the total cost. The drawings of the initial and improved vessel are presented.

**The improved design**

Based on the yards expertise the main particulars of IMPROVE project are as follows:

- Length o.a. - 182.88 m,
- Length b.p. - 175.25 m,
- Breadth - 32.20 m,
- Depth - 15.00 m,
- Draught - 11.10 m,
- Deadweight - 40 000 mt,
- Cargo tanks capacity / total / - 44 000 m3,
- Number of cargo tanks - 30,
- Capacity of Duplex cargo tanks - 26 800 m3,
- Number of Duplex cargo tanks - 18,
- Service speed - 15.0 kn.

The main frame is given in Figure 1 and the arrangement of the vessel is shown in Figure 2.

![Figure 1. Main frame of the IMPROVE tanker](image-url)
Deliverable 8.1 describes the improvements are presented and discussed from the shipyards point of view. As an example some technical drawings are given. This improved shipyard design serves as a basis for the optimization of the structure in the EU-IMPROVE project.

This new tanker design served as the initial layout for the scantlings optimization using the novel IMPROVE modules for the assessment of design quality in the early design stage. Furthermore, the process of design selection according to the assessed preferences of ship design’s stakeholders, namely the shipowner and shipyard, is presented. Quality of the selected design alternatives is also analysed through the assessment of ultimate strength of hull girder, strength assessment of structural details, etc. A very important feature of WP8 is the sensitivity analysis for the discover and established of the general design drivers for such a type of chemical tanker, aiming to give best-practice guidance for future chemical tanker designs.

According to preliminary shipyard and ship owner opinions the cost, weight and fatigue life was included as objectives into structural optimization. The knowledge of the relationship between these different objectives was required to obtain reliable techno-economical evaluation of tanker structures, see Figure 3.
The constraints of the optimization were strength criteria and production requirements according to shipyard specification. Production requirements were considered as minimum and maximum values of the design variable ranges. The tanker structure included totally 22 different stiffened panels, which each have three design variables: plate thickness of a panel, number of stiffeners of panels and stiffener type. In the case of corrugated panel, panel 23, the stiffener was not applied, but shape and height (H) of corrugations was varied. The type of this structure was a corrugated bulkhead without stiffener.

The loads are specified according to the Shipyard loading manual and classification rules (DNV Classification notes No.30.7). This specification included the quasi-static- and the fatigue strength evaluation. The pressure includes the loads due to wave-induced external pressure and the deck load due to ship motions. At first the longitudinal structural members are optimised with the ConStruct tool using the CB-method. The IMPROVE Fatigue module, see Deliverable 3.3, is used to assess the fatigue strength of the structural details corresponding to notch stresses are specified by S-N curve. The ultimate strength of the final selected IMPROVE design alternative according to the structural optimisation is investigated using non-linear coupled beam method.

The ConStruct tool aim is to assess the longitudinal strength of hull girder, and thus, it includes only vertical bending for the response evaluation of the hull girder. Therefore, torsion and horizontal bending were neglected in the present analysis.

The construct optimisation results indicate that the relation between the fatigue life and cost are almost linear. For design alternative with 30 years fatigue life, the ultimate strength is also clearly increased compared to minimum weight design, but in this case the cost and weight are also increased, from 10% to 15%, see Figure 4.

The ultimate strength of the selected candidates was evaluated with non-linear CB methods. The results of the analysis are given in Figure 5, and the values of ultimate strength are compared to design moment in hogging and sagging condition. In the case of minimum weight and cost design the margin of ultimate strength to design moment is about two. For design alternative with 30 years fatigue life, the ultimate strength is increased having value 2.5.
Structural optimizations of corrugated transverse bulkhead (TBHD), made of duplex steel (5000+6000 €/tons), were performed by UZ. Two types of corrugation were investigated: (a) horizontal (HC) and (b) vertical (VC). In that respect two FE model with different types of corrugations were optimized and compared to enable rational selection. Model fidelity was on the preliminary design phase level. Optimizations of topologically different variants required development of two partial 2-hold 3D FE MAESTRO models of the chemical tanker (CT) cargo area. Bulkheads plating was represented by the standard Q4 shell elements. Geometry of the corrugation was fixed by SSN. Plate thicknesses of corrugation zones were used as design variables. Structural design constrains based on yield and buckling, in-built in MAESTRO, were used and their safety factors were adjusted according to the BV Rules. Twelve load cases were formed from two critical loading conditions (alternate and chessboard loading) using BV load case requirements (upright “a”, “b” and inclined “d” case).

Optimizations were preformed using MAESTRO dual SLP optimizer. Comparison of weight optimal solutions of both types of corrugations shows that horizontal corrugations (HC) is approximately 15% lighter then vertical (VC) and has been chosen as the preferable one. Final optimization history regarding mass changes, including the scantling standardization cycle no. 8, is presented in Figure 7 for selected HC variant.

Figure 5. Results of the ultimate strength analysis compared to design loads

Figure 6. Two hold FE model with horizontal corrugation( HC) and vertical corrugation (VC)

Figure 7. Optimization history of selected horizontal corrugated TBHDs
The total weight of strakes in optimization module was decreased successfully by 7 % (25 tons in total) compared to the prescribed prototype design with all structural constraints being satisfied. Using the new concept design tool for topology optimization (WP3, developed by UZ), further investigations may lead to even greater savings.

From the created set of Pareto optimal alternatives, we need to select now one design alternative as a recommendation for stakeholders as the best compromise for their preferences. The multi-stakeholder decision-making methodology is applied for this purpose. In its extensive form, the methodology combines data on stakeholder preferences, obtained through semi-structured interviews with stakeholders, with formal assessment of stakeholder utility functions. Once the stakeholder utility functions are established, utilities of Pareto optimal design alternatives are conflicted in the utility space. In the end, the alternative which is the best compromise for both stakeholders is identified using the concept of Competitive optimum. Stakeholder preferences towards generated design alternatives have been elicited through a series of action, most notably through the semi-structured interviews. However, prior to this, we identified the relevant design drivers for both stakeholders, e.g. minimize the mass of duplex steel, maximize fatigue life, etc. The extensive evaluation of these drivers and their measures, i.e. the Key Performance Indicators, had been performed in deliverables D2.1 and D2.2. These KPIs are the key for defining the formal preference of a stakeholder towards a design alternative. Instead of observing its descriptors, i.e. the design variables, stakeholders effectively observe design characteristics, and based on this performance determine their preference. After performing interviews and their transcription, a formal design framework was established through which stakeholder multi-attribute utility functions could be determined. These functions, in the end, serve as the basis for multi-stakeholder decision-making.

To validate the ConStruct pareto optimum result a detailed finite element analysis is carried out by MEC. The finite element model includes tanker structure with the length of 73.4 m. The structure is loaded with external water pressure, cargo pressure and boundary moments. In total six loading cases are analysed. Also accelerations are included where necessary by including them into gravity constants and calculating the equivalent pressure based on gravity. Loading set up is shown in Figure 8.

![Figure 8. Loading setup of the FE-model](image)

The finite element model is defined with the element size suitable also for ultimate strength estimation. In total 6 loading conditions are according to Bureau Veritas are analysed. An example of the resulting stresses is given in Figure 9.

![Figure 9. Von-Mises stress in the longitudinal bulkhead](image)
The optimised scantlings are validated with LBR-5 – an optimisation software developed by ANAST and DN&T – to study if LBR-5 constraints are violated or not. At first, the analysis is done with loads defined by ANAST and Bureau Veritas. In the second part the ConStruct loads are used. Furthermore, the IMPROVE a Life Cycle Cost (LCC) Module developed by NAME was used to estimates the life cycle cost in a simplified fashion. The module has been implemented into the LBR-5 software to be used as new objective function. As a result, this evaluation shows that the life cycle cost is not influenced significantly by the optimised structural design.

The regular and stochastic real sea analyses of the vessel are carried out using a 2D strip theory based numerical code. In general, the vessel is expected to exhibit good seakeeping characteristics as most of the worst response modal periods are either far off from the dominant wave periods of operational area or wave headings may be adjusted to avoid severe responses.

The calculations show that the IMPROVE Chemical Tanker satisfies the stability requirements of applicable rules and regulations.

The total weight reduction after the structural optimization is 10% compared to the initial shipyard design. This fact, besides the possibility to increase the fatigue life or the ultimate strength of the concept structure, clearly indicates the benefit of the optimization done in the EU-IMPROVE project. The general optimization is made with the ConStruct tool, which is however limited to the longitudinal structural members. Therefore, the transverse bulkhead optimization is carried out with MAESTRO. This results in a decrease in weight of the bulkhead of 5t compared to the prescribed prototype design with all structural constraints being satisfied. The total savings for five duplex made transverse bulkheads of about 25 t can be expected with cost benefit of up to 150 000 €, showing the rationale of preliminary design phase optimization procedure.

The 3D finite element stress analysis unveiled that the global strength of the structure is sufficient. However, the shear stresses at maximum shear force locations exceeding the limit value slightly. This is a result of the missing ConStruct capability to change the thickness of the corrugated bulkhead in horizontal direction. Therefore, the longitudinal bulkhead was optimised separately and therefore the shear stiffness of this bulkhead was reduced. Due to this the bulkhead carries less shear load than in case of ConStruct model. High local bending stresses are generated also in the crossing of transversal and longitudinal bulkheads. To reduce the stress the plate thickness can be increased in the bulkhead crossing only. Another option is to increase the stiffness of transversal bulkheads, resulting in a higher bending stiffness. However, these aspects are to be considered in the detail design stage. From a conceptual design stage of view, this IMPROVEd structure represents a significant improvement over the initial shipyard design.

As a result of the structural optimization and decision making process we can conclude the following:

a) If fatigue improvement is not important, then lightweight design is good, which is expected.

b) If fatigue is to be improved, and the owner is willing to pay 100k€ or 1M€ for 1 year of increase, than it would be rational to accept the design alternative 4 with the improvements of 6.7 years in fatigue life. Higher investments would prove to be too high for the owner.

c) In both cases when there is a desire to increase the fatigue life, it seems that the quality of the engineered design alternatives is not as good as with present design, meaning that considerable reservations from the stakeholders are possible to accept proposed solution.
WP9: LESSONS LEARNED, RECOMMENDATIONS, EXPLOITATION & DISSEMINATION (Lead by NAME)

Objectives

The WP9 objectives were the ones listed below:

- D9.1: Report of the Classification Society about the three new products and recommendations.
- D9.2: The public web site to be operational, effective, tested and open to public
- D9.3: Synthetic report showing the dissemination (papers, booklet, web site, …)
- D9.4: Synthetic report about the conclusions of the workshop (task 9.3)
- D9.5: Report about exploitation & recommendations to increase the EU competitiveness (in relation with the 3 PRODUCTS delivered by the IMPROVE RDMM approach).
- D9.6: Report on raising public participation and awareness (Task 9.2). The deliverable will list the actors beyond the IMPROVE partners that have been involved to help spread awareness and to explore the wider societal implications of the proposed work.

Short summary of achieved results

More analytically, the work performed as well as the results for the mentioned deliverables are presented herein.

D9.1: Report of the Classification Society about the three new products and recommendations.

During the third year of the project, Bureau Veritas performed the activities planned in Task 9.1, by providing assistance to WP6, WP7 and WP8. This assistance was provided as:

- Answering questions from these WPs, by email, phone call and by meeting some partners in BV Head Offices.
- Specifically for the LNG carrier (WP6), by conducting two sets of direct sloshing calculations (standard fillings and partial fillings) to deliver design loads.
- Preparation of deliverable D9.1, giving BV comments on the three ships designed in WP6, 7 and 8, and on the analysis performed and presented for these designs.

Two other activities have been conducted under Task 9.1:

- Benchmark sloshing calculations with OpenFOAM software against reference calculations performed with FLOW3D. This task has been added in agreement with the Project Coordinator.
- Participation to the final open workshop in Dubrovnik (3 BV representatives attended, 1 presentation on sloshing loads determination for the LNGC made) and preparation of the associated material.

More details can be provided in the relevant deliverables/reports of the related work packages.
D9.2: The public website to be operational, effective, tested and open to public

This deliverable was achieved through the operation of the IMPROVE project website available from two URL’s, that is:

- [http://www.anast-eu.ulg.ac.be](http://www.anast-eu.ulg.ac.be)
- [http://www.improve-project.eu](http://www.improve-project.eu)

The first URL was required to be used as rules within University of Liege require the coordinator to host the website within their own servers. The website continued to provide all current news and a library of any dissemination documents released by the project on its results and achievements. Also, to include any reports, deliverables and information deemed suitable by the project steering committee for public dissemination as downloads. The website includes in its content various items, among others:

- News items
- Press releases and announcements
- Newsletters
- Results generated by the project
- Information on project progress
- Papers presented about the project
- Articles on the project
- Information on partners including links
- Project events information
- Contacts information
- Email news subscription service

A sample of the operability of the public website is that it received more than 8,000 visits and 47,000 hits during the period from November 2008 to October 2009.

D9.3: Synthetic report showing the dissemination (papers, booklet, web site)

The dissemination activities for IMPROVE project were carried out by means of:

- Newsletters
- Press releases
- Paper publications in journals and conference proceedings
- The final project workshop
- External events
- European Research and Industrial Associations
- CORDIS (Community Research and Development Information Service) and
- European Commission Publications
In the following paragraphs, an indicative list with these events and actions is presented (the whole list would be too big to present in this report). More information can be found in the detailed dissemination report prepared by Wegemt and the relevant project partners involved.

- In October 2006 a Ship Structure Optimisation Workshop took place in Liege, Belgium
- In February 2007 a press release was presented
- In June 2007, a publication was made in a German newspaper about the project. Also in the same month, "Cordis Wire" published article RCN: 15115.
- In February 2008, all the major European Research and Industrial Associations were contacted to disseminate four scientific papers about the three end products.
- In April 2008, more papers were presented in the COMPIT conference in Liege, Belgium
- In October 2008, all the major European Research and Industrial Associations were contacted to inform them about the Dubrovnik final workshop the aim of raising participation interest from the industry.
- In March 2009, a press release was made regarding the project meeting in Galati, Romania.
- In May 2009, the RINA magazine of “The Naval Architect” published a 3 page article on IMPROVE and its progress on the design of a LNG carrier.
- In June 2009, another 3 page article on IMPROVE and its progress until that time was also published in the “The Naval Architect” magazine.
- In August 2009, an 11 page summary of Design Methods developed within IMPROVE framework was published in the 17th INTERNATIONAL SHIP AND OFFSHORE STRUCTURES CONGRESS that took place in Seoul, S. Korea.
- In September 2009, the Dubrovnik final workshop took place which was one of the major dissemination events of the project. A booklet with the workshop proceedings was published as well as a CD including the papers and presentations shown was created too.

**D9.4: Synthetic report about the conclusions of the workshop (Task 9.3)**

This Deliverable (D9.4) presents the synthetic report about the final workshop of IMPROVE project that was held under Task 9.3. Besides the conclusions of each Work Package (and of some larger Tasks) of all workshop papers (e.g. short summaries of presented results) contained in the Proceedings and CD of all presentations that were held, overall conclusions from the final Workshop session are also included in the Proceedings.

The workshop was organized by University of Zagreb (UZ) at the Centre for Advance Academic Studies in Dubrovnik, Croatia from 17-18 September 2009. All WP/Task leaders presented results of each WP. Presentations were roughly divided into two main groups:

- Advanced modules and tools developed, selected and integrated through the IMPROVE project. Also, presentations of WP2 to WP5 demonstrating the scope of the new design technologies.
- Design of three improved and competitive end-products using an integrated decision support system. Benefits achieved using IMPROVE shell and modules previously presented. Also, presentation of WP6+WP8 demonstrating the practical applicability of the new design technologies.

Two invited lectures were given from the most respectable persons in the field of ship structural design (Prof. O.F.Hughes) and general ship design (Prof. K. Levander) to contrast the global trends in the field and their relations with the IMPROVE achievements. The benefits that were generated through IMPROVE project are underlined in the conclusions together with the ideas, concepts and plans for the future work.
D9.5: Report about exploitation & recommendations to increase the EU competitiveness (in relation with the 3 PRODUCTS delivered by the IMPROVE RDMM approach)

The present report includes the exploitation results of IMPROVE project together with the suggestions on how to increase the EU competitiveness regarding the new three ship types/end-products, namely LNG, ROPAX and Chemical tanker ship. The exploitation of the results occurred (and will continue to occur in the future for certain aspects of this project) through various applications. Mostly through the exploitation by the three shipyards/members of the project of the innovative three ship types/end-products as well as the common group-user platform regarding the tools and techniques developed during this project. Also, by SME’s, spin-off companies and universities on practical applicability of advanced design techniques like:

- structural response analysis models,
- structural feasibility assessment models,
- maintenance models,
- concept design synthesis models,
- Preliminary design synthesis models.

Apart from the above, a common user group platform was created in order to provide for the continuation of the IMPROVE tools and their application. IMPROVE User Group: Use for the new optimisation tools using the IMPROVE User platform, by the IMPROVE partners but also by new partners. An User Group Agreement has been established and signed by the partners (see also the new WP10 on BAL.PM)

D9.6: Report on raising public participation and awareness (Task 9.2). The deliverable will list the actors beyond the IMPROVE partners that have been involved to help spread awareness and to explore the wider societal implications of the proposed work

For IMPROVE project to be fully successful in terms of dissemination and exploitation of its processes and results, various partners outside of the project consortium have to be informed and get involved in raising the public participation and awareness. In this respect, this report shows the steps taken towards the implementation of this activity. This was achieved through various actions during the three years of the IMPROVE project. These are listed below:

- Project public website (http://www.improve-project.eu)
- Press releases
- Scientific Publications
- Scientific Conferences and Exhibitions
- European Research and Industrial Associations
- CORDIS (Community Research and Development Information Service)
- European Commission Publications
Dissemination and use

IMPROVE Project Public Deliverables

The final Conference of project IMPROVE was successfully completed in Dubrovnik, Croatia during September 17, 18, and 19 of 2009. You can download the conference proceedings from the links below:

Conference Proceedings
- Dubrovnik final workshop - Vol_I_Conference_Papers.pdf
- Dubrovnik final workshop - Vol_II_PowerPoint_Presentations.pdf

http://www.anast-eu.ulg.ac.be/proceedings.html

Publishable results of the Final results for using and disseminating the knowledge (see format in Appendix 1).

Appendix 1 includes a detailed list of all the dissemination activities performed by WEGEMT and the IMPROVE consortium during the project including what has been published as well as when and where it was published. WEGEMT also completed the following dissemination deliverables during the final period of the project:

<table>
<thead>
<tr>
<th>Event/Action</th>
<th>Dissemination Level</th>
<th>Location</th>
<th>Date</th>
<th>Partners Involved</th>
<th>Partners Involved</th>
<th>Actions from Partners</th>
<th>Dissemination material used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Publish Information Naval Architect</td>
<td>European</td>
<td>Q1 2009</td>
<td>WEGEMT, AKER, ANAST, EXMAR</td>
<td>WEGEMT</td>
<td>Contact The Naval Architect to publish an article for the LNG product.</td>
<td>Publishable information developed by the consortium regarding the LNG carrier.</td>
<td></td>
</tr>
<tr>
<td>Publish Information Naval Architect</td>
<td>European</td>
<td>Q2 2009</td>
<td>WEGEMT, ULJ, UZ, GRIM</td>
<td>WEGEMT</td>
<td>Contact The Naval Architect to publish an article for the ROPAX product.</td>
<td>Publishable information developed by the consortium regarding the ROPAX carrier.</td>
<td></td>
</tr>
<tr>
<td>Deliverable D9.3</td>
<td>Local</td>
<td>Q3 2009</td>
<td>WEGEMT &amp; Consortium</td>
<td>WEGEMT</td>
<td>Synthetic report on all project dissemination activities carried out during the project</td>
<td>Dissemination plan final version. Report was published on website.</td>
<td></td>
</tr>
<tr>
<td>Deliverable D6.3</td>
<td>European</td>
<td>Q3 2009</td>
<td>WEGEMT, Consortium</td>
<td>WEGEMT, Consortium</td>
<td>A short version of the detailed report on new innovative LNG product (D6.1).</td>
<td>LNG final report (D6.1). Report was published through the website.</td>
<td></td>
</tr>
<tr>
<td>Deliverable D7.3</td>
<td>European</td>
<td>Q3 2009</td>
<td>WEGEMT, Consortium</td>
<td>WEGEMT, Consortium</td>
<td>A short version of the detailed report on new innovative ROPAX product (D7.1).</td>
<td>ROPAX final report (D7.1). Report was published on the website.</td>
<td></td>
</tr>
</tbody>
</table>

The project deliverables for dissemination activities relate to a series of public reports the details of which are listed in Appendix 2.
## Appendix 1: IMPROVE Dissemination Actions

<table>
<thead>
<tr>
<th>Event/Action</th>
<th>Dissemination level</th>
<th>Location</th>
<th>Date</th>
<th>Partners involved</th>
<th>Actions from Partners</th>
<th>Dissemination material used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship Structure Optimisation Workshop</td>
<td>European</td>
<td>Liege, Belgium</td>
<td>4th Oct 2006</td>
<td>All</td>
<td>Presentations by ANAST, CMT, HUT, UZ, UL, SSN, NAME, AKER</td>
<td>Made available on the IMPROVE public website</td>
</tr>
<tr>
<td>Press Release</td>
<td>European</td>
<td></td>
<td>Feb 2007</td>
<td>All</td>
<td>Translate and disseminate</td>
<td>Made available on the IMPROVE public website</td>
</tr>
<tr>
<td>Dissemination by CMT</td>
<td>Local</td>
<td>Germany</td>
<td>June 2007</td>
<td>ALL</td>
<td>CMT refers to IMPROVE project aim and objectives</td>
<td>Publish on a German Newspaper</td>
</tr>
<tr>
<td>Internal Call for public information/results from the IMPROVE partners</td>
<td>Local</td>
<td></td>
<td>Sep 2007</td>
<td>ALL</td>
<td>Send any publishable information to WEGEMT</td>
<td>Update on the public website</td>
</tr>
<tr>
<td>Dissemination of information/ Press release</td>
<td>European</td>
<td></td>
<td>Sep 2007</td>
<td>WEGEMT</td>
<td>Dissemination</td>
<td>Disseminated to the ECMAR, ECSA, ESPO, EUROGIF, CESA, CORDIS, RTD INFO, Euro-abstracts, RTD Publications, Enterprise Europe networks</td>
</tr>
<tr>
<td>Activation of CORDIS WIRE Account</td>
<td>European</td>
<td></td>
<td>Sep 2007</td>
<td>WEGEMT</td>
<td>Creation of an account to disseminate information through CORDIS WIRE</td>
<td>Made available on the IMPROVE public website – request pending for approval</td>
</tr>
<tr>
<td>Dissemination of initial chemical carrier particulars</td>
<td>European</td>
<td></td>
<td>Sep 2007</td>
<td>SSN</td>
<td>Work mainly performed by SSN</td>
<td>Made available on the IMPROVE website</td>
</tr>
<tr>
<td>Dissemination of initial ROPAX carrier particulars</td>
<td>European</td>
<td></td>
<td>Sep 2007</td>
<td>ULJANIK</td>
<td>Work mainly performed by ULJANIK</td>
<td>Made available on the IMPROVE website</td>
</tr>
<tr>
<td>Dissemination of initial LNG carrier particulars</td>
<td>European</td>
<td></td>
<td>Sep 2007</td>
<td>AKER Yards</td>
<td>Work mainly performed by AKER Yards</td>
<td>Made available on the IMPROVE website</td>
</tr>
<tr>
<td>Publish Information Cordis Wire RCN: 15115</td>
<td>European</td>
<td></td>
<td>Sep 2007</td>
<td>WEGEMT</td>
<td>Cordis Wire published article RCN: 15115</td>
<td>Article disseminated to all the partners and publicly available over the internet.</td>
</tr>
<tr>
<td>Publish Information Cordis News RCN: 28315</td>
<td>European</td>
<td></td>
<td>Sep 2007</td>
<td>WEGEMT, ULG</td>
<td>Cordis News after a telephone interview with George Smyrnakis and Philippe Rigo, published article RCN: 28315 on the 10th of September</td>
<td>Article disseminated to all the partners and publicly available over the internet.</td>
</tr>
<tr>
<td>Publish Information Cordis Wire RCN: 28315</td>
<td>European</td>
<td></td>
<td>Nov 2007</td>
<td>WEGEMT</td>
<td>Cordis Wire published article RCN: 28315</td>
<td>Article disseminated to all the partners and publicly available over the internet.</td>
</tr>
<tr>
<td>Dissemination of Information to European Research and Industrial Associations – Publishable Results</td>
<td>European</td>
<td></td>
<td>Feb 2008</td>
<td>WEGEMT</td>
<td>Contacted all the major European Research and Industrial Associations to disseminate publishable results.</td>
<td>Four scientific papers (one for the project in general and one for the LNG, RoPax and Chemical Tanker products respectively.</td>
</tr>
<tr>
<td>Develop New Logo and Update the public website</td>
<td>Local</td>
<td></td>
<td>Feb 2008</td>
<td>WEGEMT</td>
<td>Developed a new Logo for the IMPROVE project</td>
<td>New logo image</td>
</tr>
<tr>
<td>Event/Action</td>
<td>Dissemination level</td>
<td>Location</td>
<td>Date</td>
<td>Partners involved</td>
<td>Actions from Partners</td>
<td>Dissemination material used</td>
</tr>
<tr>
<td>-------------</td>
<td>---------------------</td>
<td>----------</td>
<td>------------</td>
<td>-------------------</td>
<td>------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Publish Information Naval Architect</td>
<td>European</td>
<td>Apr 2008</td>
<td>WEGEMT</td>
<td>The Naval Architect published a 3 page article on IMPROVE and its progress so far.</td>
<td>Article disseminated to all Europe with the Naval Architect Journal.</td>
<td></td>
</tr>
<tr>
<td>Dissemination to InfoDBias'08 &amp; ICT International Conference SEDEF Kalkavan Shipyard</td>
<td>International</td>
<td>Istanbul, Turkey</td>
<td>16-18 June 2008</td>
<td>All</td>
<td>Published IMPROVE results and presented those results in the conference.</td>
<td>1 scientific paper &quot;IMPROVE - Design of Improved and Competitive Products&quot; considering all 3 ship designs.</td>
</tr>
<tr>
<td>Publish Information Naval Architect</td>
<td>European</td>
<td>July 2008</td>
<td>WEGEMT</td>
<td>The Naval Architect published a 6 page article on COMPIT mentioning IMPROVE as well.</td>
<td>Article disseminated to all Europe with the Naval Architect Journal.</td>
<td></td>
</tr>
<tr>
<td>Dissemination of Information to European Research and Industrial Associations – Publishable Results</td>
<td>European</td>
<td>Oct 2008</td>
<td>WEGEMT</td>
<td>Contacted all the major European Research and Industrial Associations to disseminate publishable results.</td>
<td>Informed them about the Dubrovnik final event with the aim of raising participation interest from the industry.</td>
<td></td>
</tr>
<tr>
<td>Dissemination of information/Press release</td>
<td>Local</td>
<td>March 2009</td>
<td>WEGEMT</td>
<td>Meeting press release (in Romanian)</td>
<td>Meeting press release</td>
<td></td>
</tr>
<tr>
<td>Dissemination to 17th INTERNATIONAL SHIP AND OFFSHORE STRUCTURES CONGRESS</td>
<td>International</td>
<td>SEOUL, KOREA</td>
<td>16-21 August 2009</td>
<td>All</td>
<td>Volume 1 includes 11 pages as a summary of the findings of IMPROVE project</td>
<td>A summary of Design Methods developed within IMPROVE framework were disseminated.</td>
</tr>
<tr>
<td>Publish Information Naval Architect</td>
<td>European</td>
<td>May 2009</td>
<td>WEGEMT</td>
<td>The Naval Architect published a 3 page article on IMPROVE and its progress on the design of a LNG carrier.</td>
<td>Article disseminated to all Europe with the Naval Architect Journal.</td>
<td></td>
</tr>
<tr>
<td>Publish Information Naval Architect</td>
<td>European</td>
<td>June 2009</td>
<td>WEGEMT</td>
<td>The Naval Architect published a 3 page article on IMPROVE and its progress so far.</td>
<td>Article disseminated to all Europe with the Naval Architect Journal.</td>
<td></td>
</tr>
<tr>
<td>D 6.3, 7.3, 8.3</td>
<td>European</td>
<td>June - Sept. 2009</td>
<td>WEGEMT</td>
<td>To be used for dissemination</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scientific paper on the main outcomes of IMPROVE project</td>
<td>European</td>
<td>Dubrovnik, Croatia</td>
<td>Sep 2009</td>
<td>ANAST, Univ. of Liège</td>
<td>Published and presented he main outcomes of IMPROVE project.</td>
<td>The main outcomes of IMPROVE project.</td>
</tr>
</tbody>
</table>
## Appendix 2 Dissemination Deliverables

<table>
<thead>
<tr>
<th>Deliverable.</th>
<th>Deliverable name</th>
<th>WP No.</th>
<th>Lead Partner</th>
<th>Delivery Month</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1.1</td>
<td>Dissemination Plan (in collaboration with WP9)</td>
<td>1</td>
<td>WEGEMT</td>
<td>2</td>
</tr>
<tr>
<td>D6.3</td>
<td>A short version of the detailed report on new innovative LNG product (D6.1) will be realized for dissemination version (in collaboration between the WP leader, and WEGEMT)</td>
<td>6</td>
<td>WEGEMT</td>
<td>36</td>
</tr>
<tr>
<td>D7.3</td>
<td>A short version of the detailed report on new innovative ROPAX product (D7.1) will be realized for dissemination version (in collaboration between the WP leader, and WEGEMT)</td>
<td>7</td>
<td>WEGEMT</td>
<td>36</td>
</tr>
<tr>
<td>D8.3</td>
<td>A short version of the detailed report on new innovative TANKER product (D8.1) will be realized for dissemination version (in collaboration between the WP leader, and WEGEMT)</td>
<td>8</td>
<td>WEGEMT</td>
<td>36</td>
</tr>
<tr>
<td>D9.2</td>
<td>Public Website – tested and open to public</td>
<td>9.2</td>
<td>WEGEMT</td>
<td>3</td>
</tr>
<tr>
<td>D9.3</td>
<td>Synthetic report on all project dissemination activities carried out during the project</td>
<td>9.2</td>
<td>WEGEMT</td>
<td>36</td>
</tr>
<tr>
<td>D9.4</td>
<td>Synthetic report about the conclusions of the workshop to present the final results of the project (task 9.3)</td>
<td>9.3</td>
<td>UZ</td>
<td>36</td>
</tr>
<tr>
<td>D9.6</td>
<td>Report on raising public participation and awareness</td>
<td>9.4</td>
<td>NAME</td>
<td>36</td>
</tr>
</tbody>
</table>