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Cost Effectiveness and Complexity Assessment in Ship Design within a *Concurrent Engineering* and *"Design for X"* Framework

Thèse de Doctorat présentée en vue de l'obtention du grade de

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Chapter 5

Conclusion and recommendations

This PhD thesis concludes with an evaluation of the proposed prototypes related to cost effectiveness and complexity assessment in ship design and a discussion about the obtained results with regards to performance, their wider implication and their future development.

5.1 Introduction

After 20 years of high activity and good earnings, the shipbuilding and shipping industry are today facing the consequences of a of world economy recession and the financial crisis. The above developments are expected to lead to a consolidation of the maritime industry and increase pressure towards sustainable development and competitive products and services.

The ability of a shipyard to compete effectively on the increasingly competitive global market is influenced to a large extent by the cost as well as the quality of its ships. A wider understanding of the methods and problems of cost assessment will result in clearer specifications, more economical and prompt performance, and a consequent saving of time, effort, and money for both the operators of ships and the shipyards that build and repair them.

The author has provided some valuable insights into the mechanisms that have been established in shipyards for the real time control of cost process trends. That will allow the designers to take corrective actions in sufficient time to actually improve or overcome projected unfavourable performance.

5.2 Key findings and achievements

The implications of the research for further understanding of the research problem are explored in this section.

5.2.1 Key findings and achievements

Every ship owner wants a cost-effective ship. But what does this mean? In many respects the interpretation is influenced by an individual's interests and objectives.

- Is it the lowest construction cost of a ship structure that meets the initial requirements?

- Is it the design with the lowest operating and maintenance costs?
- Is it the ship in which users are most productive?
- Is it the ship that offers the greatest return on investment?

While an economically efficient ship is likely to have one or more of these attributes, it is impossible to summarize its cost-effectiveness by a single parameter. Determining true cost-effectiveness requires a life-cycle perspective where all the costs and benefits of a given project are evaluated and compared over its economic life. In economic terms, a ship design is deemed to be cost-effective if it results in benefits equal to those of alternative designs and has lower life-cycle costs.

These grounds provide the elements to reply to the research problem developed in this PhD thesis.

Nowadays, the current estimating methods do not take into account life cycle costs. This is major impediment when making trade off studies between different designs. Operating costs over the life of a vessel can amount to over 33% of the total life cycle costs. Thus a cost assessment system that only focuses on initial acquisition costs without consideration of life cycle costs is inherently flawed. It is important and necessary that designers would be able to conduct both reliable cost benefit analysis and design trade-offs at the early stage of ship development; and that managers ensure that the initial design for X requirements are realistic and can be met in an efficient and cost effective manor.

Considering the life cycle cost of a product means looking at all the phases of product life and analysing the cost effective and cost sensitive elements.

5.2.2 Main contributions

This section describes the specific outcomes of the research developed in this PhD thesis and describes their importance.

Systematic and objective analysis of cost effectiveness and complexity in ship design are important for several reasons. First, it helps design engineers to develop a better understanding of various aspects of complexity and thereby evolve toward simpler design solutions. Second, it enables design automation tools to systematically evaluate different design alternatives based on their inherent complexities.

As the complexity of a ship increases, the life cycle costs of the ship will typically increase as well. Also, a complex ship is commonly the result of a lengthy and complicated, and therefore, costly, design process. Furthermore, because of the interconnection of various components and sub-assemblies in a complex ship, the engineering change process is often a complex and cumbersome task. Next, the manufacturing of a complex ship entails adaptation of complex process plans and sophisticated manufacturing tools and technologies. Additionally, a complex ship results in a complex supply chain which introduces various managerial and logistic problems. Finally, serviceability in a complex ship is a challenging issue as well, due to the existence of numerous failure modes with multiple effects having varying levels of predictability. Therefore, it is beneficial to objectively measure the cost effectiveness and complexity of ship design and systematically reduce their inessential details.

Various cost effectiveness and complexity estimation methods intended to be used by ship designers have been presented in this PhD study. Two types of complementary measures have been investigated: the *cost assessment* and the *complexity assessment*. A feature based costing, a complexity metric, two straightening cost assessment modules, a statistical cost evaluation and a cost assessment through production simulation have been described, and the results have been extensively discussed.

These methodologies will provide :

- an aid for designers in order to compare various design alternatives on the basis of cost effectiveness and complexity,
- an environment which supports strategic decisions made as early as possible to make ship design more cost-effective
- a monitoring of the sources of complexity and cost which helps to determine the consequences of decision making early on during the design process
- a spotting of the sources of complexity and cost which helps to reduce "design effort", that is, shortening production time and cutting project costs.

Fundamentally, these methods will provide design engineers with objective, quantifiable measures of cost and complexity, aiding rational design decision making. The measures proposed in this PhD are objective as they are dependent not on an engineer's interpretation of information, but rather on the model generated to represent the ship design. This objectivity is essential to using the complexity and cost measures in design automation systems. A prospective computer-aided system should also be capable of assisting innovative design. It should not just provide a limited series of conventional solutions.

To this end, design engineers should be provided with well-defined and unambiguous metrics for the measurement of different types of cost effectiveness and complexities in engineered artefacts. Such metrics aid designers and design automation tools in objective and quantitative comparisons of alternative design solutions, cost estimation, as well as design optimisation.

5.3 SWOT analysis

This final section is written to help PhD and other researchers in the selection of future researches. Tab. 5.1 shows the SWOT analysis of this PhD thesis, where Strength, Weaknesses, Opportunities and Threats (SWOT) are presented. This table discusses and also outlines limitations that became apparent during the progress of the research.

<table>
<tr><th></th><th>Helpful
to achieve the objectives</th><th>Harmful
to achieve the objectives</th></tr>
<tr><td rowspan="2">Internal Origine
Attributes of the project</td><td>Strengths</td><td>Weaknesses</td></tr>
<tr><td>This study provides some innovative solutions for cost and complexity assessment during ship design to enhance the "design for X" concept.
The study places the developments in a holistic ship design optimisation strategy where all conception and design objectives are considered simultaneously.
The real-time evaluation of design complexity metrics which requires less computing time than the cost assessment is a new concept.
An optimized fuzzy straightening cost metric has been introduced. In parallel, the limitation of the neural network analysis and production simulation to handle innovative design or to manage design optimisation has been highlighted.</td><td>It is difficult to model some design criteria such as safety with the life-cycle cost.
The research study has been confined to a ship's structure (i.e. mainly steel parts and not outfitting).
The applications have been mainly focused on labour cost and complexity assessment (i.e. not on material cost).
The majority of the developments have been applied only to large passenger ships.</td></tr>
<tr><td rowspan="2">External Origine
Attributes of the environment</td><td>Opportunities</td><td>Threats</td></tr>
<tr><td>The maintenance part of the life-cycle cost should be investigated more deeply; it requires that the ship will be considered as a whole i.e. not only the steel structure.
This research may ultimately lead to the implementation of the cost and complexity assessment in a commercial CAD/CAM tool for ship design.
This research on holistic ship design optimisation may be used as an education and training guide for industry.</td><td>The availability of historical data for small shipyards is often compromised; without them it will be difficult to apply the developed tool.
If the maintenance cost rises rapidly in the near future compared to the initial cost, current development becomes minor.</td></tr>
</table>

Table 5.1: SWOT analysis of the PhD thesis

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Glossary

Notation	Description
2D	Two Dimensions
3D	Three Dimensions
ANAST	Architecture Navale et Analyse des Systèmes de Transport
ANN	Artificial Neural Networks
AOD	Assembly-Oriented Design
ARGENCO	Département d'Architecture, Géologie, Environnement et Constructions
CAC	Computer Aided Costing
CAD	Computer Aided Design
CAD	Computer aided design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CAM	Computer aided manufacturing
CAPP	Computer Aided Process Planning
CBR	Case Based Reasoning
CE	Concurrent Engineering
CEF	Cost Estimate Formulae is a simple mathematical relationship, connecting the cost of a product or an activity to a limited number of technical parameters specifying the product
CER	Cost Estimating Relationship is a simple mathematical relationship, connecting the cost of a product or an activity to a limited number of technical parameters specifying the product
CESA	Community of European Shipyard Associations
CFD	Computational Fluid Dynamics

Notation	Description
CGT	Compensated Gross Tonnage (CGT) is calculated by multiplying the tonnage of a ship by a coefficient, which is determined according to type and size of a particular ship. CGT is used as an indicator of volume of work that is necessary to build a given ship. The Compensated Gross Tonnage of a ship is given by the following equation where a and b depend only on the type of ship and GT is the Gross Tonnage: $CGT = a \times GT^b$
CGT	Compensated Gross Tonnage
CIM	Computer Integrated Manufacturing
DA	Design Alternatives
DB	Database
DBMS	DataBase Management System
DES	Discrete Event Simulation
DFA	Design For Assembly
DFE	Design For Environment
DFM	Design For Maintenance
DFM	Design For Manufacturing
DFP	Design For Production
DFR	Design For Robustness
DFS	Design For Safety
DFSP	Design For Simplicity
DFSS	Design For Six Sigma
DFX	Design For X
DM	Data Mining
DMADV	Six Sigma Methodology – Define, Measure, Analyse, Design, Verify
DMAIC	Six Sigma Methodology – Define, Measure, Analyse, Improve, Control
DPMO	Defective Parts Per Million Opportunities
DT	Decision Trees
DTC	Design To Cost
DWT	DeadWeight Tonnage (DWT) is a measure of how much mass or weight of cargo or burden a ship can safely carry. Deadweight tonnage was historically expressed in long tons but is now largely replaced internationally by tonnes. Deadweight tonnage at any given time is defined as the sum of the weights or masses of cargo, fuel, fresh water, ballast water, provisions, passengers and crew.
ERD	Entity Relationship Diagram
ERP	Enterprise Resource Planning

Notation	**Description**
FBC	Feature-Based Costing
FEM	Finite Element Modelling
FLM	Fuzzy Logic Method
FSA	Faculté des Sciences Appliquées
GA	General Arrangement
GT	Gross Tonnage (GT) is a unit less index related to a ships overall internal volume. GT is calculated based on the moulded volume of all enclosed spaces of the ship (V) and is used to determine things such as a ships manning regulations, safety rules, registration fees and port dues. The Gross Tonnage of a ship is given by the following equation: $GT = V \times (0.2 + 0.02 \times \log_{10} V)$
GTech	Group Technology
GUI	Graphical User Interface
HVAC	Heating, Ventilation and Air-Conditioning
HVSA	Hamburgische Schiffbau-Versuchsanstalt
IACS	International Association of Classification Societies
IM	Intuitive Method
IMO	International Maritime Organisation
IMPROVE	European STREP Project entitled: Design of Improved and Competitive Products Using an Integrated Decision Support System
InterSHIP	European IP Project entitled: Integrated Collaborative Design and Production of Cruise Vessels, Passenger Ships and RoPax
IP	European Integrated Project
ISO	International Organisation for Standardisation
IT	Information Technology
KSA	Korean Shipbuilders Association
LBR5	French acronym of Stiffened PanelsSoftware, version 5.0
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCP	Life Cycle Performance

Notation	Description
Lean manufacturing	Lean manufacturing which is often known simply as Lean, is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination.
Lean production	see *Lean manufacturing*
MARIN	Maritime Research Institute Netherlands
MARPOL	International Convention for the Prevention of Pollution from Ships
MARSTRUCT	European Project entitled: Network of Excellence in Maritime Structures
MCA	Multiple Criteria Analysis
MCDA	Multiple Criteria Decision Aid
MCDM	Multiple Criteria Decision Making
MHI	Mitsubishi Heavy Industries
MSC	Maritime Safety Committee
NAPA	Software Solutions for Design and Operation of Ships
NNM	Neural Networks Method
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
PCA	Principal Components Analysis
PDM	Product Data Management
PM	Parametric Method
PROMETHEE	Preference Ranking Organization METHod for Enrichment Evaluations
PWBS	Product oriented Work Breakdown Structure
RBD	Risk Based Design
Ro-Ro	Roll-On/Roll-Off
SAJ	Shipbuilders Association of Japan
SES	Surface Effect Ship
SOLAS	international convention for Safety Of Life At Sea
SPM	Smart Product Model
STREP	Specific Targeted Research Projects
SWATH	Small Waterplane Area Twin Hull
SWBS	Ship Work Breakdown Structure
SWOT	Strengths, Weaknesses, Opportunities, and Threats

Notation	Description
TLU+C	Secteur – Transport, Logistique, Urbanisme, Conception
TRIBON	Integrated Design, Production and Life-cycle Management Solutions for Marine Industry
ULG	Université de Liège
VIRTUE	European project entitled: *The Virtual Tank Utility in Europe*
VISION	European Project entitled: Network of Excellence of Visionary Concepts for Vessels and Floating Structures
VLCC	Very Large Container Carrier
VM	Virtual Manufacturing
WWI	World War I
WWII	World War II

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Appendix A

Multicriteria analysis

This appendix is partialy based on the following bibliography reference [BM92, BM03, BM05].

A.1 Introduction

Most of the industrial or economical decision problems are multicriteria. Nobody buys a product on base of the price only (financial criterion). Obviously people always consider several criteria such as the cost, the comfort, the quality, the performance, the time to delivery, the prestige, etc. As there is no product optimising all the criteria at the same time, a compromise solution should be selected. Most decision problems have such a multicriteria nature. On the other hand nobody reacts in the same way. The selection is submitted to each individual's personal taste. Everybody allocates a different set of weights to the criteria. The solution of a multicriteria problem depends not only on the basic data included in the evaluation table but also on the decision-maker himself. There is not absolute best solution! The best compromise solution also depends on the individual preferences of each decision-maker

The problem of the selection or the ranking of alternatives submitted to a multicriteria evaluation is not an easy problem. Neither economically nor mathematically! Usually there is no optimal solution; no alternative is the best one on each criterion. A better quality implies a higher price. The criteria are conflicting. Compromise solutions have to be considered.

In this appendix we give, on basis of a short example, an overview of the PROMETHEE-GAIA methodology for treating multicriteria problems. This methodology is known as one of the most efficient but also one of the easiest to use.

A.2 Multicriteria Problems

Let us consider the following multicriteria problem:

$$\max\{g_1(a), g_2(a), \ldots, g_j(a), \ldots, g_k(a) | a \in A\} \tag{A.1}$$

where $\{a_1, a_2, \ldots, a_i, \ldots, a_n\}$ is a set of possible alternatives,
$\{g_1(\cdot), g_2(\cdot), \ldots, g_j(\cdot), \ldots g_k(\cdot)\}$ a set of evaluation criteria.

There is no objection to consider some criteria to be maximised and the others to be minimised. The expectation of the decision-maker is to identify an alternative optimising all the criteria.

A.3 PROMETHEE method

The PROMETHEE method is used for solve problems presented in equation A.1.

The ranking of alternatives is carried out by pairwise comparison of the alternatives for each criterion. The comparison is measured using a predefined preference function. For a preference function P, alternatives a and b, and criterion j,

$$P_j(a,b) = F_j\left[d_j(a,b)\right] \qquad \forall a,b \in A \quad and \quad 0 \leq P_j(a,b) \leq 1 \tag{A.2}$$

$$d_j(a,b) = g_j(a) - g_j(b) \tag{A.3}$$

where equation A.3 gives the difference in measurement for a criterion j.

The PROMETHEE method gives a choice of six generalized criteria to define the preference function. These generalized criteria are shown in Tab. A.1.

The aggregate ranking or preference of the two alternatives is determined by summing up the weighted values of the preference functions of the complete set of criteria. That is the overall measure is given by equation A.4 where w_i is the weight given to criterion j. $\pi(a,b)$ is expressing with which degree a is preferred to b over all the criteria and $\pi(b,a)$ how b is preferred to a.

$$\begin{cases} \pi(a,b) = \sum_{j=1}^{k} w_i P_j(a,b) \\ \pi(b,a) = \sum_{j=1}^{k} w_i P_j(b,a) \end{cases} \tag{A.4}$$

The weights w_i are obtained from the decision maker and they are normalized to sum up to unity. If the number of alternatives is more than two, the overall ranking is done by aggregating the measures of pairwise comparisons.

For each alternative $a \in A$, the two outranking dominance flows shown in equations A.5 and A.6 can be obtained with respect to all the other alternatives $x \in A$. The positive outranking flow expresses how an alternative a is outranking all the others. The higher $\phi^+(a)$, the better the alternative character. The negative outranking flow expresses how an alternative a is outranked by all the others. The lower $\phi^-(a)$ the better the alternative.

- the positive outranking flow:

$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x) \tag{A.5}$$

- the negative outranking flow:

$$\phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x,a) \tag{A.6}$$

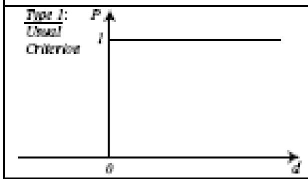
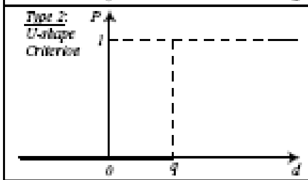
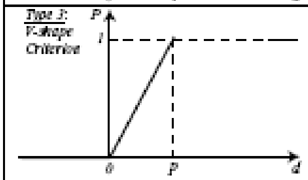
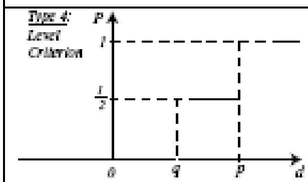
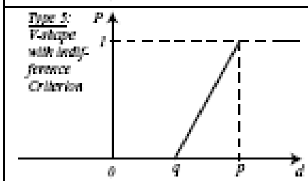
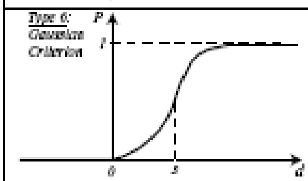
Generalised criterion	Definition	Parameters to fix
	$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 & d > 0 \end{cases}$	–
	$P(d) = \begin{cases} 0 & d \leq q \\ 1 & d > q \end{cases}$	q
	$P(d) = \begin{cases} 0 & d \leq 0 \\ \frac{d}{p} & 0 \leq d \leq p \\ 1 & d > p \end{cases}$	p
	$P(d) = \begin{cases} 0 & d \leq q \\ \frac{1}{2} & q < d \leq p \\ 1 & d > p \end{cases}$	p, q
	$P(d) = \begin{cases} 0 & d \leq q \\ \frac{d-q}{d-p} & q < d \leq p \\ 1 & d > p \end{cases}$	p, q
	$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & d > 0 \end{cases}$	s

Table A.1: PROMETHEE preference functions $P(d)$ [BM03]

The complete ranking of the set of alternatives is obtained by computing, for each alternative, the next outranking flow given by equation A.7. The higher the complete outranking flow, the better the alternative.

$$\phi(a) = \phi^+(a) - \phi^-(a) \tag{A.7}$$

A.4 GAIA representation

The GAIA plane is the plane for which as much information as possible is preserved after projection. According to the Principal Components Analysis (PCA) technique it is defined by the two eigenvectors corresponding to the two largest eigenvalues of the covariance matrix M0M of the complete outranking flow $\phi(a)$. Of course some information get lost after projection. δ is the quantity of information preserved (ofen bigger than 80%)

Let $\{A_1, A_2, \ldots, A_i, \ldots, An\}$ be the projections of the n points representing the alternatives and let $\{C_1, C_2, \ldots, C_j, \ldots, C_k\}$ be the projections of the k unit vectors of the coordinates axes of $\Re^k$ representing the criteria. We then obtain a GAIA plane shown on Fig. A.1. The projection of the unit vector of the weights π plays a crucial role in the GAIA plane. This vector is called *PROMETHEE decision axis*.

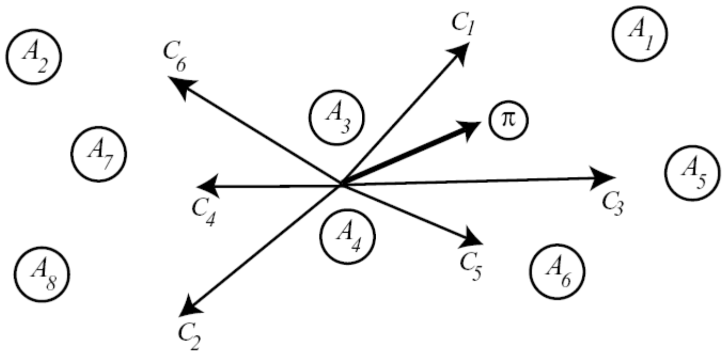


Figure A.1: Alternative and criteria in the GAIA plane

The following properties can be assume:

- The longer a criterion axis in the GAIA plane, the more discriminating this criterion.
- Criteria expressing similar preferences are represented by axes oriented in approximatively the same direction.
- Criteria expressing conflicting preferences are oriented in opposite directions.
- Independent criteria are represented by orthogonal axes.
- Similar alternatives are represented by points located close to each other.
- Alternatives being good on a particular criterion are represented by points located in the direction of the corresponding criterion axis.

- When the weights w_i are modified, the positions of the alternatives A_i and of the criteria C_j remain unchanged in the GAIA plane.
- If π is long, the PROMETHEE decision axis has a strong decision power and the decision-maker is invited to select alternatives as far as possible in its direction.
- If π is short, the PROMETHEE decision axis has no strong decision power. It means, according to the weights, that the criteria are strongly conflicting and that the selection of a good compromise is a hard problem.

A.5 Conclusion

The PROMETHEE method, with its pairwise comparisons and its choices of generalized criteria for the decision-making criteria proved to be easy for understanding and applications among the decision makers. The advantages is that the decision makers could input criteria of their interest into the model as separate entities. The impact of the decisions on these criteria could be perceived directly. They could also examine the sensitivity of the decisions to the changes in the subjective weights given to the criteria.

Appendix B

Survey about life cycle cost management

B.1 Form of the survey

This survey is conducted by University of Liege (Belgium) concerning the life cycle cost management in the maritime industry. The purpose of this survey is to determine what are the main methods and tools used to evaluate/assess/control costs during the life cycle of a ship (design, manufacturing, operation and retirement). This survey is primarily intended for design offices, shipyards and ship owners. We expect answers from office, IT, R& D, design, production, finance managers, or all other people working with cost evaluations.

We invite you to take a few moment (3-5 minutes) to complete our survey. The survey will end on 31 March 2009. We guarantee that the information provided will be kept confidential and anonymous. The data will be exclusively used for the research study. Moreover, this study is performed without any connection with software providers.

Thank you for taking the time to participate in this evaluation. Your comments will enable us to improve our study and meet our objectives.

* Required

01/20 - What is the main activity of your company? *

❍ Shipyard

❍ Ship owner

❍ Research center or University

❍ Design office

❍ Other: _______

02/20 - What are the main industrial sectors of your company? *

Select all possible options

- ❑ Naval
- ❑ Offshore
- ❑ Navy
- ❑ Other: ________

03/20 - Where is the main site of your company? *

- ❍ Asia
- ❍ Europe
- ❍ North America
- ❍ South America
- ❍ Other: ________

04/20 - Among the following Concurrent Engineering tools, what are those you've implemented in your company? *

Select all possible options

- ❑ Design for Production or Design for Manufacturing
- ❑ Design for Assembly or Assembly-Oriented Design
- ❑ Design to Cost
- ❑ Design for Simplicity
- ❑ Design for Maintenance
- ❑ Design for Environment
- ❑ Design for Safety
- ❑ Design for Disposal
- ❑ Design for Life Cycle
- ❑ Design for Robustness
- ❑ Design for Six Sigma
- ❑ Design for Lean Manufacturing
- ❑ Not allowed or not used in my company
- ❑ Other: ________

05/20 - Among the following Concurrent Engineering tools, could you select two options that you feel is the future for your company? *

Select 2 possible options

- ❑ Design for Production or Design for Manufacturing
- ❑ Design for Assembly or Assembly-Oriented Design
- ❑ Design to Cost
- ❑ Design for Simplicity
- ❑ Design for Maintenance
- ❑ Design for Environment
- ❑ Design for Safety
- ❑ Design for Disposal
- ❑ Design for Life Cycle
- ❑ Design for Robustness
- ❑ Design for Six Sigma
- ❑ Design for Lean Manufacturing
- ❑ Not allowed or not used in my company
- ❑ Other: ________

06/20 - Among the following "Cost evaluation" methods, what are those you've implemented in your company during the "concept design stage" of a ship (before contract)? *

Select all possible options

- ❑ Intuitive method (expertise analysis)
- ❑ Case based reasoning (analogy analysis)
- ❑ Parametric method (statistical analysis)
- ❑ Feature-Based Costing (analytical analysis)
- ❑ Not allowed or not used in my company
- ❑ Other: ________

07/20 - Among the following "Cost evaluation" methods, what are those you've implemented in your company during the "basic design stage" of a ship (after contract)? *

Select all possible options

- ❑ Intuitive method (expertise analysis)
- ❑ Case based reasoning (analogy analysis)
- ❑ Parametric method (statistical analysis)
- ❑ Feature-Based Costing (analytical analysis)
- ❑ Not allowed or not used in my company
- ❑ Other: ________

08/20 - Among the following "Cost evaluation" methods, what are those you've implemented in your company during the "manufacturing" of a ship? *

Select all possible options

- ❑ Intuitive method (expertise analysis)
- ❑ Case based reasoning (analogy analysis)
- ❑ Parametric method (statistical analysis)
- ❑ Feature-Based Costing (analytical analysis)
- ❑ Not allowed or not used in my company
- ❑ Other: _______

09/20 - Among the following "Cost evaluation" methods, what are those you've implemented in your company during the "operation" of a ship? *

Select all possible options

- ❑ Intuitive method (expertise analysis)
- ❑ Case based reasoning (analogy analysis)
- ❑ Parametric method (statistical analysis)
- ❑ Feature-Based Costing (analytical analysis)
- ❑ Not allowed or not used in my company
- ❑ Other: _______

10/20 - If you use the "parametric method (statistical analysis)" for cost evaluation, what are the mathematical model that you use frequently? *

Select all possible options

- ❑ (Multi) Linear regression methods
- ❑ Fuzzy logic method
- ❑ Neural networks method
- ❑ Not allowed or not used in my company
- ❑ Other: _______

11/20 - Do you use commercial software for "cost evaluation" during the life cycle of the ship (design, manufacturing, operation and retirement)? *

If "NO" please pass to question 13

- ❍ Yes
- ❍ No

12/20 - What are the name of the commercial softwares that you use for "cost evaluation" during the life cycle of the ship?

Optional information - If you use more than one, please specify

____

13/20 - How effective do you consider your "cost evaluation" software during the life cycle of the ship? *

	1	2	3	4	5	
Inefficient	❍	❍	❍	❍	❍	Very effective

14/20 - What are the 4 best qualities of your "cost evaluation" software? *

Select 4 possible options

❏ Good logic visibility

❏ Reusable

❏ High accuracy of results

❏ Good ability to reflect design changes

❏ Good ability to reflect production changes

❏ Good ability to reflect operational behaviour changes

❏ Few historical data needs

❏ Low cost database size

❏ Quick computation time

❏ Low development cost

❏ Ability to use the same software at different stage of the design/manufacturing/operation process

❏ Good compatibility with the other IT company softwares

❏ Ease of use

❏ Other: ________

15/20 - Did you failed to answer to some questions for confidentiality reasons? *

❍ Yes

❍ No

16/20 - What is your occupation? *

❍ Office Manager & Supervisor

❍ Computer & Information Systems Manager

❍ Research & Development Manager

❍ Design & Conception Manager

❍ Production & Manufacturing Manager

❍ Finance & Cost Manager

❍ Other: ________

17/20 - What is the country where you work? *

____

18/20 - What is your company name?

Optional information

———

19/20 - What is your email address?

Optional information - To receive the survey results

———

20/20 - Could you leave your comments or questions about this topic?

Optional information

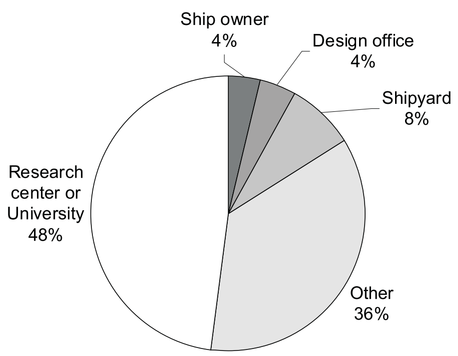
———

B.2 Results of the survey

The survey as been sent to 1250 people. Only 2% (25) of respondents have sent a reply.

01/20 - What is the main activity of your company? *

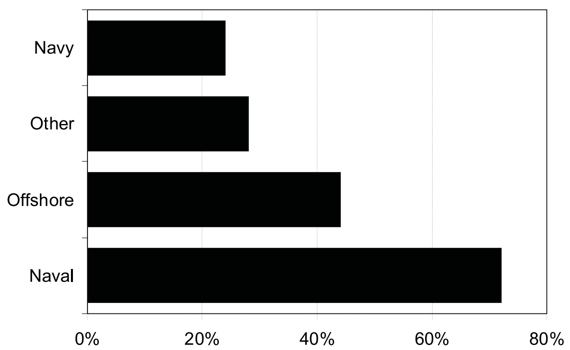
Ship owner	**1**	*4%*
Design office	**1**	*4%*
Shipyard	**2**	*8%*
Other	**9**	*36%*
Research center or University	**12**	*48%*



02/20 - What are the main industrial sectors of your company? *

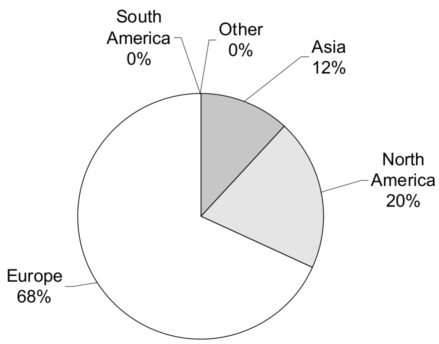
People may select more than one checkbox, so percentages may add up to more than 100%.

Navy	**6**	*24%*
Other	**7**	*28%*
Offshore	**11**	*44%*
Naval	**18**	*72%*



03/20 - Where is the main site of your company? *

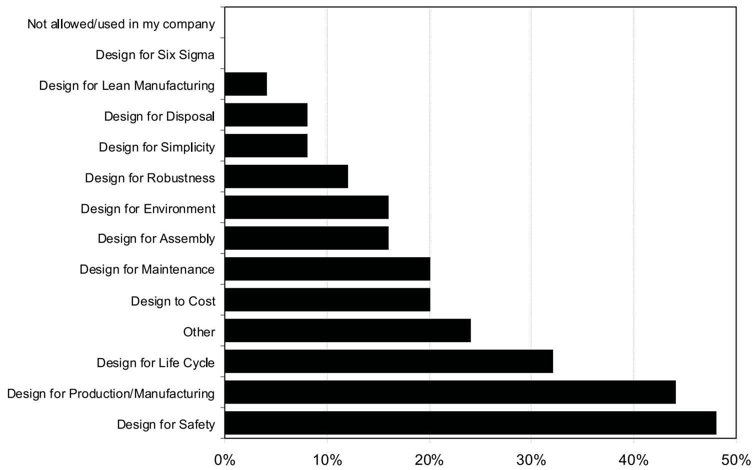
South America	**0**	*0%*
Other	**0**	*0%*
Asia	**3**	*12%*
North America	**5**	*20%*
Europe	**17**	*68%*



04/20 - Among the following Concurrent Engineering tools, what are those you've implemented in your company? *

People may select more than one checkbox, so percentages may add up to more than 100%.

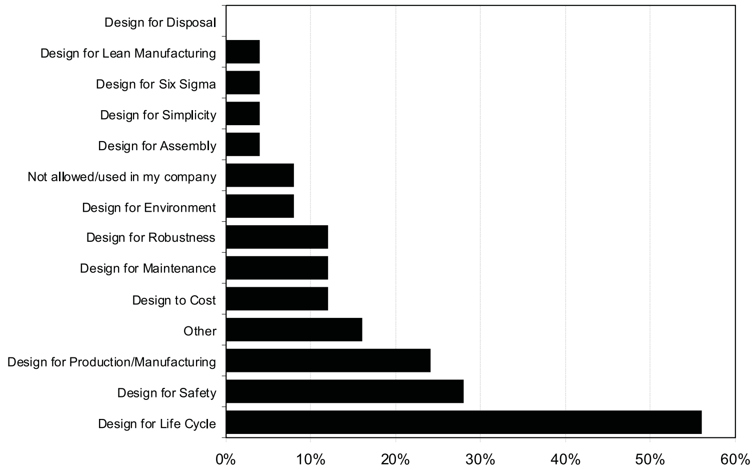
Design for Six Sigma	**0**	*0%*
Not allowed/used in my company	**0**	*0%*
Design for Lean Manufacturing	**1**	*4%*
Design for Simplicity	**2**	*8%*
Design for Disposal	**2**	*8%*
Design for Robustness	**3**	*12%*
Design for Assembly	**4**	*16%*
Design for Environment	**4**	*16%*
Design to Cost	**5**	*20%*
Design for Maintenance	**5**	*20%*
Other	**6**	*24%*
Design for Life Cycle	**8**	*32%*
Design for Production	**11**	*44%*
Design for Safety	**12**	*48%*



05/20 - Among the following Concurrent Engineering tools, could you select two options that you feel is the future for your company? *

People may select more than one checkbox, so percentages may add up to more than 100%.

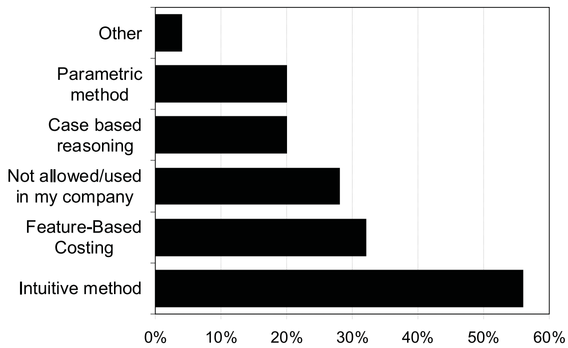
Design for Disposal	**0**	*0%*
Design for Assembly	**1**	*4%*
Design for Simplicity	**1**	*4%*
Design for Six Sigma	**1**	*4%*
Design for Lean Manufacturing	**1**	*4%*
Design for Environment	**2**	*8%*
Not allowed/used in my company	**2**	*8%*
Design to Cost	**3**	*12%*
Design for Maintenance	**3**	*12%*
Design for Robustness	**3**	*12%*
Other	**4**	*16%*
Design for Production	**6**	*24%*
Design for Safety	**7**	*28%*
Design for Life Cycle	**14**	*56%*



06/20 - Among the following "Cost evaluation" methods, what are those you've implemented in your company during the "concept design stage" of a ship (before contract)? *

People may select more than one checkbox, so percentages may add up to more than 100%.

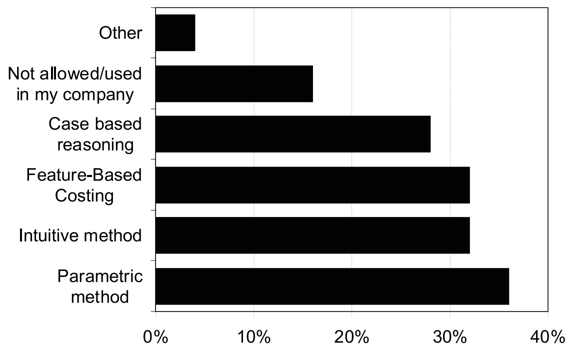
Other	**1**	*4%*
Case based reasoning	**5**	*20%*
Parametric method	**5**	*20%*
Not allowed/used in my company	**7**	*28%*
Feature-Based Costing	**8**	*32%*
Intuitive method	**14**	*56%*



07/20 - Among the following "Cost evaluation" methods, what are those you've implemented in your company during the "basic design stage" of a ship (after contract)? *

People may select more than one checkbox, so percentages may add up to more than 100%.

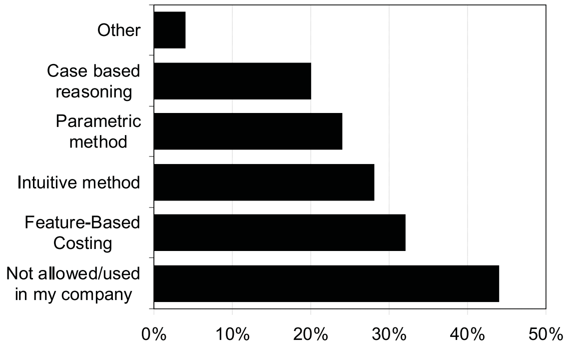
Other	**1**	*4%*
Not allowed/used in my company	**4**	*16%*
Case based reasoning	**7**	*28%*
Intuitive method	**8**	*32%*
Feature-Based Costing	**8**	*32%*
Parametric method	**9**	*36%*



08/20 - Among the following "Cost evaluation" methods, what are those you've implemented in your company during the "manufacturing" of a ship? *

People may select more than one checkbox, so percentages may add up to more than 100%.

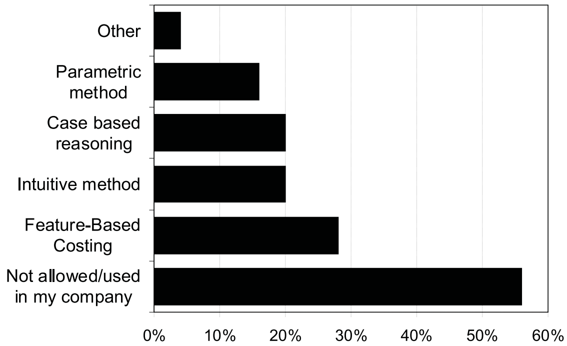
Other	**1**	*4%*
Case based reasoning	**5**	*20%*
Parametric method	**6**	*24%*
Intuitive method	**7**	*28%*
Feature-Based Costing	**8**	*32%*
Not allowed/used in my company	**11**	*44%*



09/20 - Among the following "Cost evaluation" methods, what are those you've implemented in your company during the "operation" of a ship? *

People may select more than one checkbox, so percentages may add up to more than 100%.

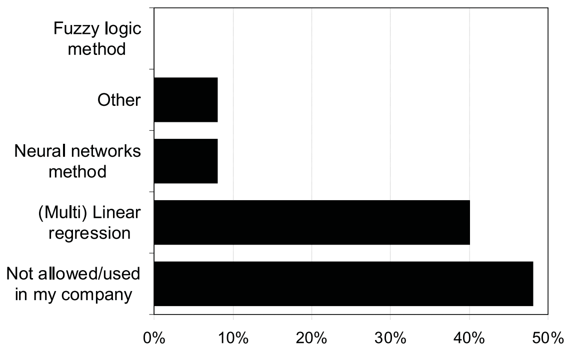
Other	**1**	*4%*
Parametric method	**4**	*16%*
Intuitive method	**5**	*20%*
Case based reasoning	**5**	*20%*
Feature-Based Costing	**7**	*28%*
Not allowed/used in my company	**14**	*56%*



10/20 - If you use the "parametric method (statistical analysis)" for cost evaluation, what are the mathematical model that you use frequently? *

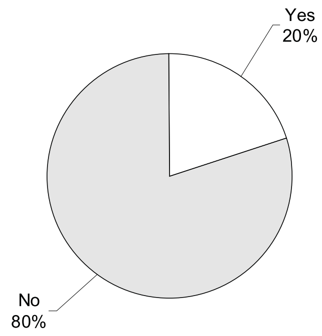
People may select more than one checkbox, so percentages may add up to more than 100%.

Fuzzy logic method	**0**	*0%*
Neural networks method	**2**	*8%*
Other	**2**	*8%*
(Multi) Linear regression	**10**	*40%*
Not allowed/used in my company	**12**	*48%*



11/20 - Do you use commercial software for "cost evaluation" during the life cycle of the ship (design, manufacturing, operation and retirement)? *

Yes	**5**	*20%*
No	**20**	*80%*



12/20 - What are the name of the commercial softwares that you use for "cost evaluation" during the life cycle of the ship?

- As a university research team, we developed a life cycle costing (LCC) and life cycle assessment (LCA) software application under a research grant from the United States Office of Naval Research (ONR) for use by the Navy yards and the US private shipyards. Concepts developed by our research group can be used to develop LCC/LCA models for other processes used for ship production (design and fabrication), ship operation, and ship dismantling/breaking. Also, these concepts can be used for other industrial sectors.

- SPAR's PERCEPTION ESTI-MATE

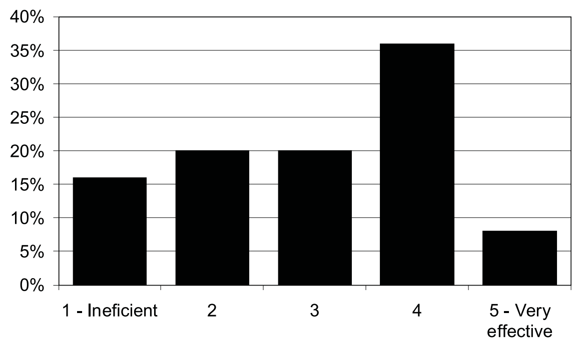
- Private methods that are introduced by experts following actual cases

- In house development

- Excel

13/20 - How effective do you consider your "cost evaluation" software during the life cycle of the ship? *

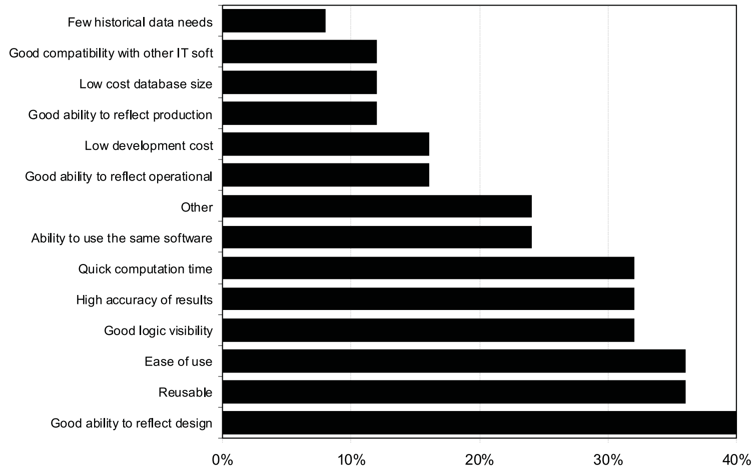
1 - Ineficient	**4**	*16%*
2	**5**	*20%*
3	**5**	*20%*
4	**9**	*36%*
5 - Very effective	**2**	*8%*



14/20 - What are the 4 best qualities of your "cost evaluation" software? *

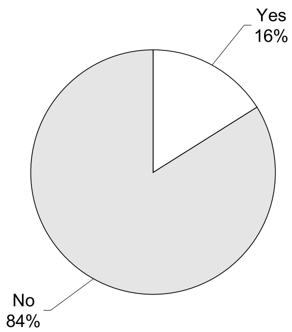
People may select more than one checkbox, so percentages may add up to more than 100%.

Few historical data needs	**2**	*8%*
Good ability to reflect production ...	**3**	*12%*
Low cost database size	**3**	*12%*
Good compatibility with other IT ...	**3**	*12%*
Good ability to reflect operational ...	**4**	*16%*
Low development cost	**4**	*16%*
Ability to use the same software ...	**6**	*24%*
Other	**6**	*24%*
Good logic visibility	**8**	*32%*
High accuracy of results	**8**	*32%*
Quick computation time	**8**	*32%*
Reusable	**9**	*36%*
Ease of use	**9**	*36%*
Good ability to reflect design ...	**10**	*40%*



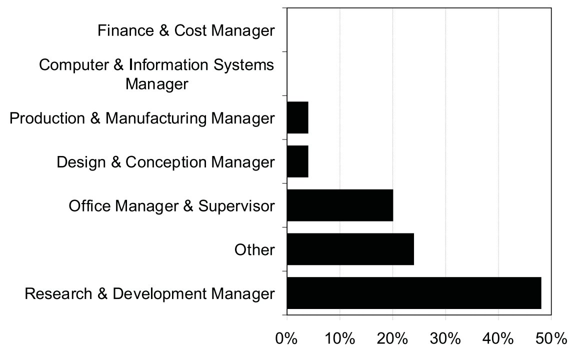
15/20 - Did you failed to answer to some questions for confidentiality reasons? *

Yes	**5**	*16%*
No	**20**	*84%*



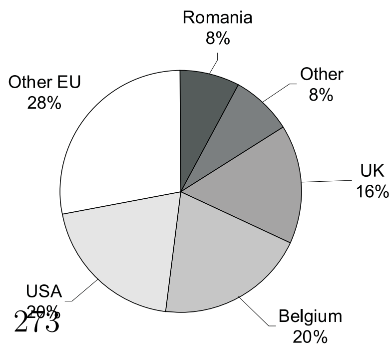
16/20 - What is your occupation? *

Computer & Information Systems Manager	**0**	*0%*
Finance & Cost Manager	**0**	*0%*
Design & Conception Manager	**1**	*4%*
Production & Manufacturing Manager	**1**	*4%*
Office Manager & Supervisor	**5**	*20%*
Other	**6**	*24%*
Research & Development Manager	**12**	*48%*



17/20 - What is the country where you work? *

Romania	**2**	*8%*
Other	**2**	*8%*
UK	**4**	*16%*
Belgium	**5**	*20%*
USA	**5**	*20%*
Other EU	**7**	*28%*



Appendix C

Feature based costing prototype

C.1 Welding considerations

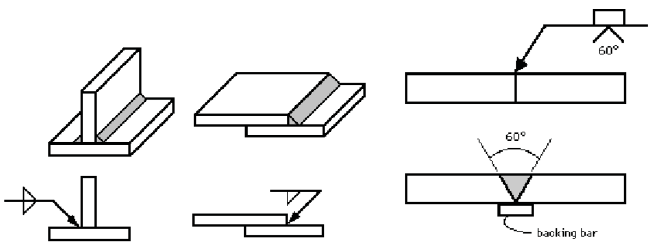
C.1.1 Definition of the welding type

Two welding type are available for the shipbuilding industry:

- **Fillet weld**[1] – is used to make lap joints, corner joints, and T joints. As showed on Fig. C.1(a), weld metal is deposited in a corner formed by the fit-up of the two members and penetrates and fuses with the base metal to form the joint.

- **Butt weld** – is commonly used to make edge-to-edge joints, although it is also often used in corner joints, T joints, and joints between curved and flat pieces. As showed on Fig. C.1(b), weld metal is deposited within the groove and penetrates and fuses with the base metal to form the joint. They are various type of butt welds.

The angle α between two steel parts has been used in order to define the welding type feature. The ε angle parameter determines the angle interval in which welds are declared as "butt weld". This interval is included between $(180^{\circ} - \varepsilon)$ and $(180^{\circ} + \varepsilon)$. For any other connecting angles the welds are defined as fillet weld. In this study we took $\varepsilon = 5^{\circ}$.



(a) Fillet weld (b) Butt weld

Figure C.1: Weld type definition

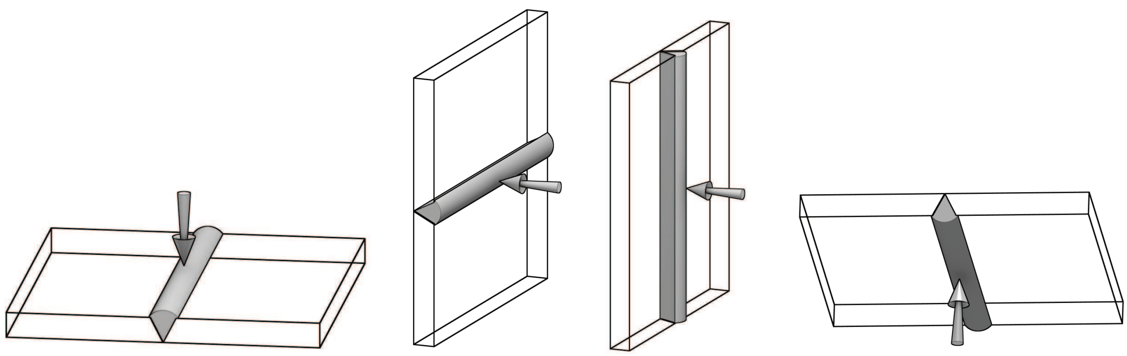
[1]pronounced "fill-it," and not "fil-lay"

C.1.2 Definition of the welding position

During the assembly process of a ship several welding position are used i.e. flat (F), horizontal (H), vertical (V) and overhead (O) (see Fig. C.2).

Fig. C.3 define the weld position according to the *inclination angle* β and the *rotation angle* γ of the weld seems. These angle definitions are based on the ANSI/AWS A.3.0 SECTION IX standard and were modified to fit with the CAD/CAM tool and the requirements of the shipyards. Fig. C.4 represents a 3D view of the combination of the β angle and the γ angle. This figure also indicates the considered welding direction. As example, the welding position of a fillet weld having a β angle of 7° and a γ angle of 110° is flat. As against, if it is a butt weld his position will be defined as horizontal.

The weld position database, Tab. C.1, has been filled thanks to the Fig. C.3.

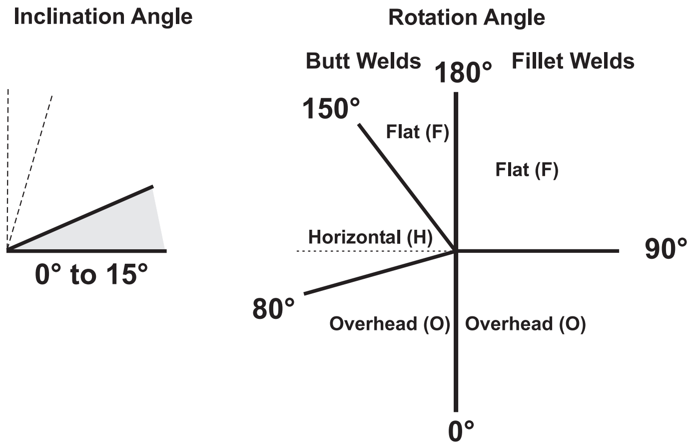


(a) Flat (b) Horizontal (c) Vertical (d) Overhead

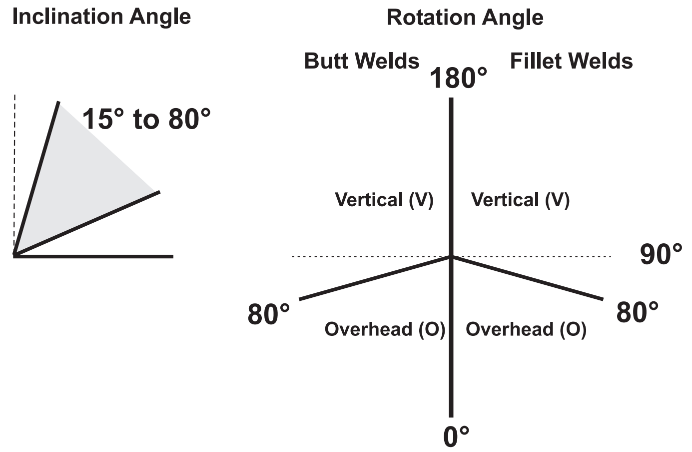
Figure C.2: Welding position

α		β		γ		Weld type		Weld position	
min	max	min	max	min	max				
0°	175°	0°	15°	90°	180°	Fillet	F	Flat	F
0°	175°	15°	80°	80°	180°	Fillet	F	Vertical	V
0°	175°	80°	90°	0°	180°	Fillet	F	Vertical	V
0°	175°	15°	80°	0°	80°	Fillet	F	Overhead	O
0°	175°	0°	15°	0°	90°	Fillet	F	Overhead	O
175°	185°	15	80	0	80	Butt	B	Overhead	O
175°	185°	0	15	150	180	Butt	B	Flat	F
175°	185°	0	15	80	150	Butt	B	Horizontal	H
175°	185°	15	80	80	180	Butt	B	Vertical	V
175°	185°	80	90	0	180	Butt	B	Vertical	V
175°	185°	0	15	0	80	Butt	B	Overhead	O
185°	360°	0°	15°	90°	180°	Fillet	F	Flat	F
185°	360°	15°	80°	80°	180°	Fillet	F	Vertical	V
185°	360°	80°	90°	0°	180°	Fillet	F	Vertical	V
185°	360°	15°	80°	0°	80°	Fillet	F	Overhead	O
185°	360°	0°	15°	0°	90°	Fillet	F	Overhead	O

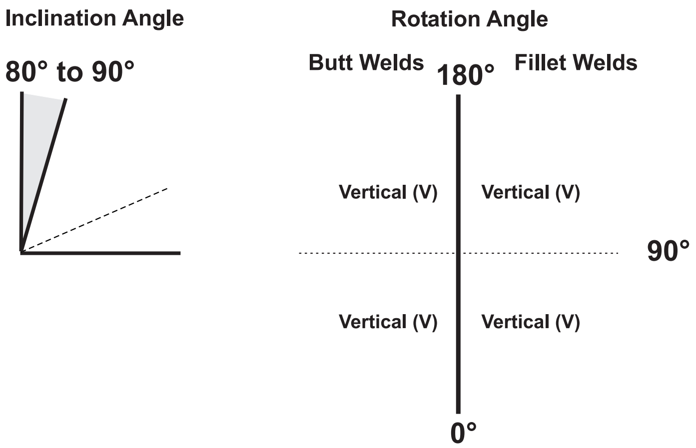
Table C.1: Weld position definition



(a) β from 0° to 15°



(b) β from 15° to 80°



(c) β from 80° to 90°

Figure C.3: Weld position definition

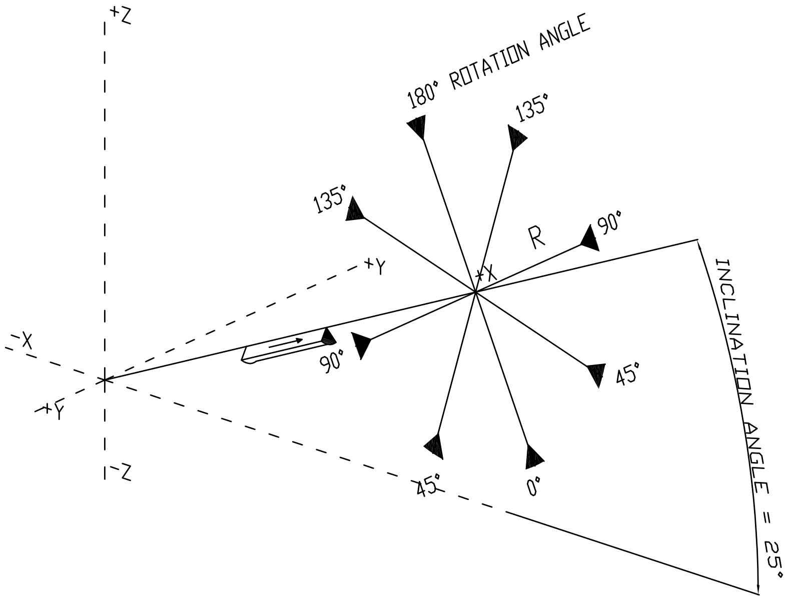


Figure C.4: Combination of the β angle and the γ angle of welds in a 3D view

C.2 Database structures

All databases presented here have been implemented using the Oracle9i DataBase Management System (DBMS).

C.2.1 CAD/CAM relational database

The CAD/CAM relational database is designed to store the data related to the Ship Work Breakdown Structure (SWBS) including all features of the ship structure like blocks, section, assemblies, plates, stiffeners, geometries and cutting contours, seams, welds, etc. Some additional details about the internal structure of the relational CAD/CAM database are presented in Fig. C.5.

C.2.2 Cost relational database

The cost relational database is designed to store:

- the hierarchical work stage and hierarchical work type – see section C.2.2.1
- the CER's and their related parameters – see section C.2.2.1 and C.2.2.2
- the unitary costs – see section C.2.2.2
- the cost results – see section C.2.2.3
- the global variables of the software

C.2.2.1 Data relating to the cost structure

Fig. C.6 shows the Entity Relationship Diagram (ERD) of a part of the cost database related to the storage of the Product Work Breakdown Structure (PWBS).

As presented in section 4.3.2.2, the hierarchical work stage and the hierarchical work type can be represented by the path *sectors – workshops – stages – operation – nature*. This structure is stored into the following tables:

- *CST_TA_SECTEURS*,
- *CST_TA_ATELIERS*,
- *CST_TA_POSTES*,
- *CST_TA_ETAPES*,
- *CST_TA_OPERATION*.

One CER and his attached parameters decribed in the section 4.3.2.3 can be store inside each leaf of the hierarchical structure. The following tables are involves in this purpose:

- *CST_TA_ETAPE_T_OPERATION*,
- *CST_TA_POSTE_ETAPES*,
- *CST_TA_TYPE_OPERATION*,
- *CST_TA_FILTER_WELD*.

However, three specific cost natures, i.e. "Preparation", "Welding" and "Machining" require a particular treatment due to the possible link with design variables like plate thickness, weld throat, weld type (butt or fillet), weld position, bevels, profile scantling, etc. Theze features are stored inside the tables:

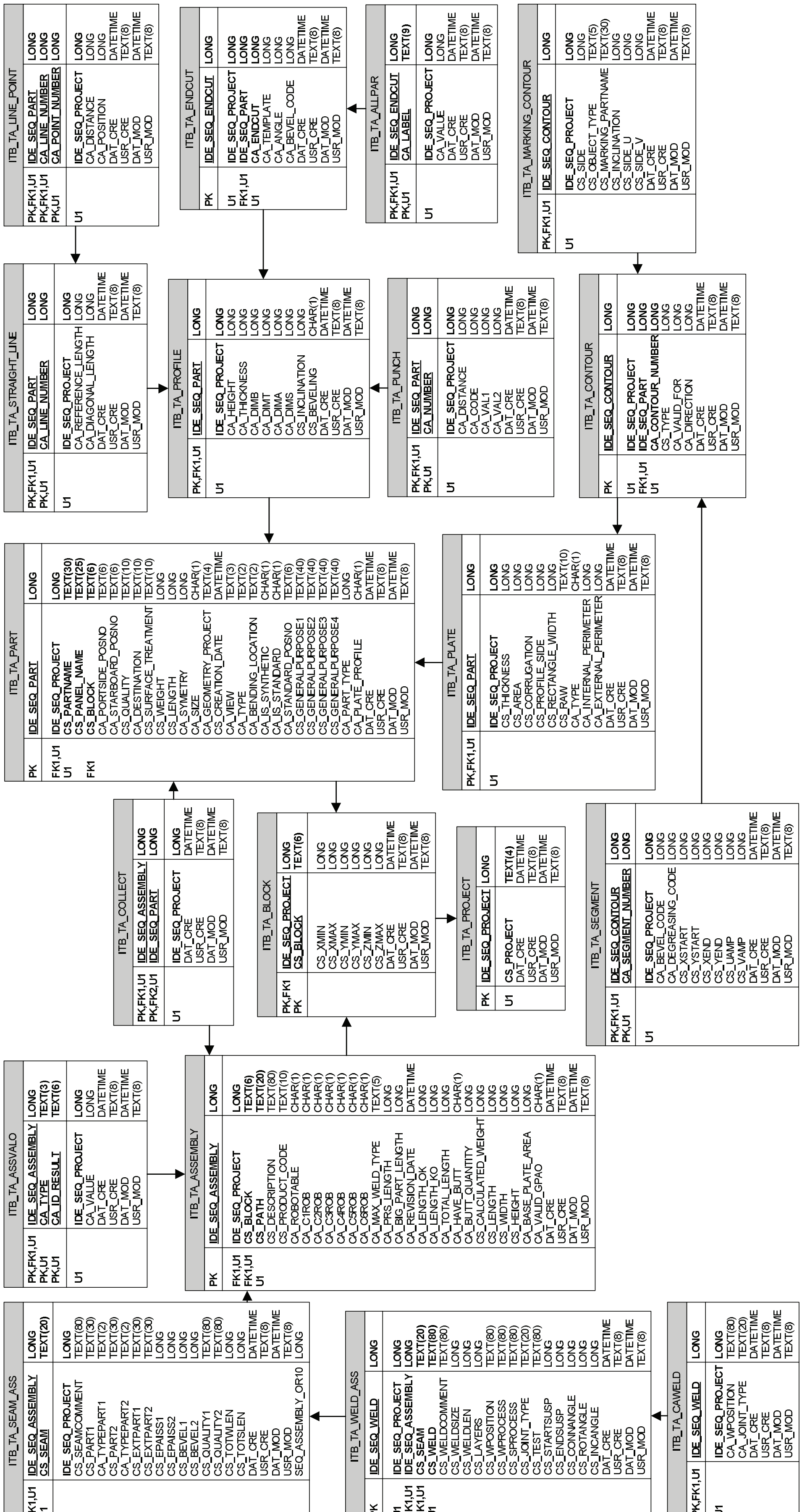


Figure C.5: Entity Relationship Diagram (ERD) of the CAD/CAM relational database

- *CST_TA_TOLERIE*,
- *CST_TA_ETAPE_TOLERIE*,
- *CST_TA_SOUDURES*,
- *CST_TA_ETAPE_SOUDURE*
- *CST_TA_USINAGE*,
- *CST_TA_ETAPE_USINAGE*.

C.2.2.2 Data relating to the cost scales and design variables

Preparation activity Fig. C.7 shows a part of the Entity Relationship Diagram (ERD) of the cost database which highlight the influance of the various design variables on the unitary *preparation* costs. The following design variables were taken into account:

- profile height,
- plate thickness,
- angle of profiles,
- etc.

The table *CST_TA_SOUDURE* stores the list of all possible preparation strategies inside the shipyard while the table *CST_TA_COUT_HORAIRE_SOURURE* stores the related unitary cost in function of each variation of the design variables.

The intermediate tables *CST_TA_TOLE_XXX*, in a similar way to welding activities, stores for each preparetion strategy which are the possible values of the design variables. From there, we will be able to create various automatic tables for scales introduction in the GUI.

Welding activity Fig. C.8 shows a part of the Entity Relationship Diagram (ERD) of the cost database which highlight the influance of the various design variables on the unitary *welding* costs. The following design variables were taken into account:

- the wedling type (*fillet* or *butt* see appendix C.1.1),
- the welding position (see appendix C.1.2),
- the plate tickness,
- the welding throat,
- the welding continuity (continuous one or two sides, discontinuous, etc.),
- the welding chamfer,
- the profile height,
- etc.

The table *CST_TA_TOLERIE* stores the list of all possible welding strategies inside the shipyard while the table *CST_TA_COUT_HORAIRE_TOLE* stores the related unitary cost in function of each variation of the design variables e.g. 0.6 hour per meter lenght of a discontinuous welding in horizontal position with a welding throat of 4 mm.

The intermediate tables *CST_TA_SOUD_XXX* stores for each welding strategy which are the possible values of the design variables. From there, we will be able to create various automatic tables for scales introduction in the GUI. For example, the butt welding for the blocks adjustment in the dry dock is valid only in vertical position and for 10 to 25 plate thicknesses.

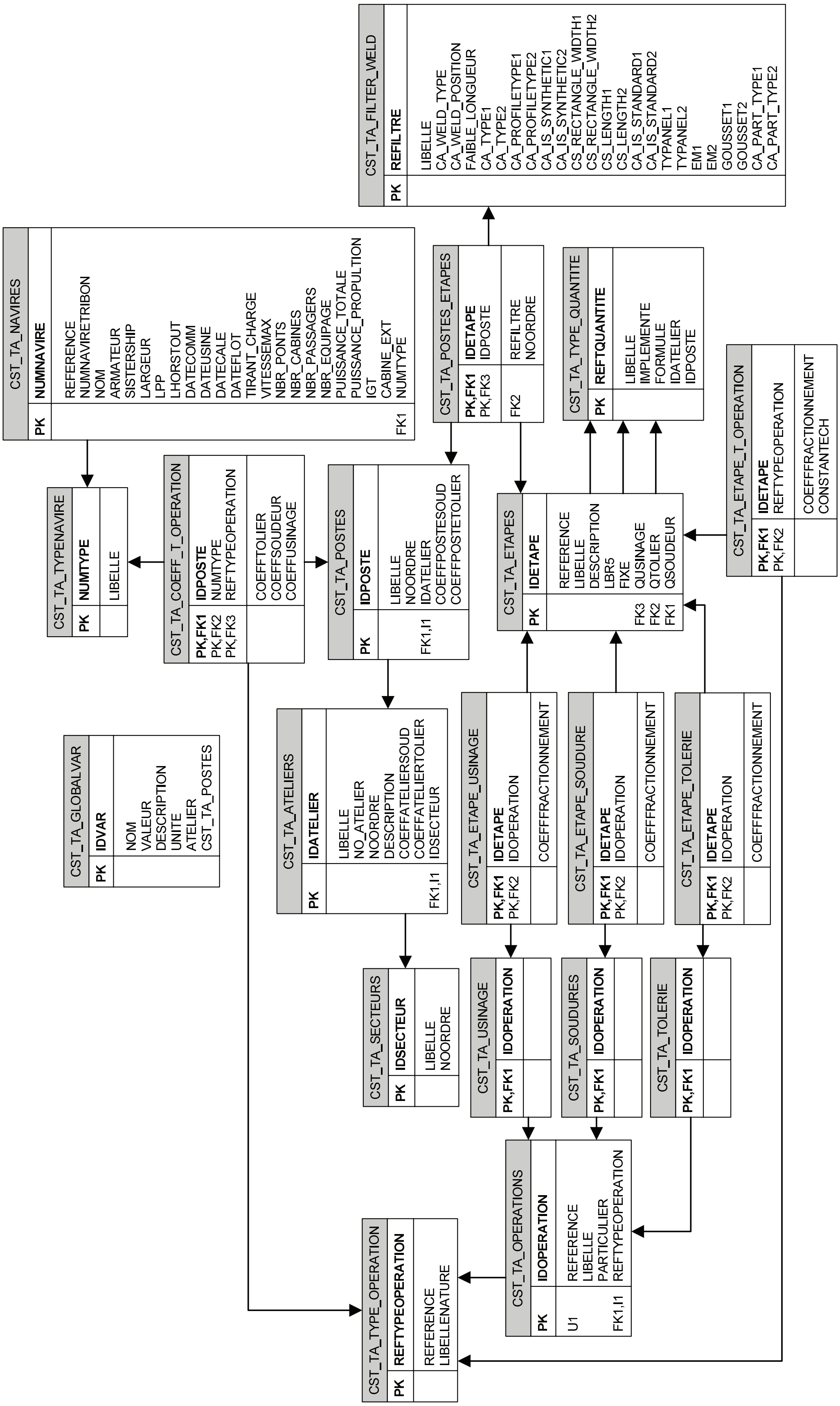


Figure C.6: Entity Relationship Diagram (ERD) of the COST database – Cost structure

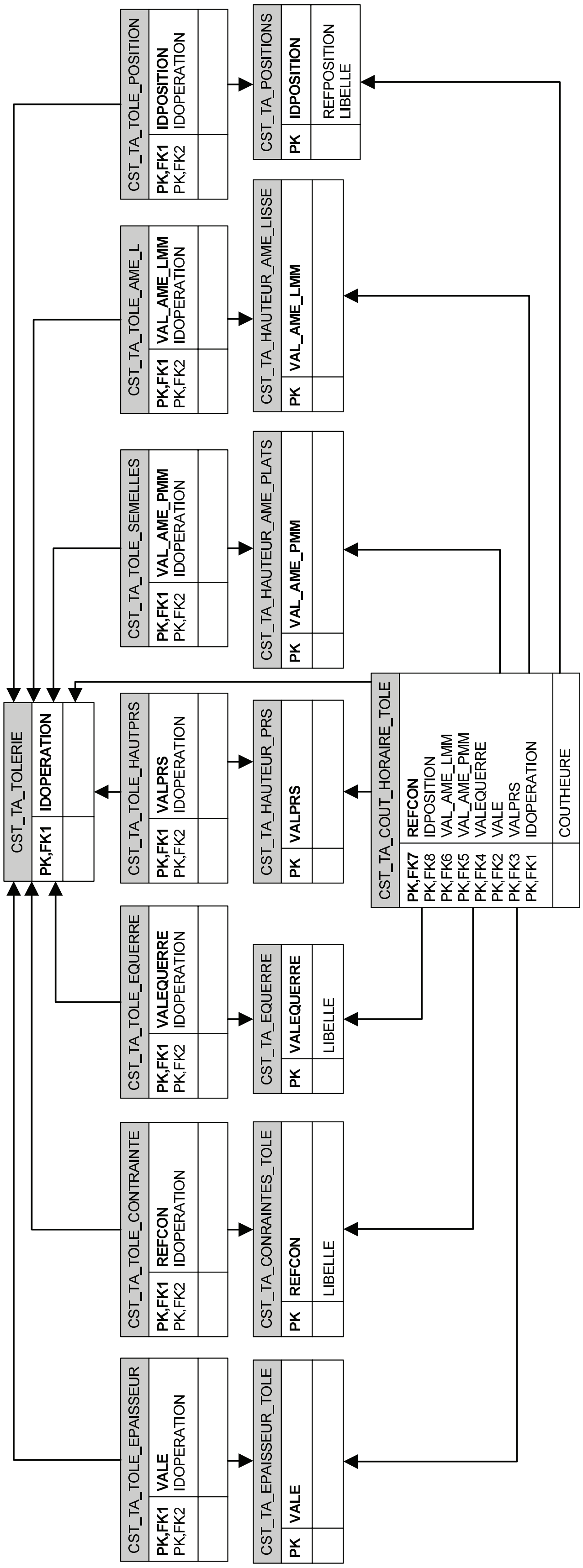


Figure C.7: Entity Relationship Diagram (ERD) of the COST database – Design variables – Preparation

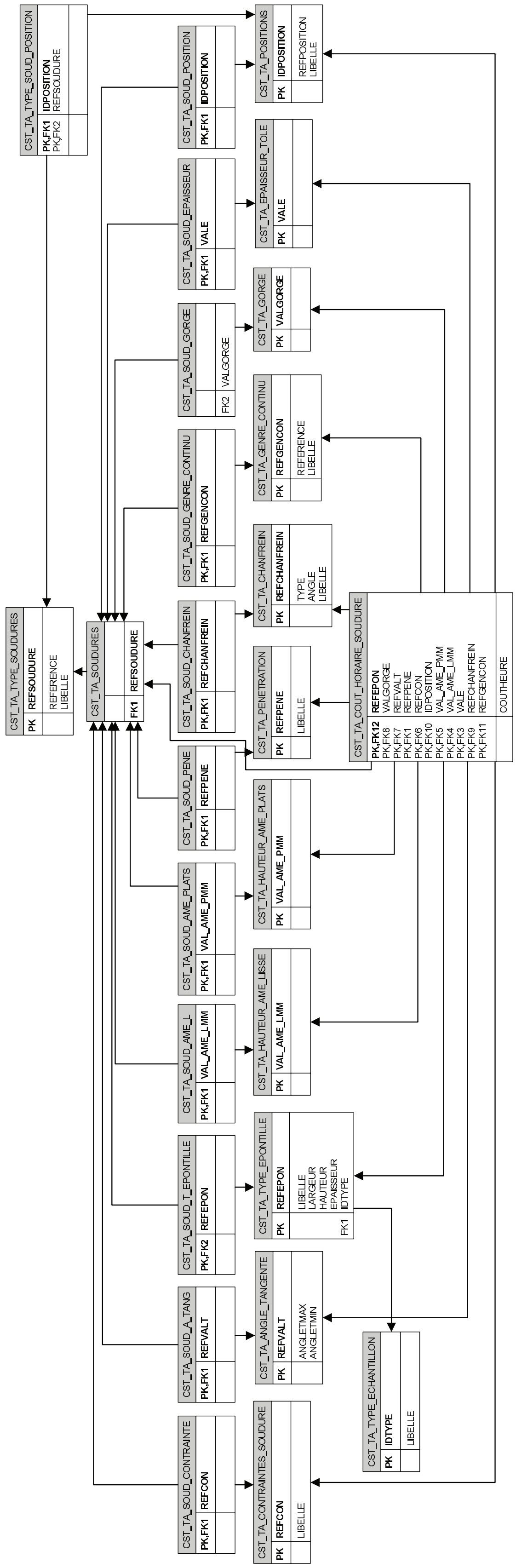


Figure C.8: Entity Relationship Diagram (ERD) of the COST database – Design variables – Welding

C.2.2.3 Data relating to the cost results

Fig. C.9 shows the various tables where the cost results are stored. We created 8 different tables according the cost natures and the type of ship elments (parts, assemblies, blocks, ships) in order to allow the parallel processing of the CER's so that the computation time was reduced.

C.3 Graphical User Interface (GUI)

Fig. C.10 shows the main frame of the Encode Cost module. Left side of the main frame of the FBC prototype module (Fig. 4.9) shows the different cost levels as defined in Tab. 4.1: the *sectors – workshops – stages – operation*. The fifth level related to cost natures are presented on the right side of the Fig. 4.9.

For each cost operation a production process can be choose. An for each process a unit cost can be defined. Curves which represent actual costs of operations devoted to a specific production technique, and which show the relation between the time (in hours) and the units (plate thickness, welding throat, etc.) can be stored in the model (see Fig. C.11).

Fig. C.12 is the frame to launch manually the cost evaluation. Some assemblies can be selected in the SWBS and then the user can start the cost computation. During calculation the user can control the calculation progress trough the progress bars. Fig. C.13 shows the main frame of the server cost module.

Fig. C.14 shows the main frame of the visualization module. This frame is divided in two hierarchical structure which represent on the first hand the ship hierarchy (upper left side) and on the second hand the cost structure (lower right side). These two parts interact to show the cost results in a user friendly way.

Fig. C.15 and Fig.C.16 shows some additional information available for the designer during the cost assessment process. These information are important to identify what are the causes of the over costs.

Fig. C.17 shows the GUI of the data warehouse module.

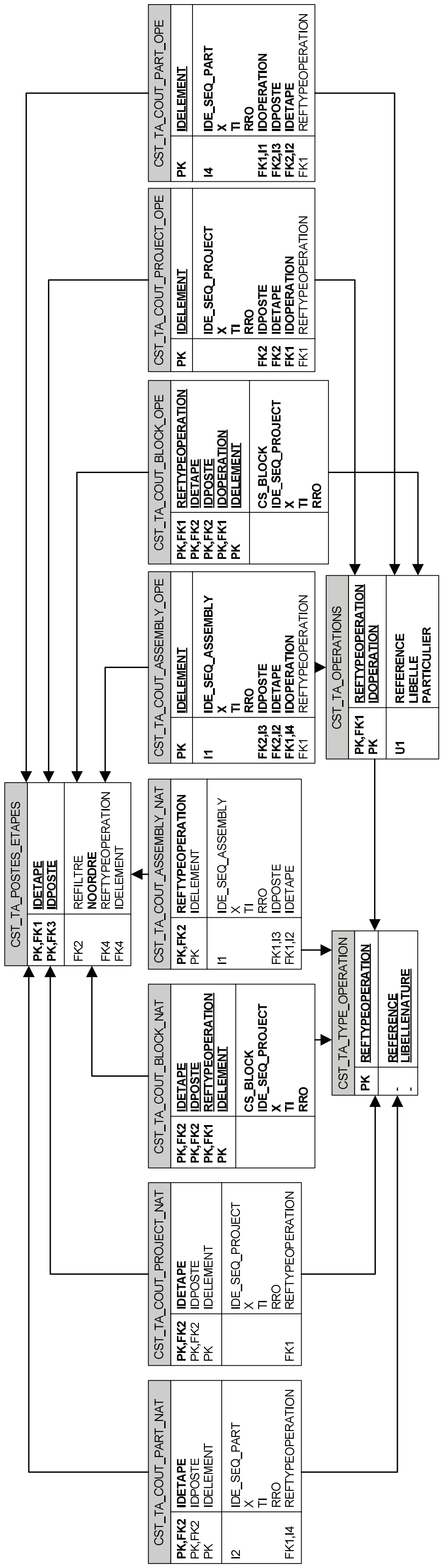


Figure C.9: Entity Relationship Diagram (ERD) of the COST database – Cost results

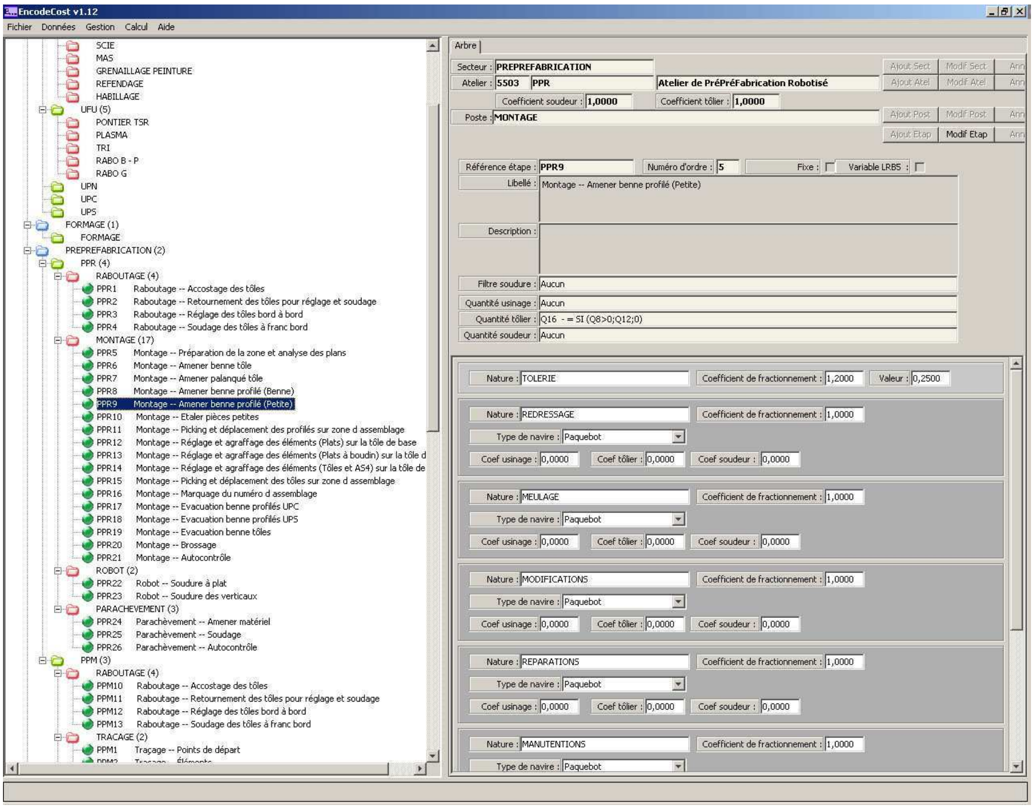


Figure C.10: Main frame of the EncodeCost module

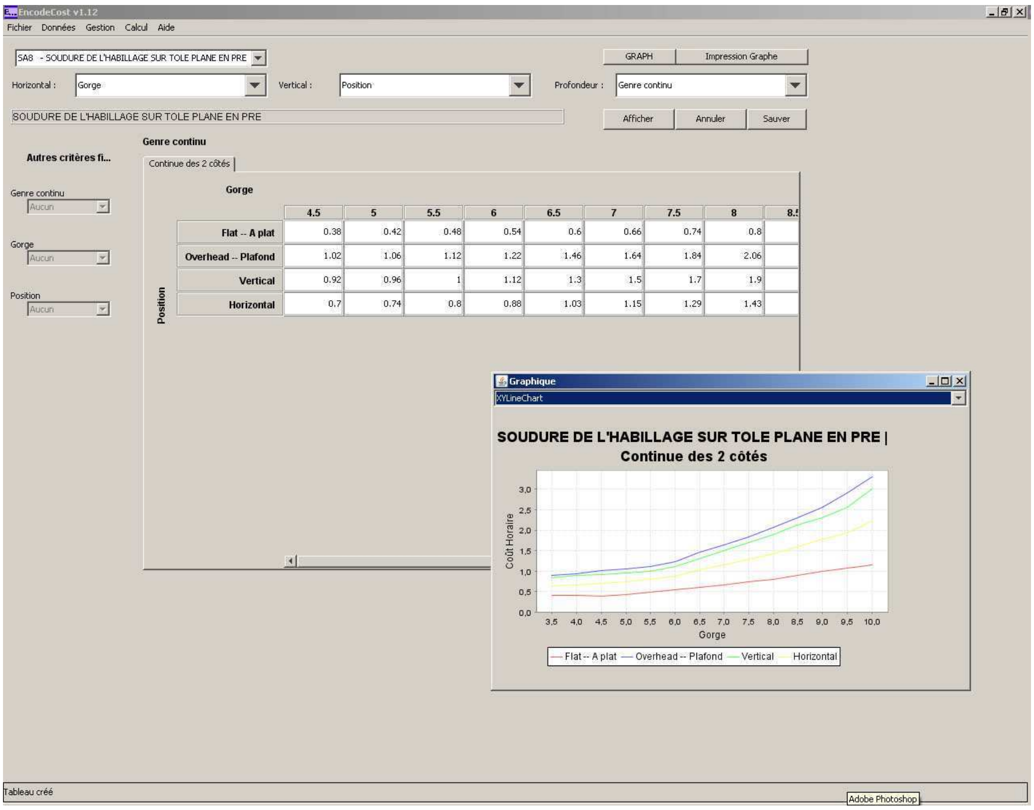


Figure C.11: Relation between working time (hour) and units (plate thickness, welding throat, etc.)

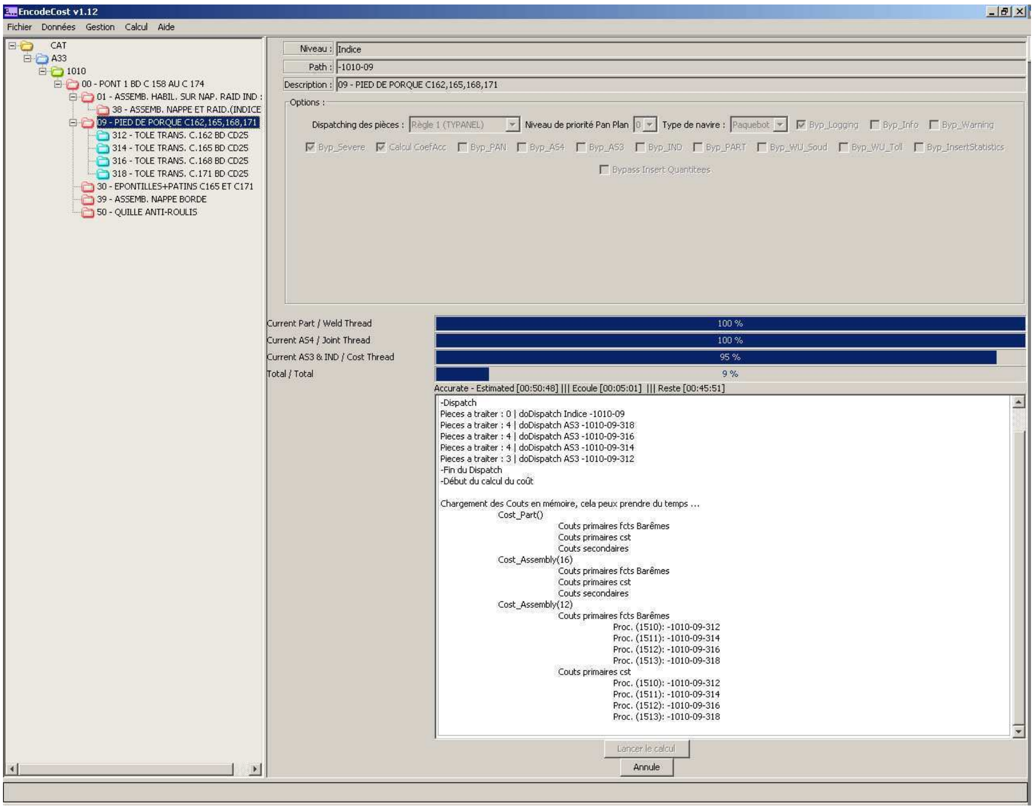


Figure C.12: Selection frame for cost calculation (manual trigger)

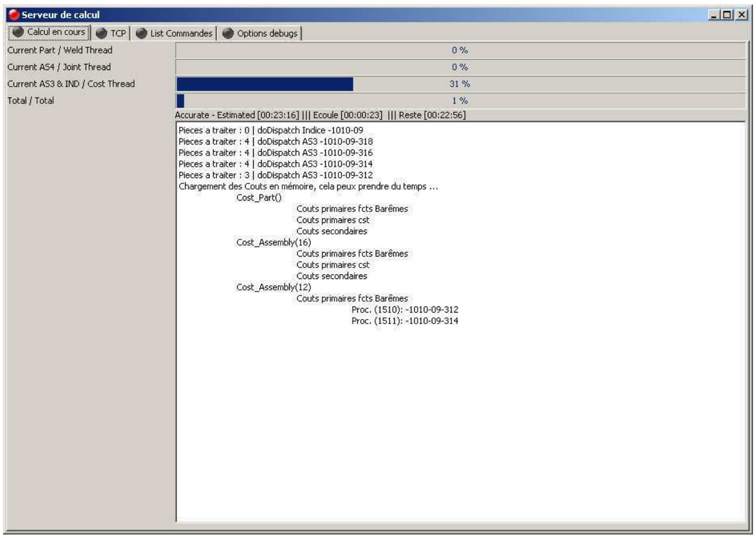


Figure C.13: Main frame of the server cost module

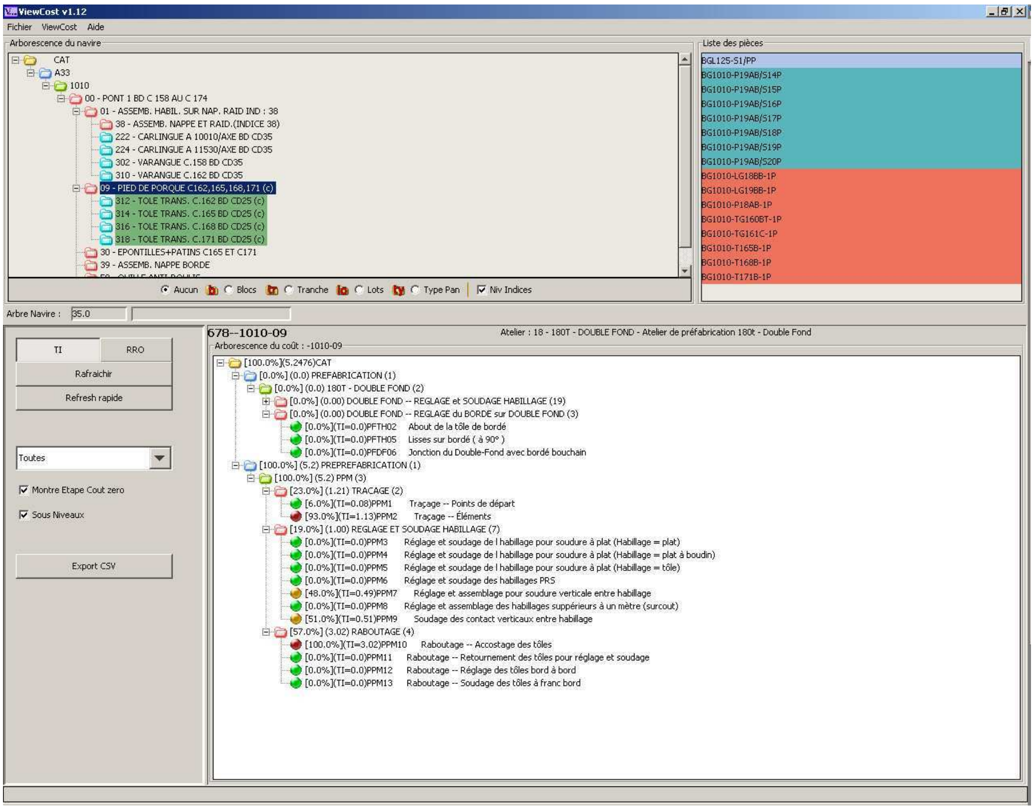


Figure C.14: Main frame of the View Cost module

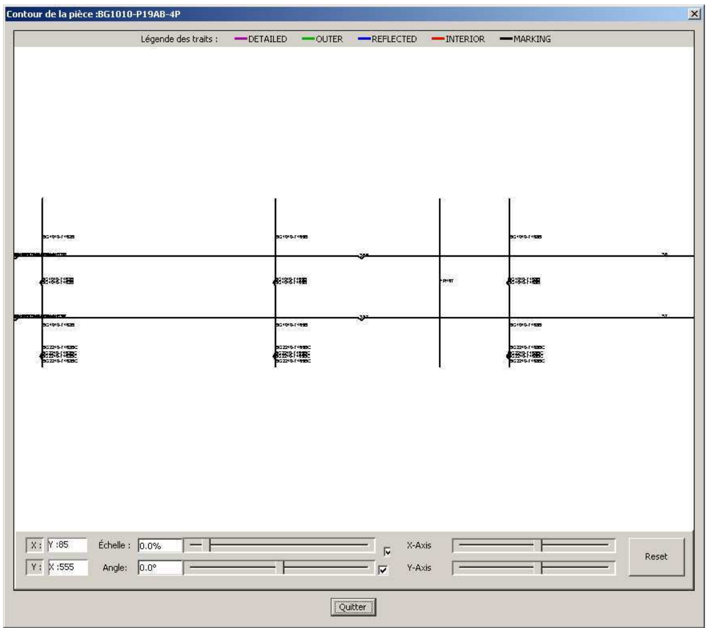


Figure C.15: Windows for steel contour part visualization

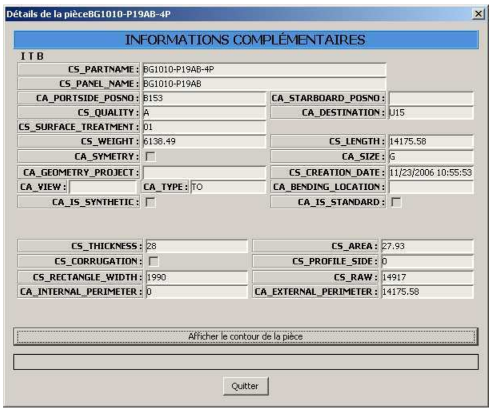


Figure C.16: Details meta data on assemblies and steel parts

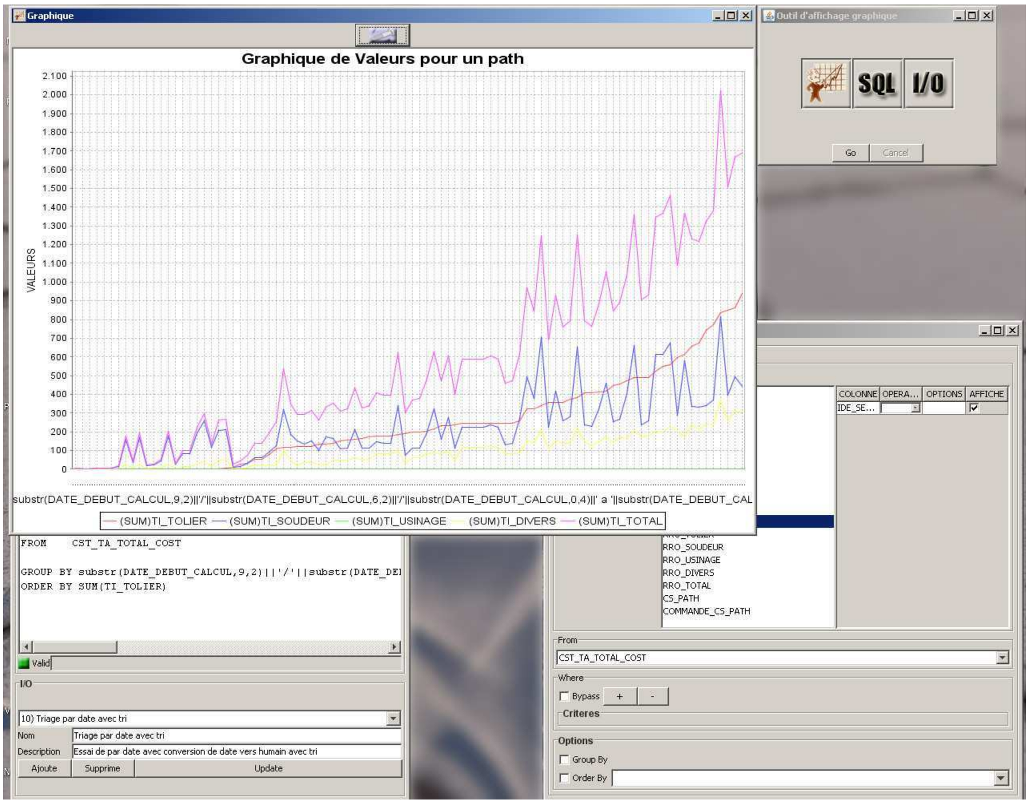


Figure C.17: Main frame of the datawarehouse module

Appendix D

Production simulation

D.1 STS tool set for shipbuilding

The implementation of simulation models is based on the discrete event simulation software called (Plant Simulation) and developed by Siemens. The development presented in the PhD are performed using the additional library Simulation Tool set for Shipbuilder (STS). This toolkit conatains the whole variety of simulation functions needed for modelling the production of a shipyard or its suppliers. The STS is programmed shipyard independently. The tools can be easily implemented in all kind of simulation models. They can be adapted to certain tasks and specifics by adjusting their parameters. Because the STS can be used universally and to speed up the development in the field of simulation in shipbuilding an international cooperation community has been established consisting of shipyards, universities and research centres called SIMCOMAR consortium. From this tool set different objects has been used. The Simulation Toolkit Shipbuilding offers a variety of tools to model assembly processes. The main aspects of the block assembly can be considered by combination of the simulation tools assembly control and space. A short explanation of the objects is described in Tab. D.1 and Tab. D.2.

In a production simulation model the different modules interact considering simulation rules and constraints. It is event driven and controlled by different additional methods (see Fig. D.1).

D.2 Database structure

Fig. D.2 shows the Entity Relationship Diagram (ERD) of the Ship Work Breakdown Structure (SWBS) database used foe the production simulation. This database has been implemented in Microsoft Access software for the study.

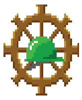
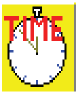
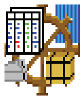
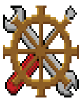
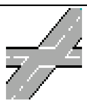
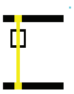
Icon	Object	Description
	Model administration	To administrate the models a special tool is implemented. It allows the user to configure the main frame of the simulation. Configurations regarding scale, animation, paths, user menus, etc. could be done in this module.
	Personnel control	The central personnel control was implemented to consider the personnel as an essential resource within the assembling process. The central personnel control enables it to meet the incoming requirements with the existing personnel. Whereas qualification, workload as well as allocation are considered, e.g. performing group.
	Calendar	Working shifts and operation calendars can be defined for the personal. For the shifts start, end and breaks will be defined. The operation calendar contains the working days. The allocation of the shifts and the operation calendar is done by the personal control.
	Transport control	The transportation control is used for the management of the transport actions within the model. The transport requests, coming from assembling areas, are collected, supplied with priorities and accordingly sorted via the transportation control. The transportation orders will be processed according to the resulting hierarchy, which means that the orders are allocated to every free or just about to be free vehicle. The vehicles heading towards the loading area and will transport the ordered part to its destination. A special method manages the ongoing procedure for the special place, e. g. order a crane to load or unload a part as well as a call for the material management.
	Material control	Essential is the material controlling or management which administrates the orders and locations of the manufactured products. Those products will be sent to the required location according to the defined priorities. The approach within the material management is as follows. The produced parts will be registered with the location at the material management after the manufacturing of the parts is complete. All parts will be logged off after the loading and fetching process and will be registered again at the new station. This is valid for all stations except the assembly station where the parts will not be available after the assembling process. The parts needed within the assembly area are ordered by a request. The transportation process will be started when the requested parts are available. In the case that the ordered part does not exist so far, the order stays active until the part is produced.
	Assembly Control	The assembly control is the central control for the processes dedicated to the assembly processes. Considering the specific assembly procedure all necessary steps will be defined and control here. It implies all processes from the order of material until the welding and declaration of the construction or ship. The assembly contains also methods to order material and parts for the assembly, to manage the transport from different places to the assembly shop, to handle the transport equipment, to assemble parts, to manage breaks. To keep the right assembly sequence the constraint manager was installed.
	Streets	Streets are connecting different areas and will be used by vehicles.
	Vehicles	Heavy lifter, trucks or fork lifter could be considered in the model. The vehicle use streets to transport parts or assemblies between different manufacturing places.
	Crane	In the manufacturing process different kinds of cranes are in use. Usually it picks up a part and moves it to another location or a destination like a vehicle. Each crane could be configured by lifting capacity, dimensions and speed. It is also possible to request personnel.

Table D.1: Main STS production simulation objects – Part I

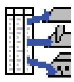
Icon	Object	Description
	Order generator	A production starts with the generation of orders. A order could be a virtual part which symbolize the request of material and work. The order will be finalised when a construction is assembled. It needs a implementation of controls to generate, identify and distribute orders for the assembly areas.
	Model statistic	For the aggregation and preparation of the results of the simulation run the model statistic will be used. Therefore a summary of the detail statistics will be created. The documentation of the statistic could be done daily or weekly. The interface of the model statistic allows to define the period of statistic, the interesting resources (machines and personal) as well as the transports (vehicles). It can be used for a very fast detection of bottlenecks or other interesting aspects. But the user who will read and process the statistics should be experienced in this field. He has to be careful by the interpretation of the statistic results.
	Constraint manager	Considering the assembly strategies there are sometimes technical restrictions for the sequence of processes. The constraint manager allows with global and local rules to restrict the assembly procedures.
	Import and export	The import and export interface allows a complete and automatically import of all simulation data from the various database. Via ODBC the data will be imported and stored locally during the simulation. When the simulation run is finished the results (statistical data from the transport resources, human resources and constructions) will stored into the simulation database.

Table D.2: Main STS production simulation objects – Part II

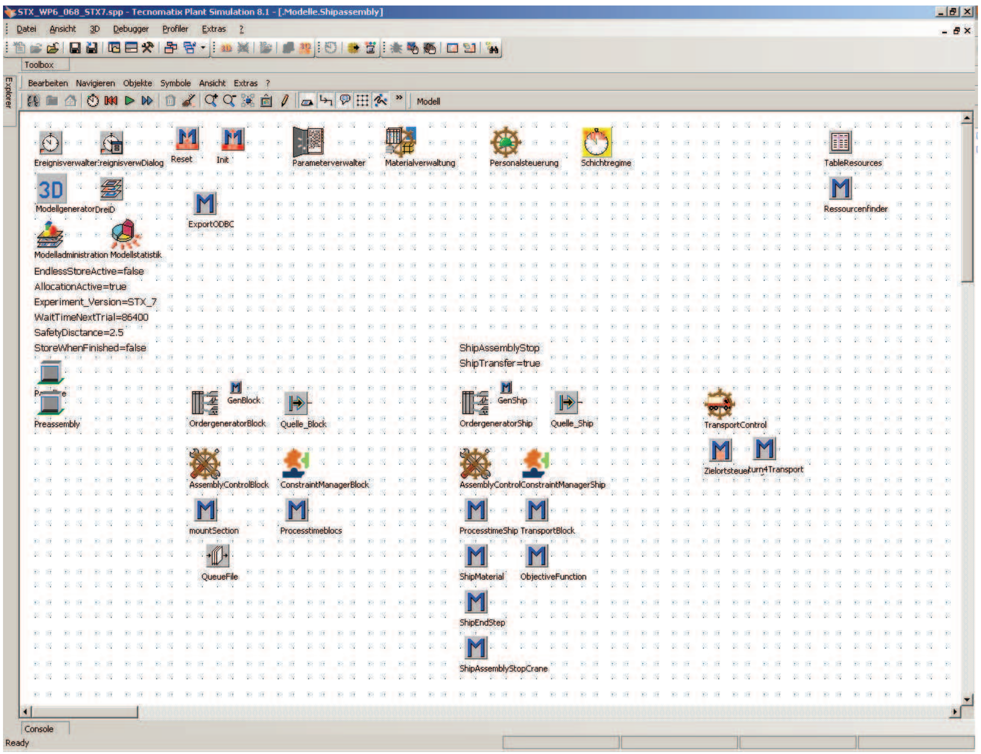


Figure D.1: Objects and methods of the production simulation model

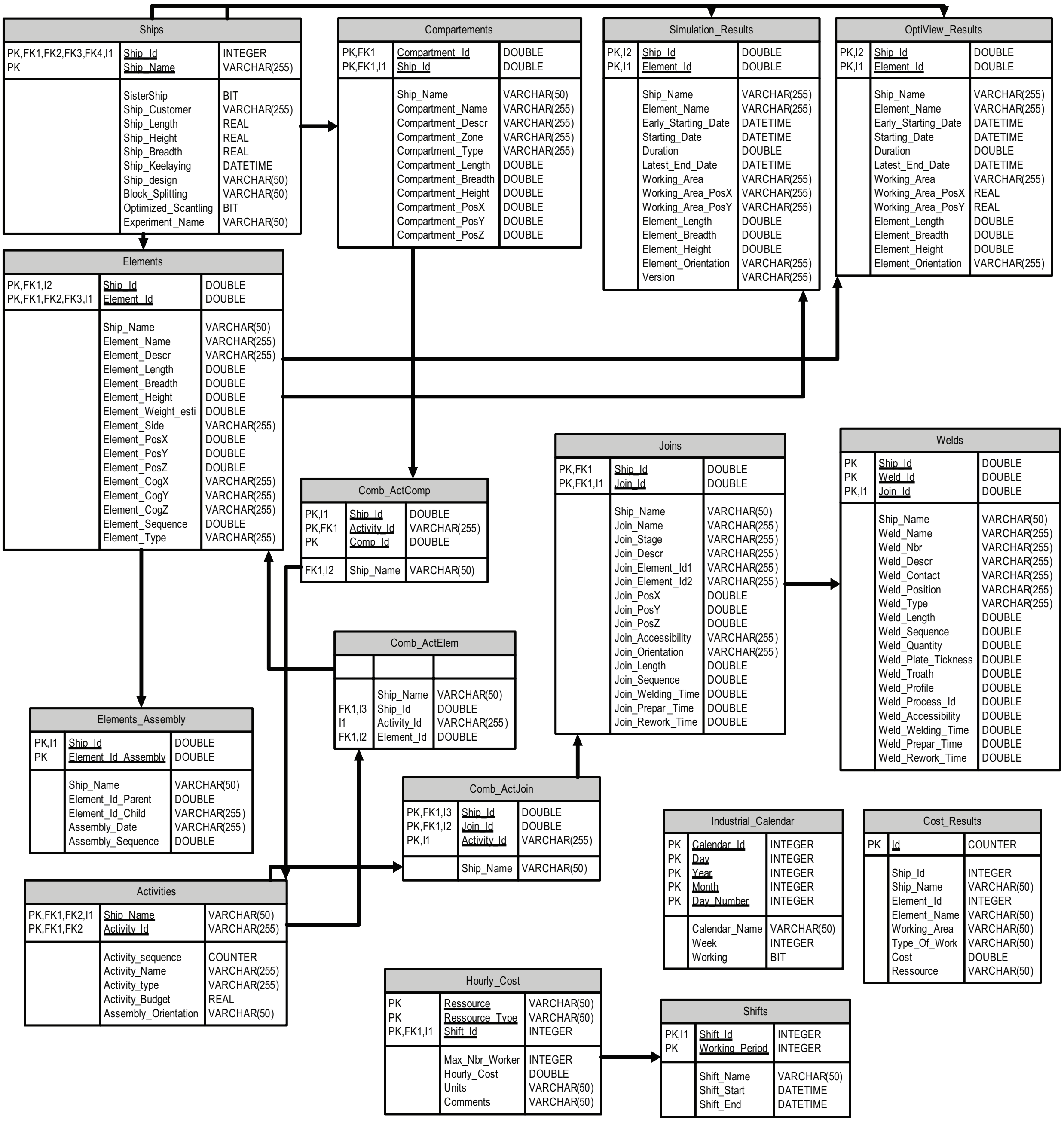


Figure D.2: Entity Relationship Diagram (ERD) of the SWBS relational database

Appendix E

Productivity measurement and improvement

E.1 Productivity measurement

There are a wide variety of productivity measures in use in shipyards. Their primary use is to set targets, at trade, department or work station level. The main requirement of each productivity parameter is that it should provide a consistent measure of the time taken to complete a specific task. Rather than simply recording the time taken, the system of productivity measurement should encourage performance and quality improvement.

There are several generally accepted methods of determining the work content of a task (see section 3.4). In all cases, the method depends on accurate feedback of current performance data. This in turn depends on accurate values of work content. In order to determine the work content accurately, it is initially necessary to work from detailed production information. As discussed in section 3.4, some cost assessment are better than others especially when there is no past performance data. As has been noted, *feature base costing* or *production simulation* will typically predict results which are far better than has previously been achieved.

It is therefore necessary to review the outcome alongside the past data, and to arrive at a consensus estimate which satisfies [BC92]:

- the target improvement in productivity;
- the acceptance of the targets by production management and supervisors.

An essential requirement is the establishment of suitable indices which enable the impact of action, aimed at improvement of any process, taken at any level to be quantified, even such major changes as the introduction of new management quality or lean production.

The indices chosen must be flexible in that they can be used on an ongoing basis, despite technology changes and working practices. They must be as useful for cost assessment as for work content or performance measurement. Good estimates are made by accurate comparison with the previous costs, allowing for any special changes in equipment or method, and hence a good estimate becomes a standard with which to compare the actual cost when the production is completed, and thus show any increase or decrease in efficiency of the shipyards in respect to the particular product. The change in efficiency of operations can be localized and investigated. It is one of benefit to know that inefficiency exists unless it can be localized, investigated and possibly remedied.

Productivity metrics, when properly structured and applied, help management to:

- monitor productivity
- forecast manpower requirements and allocate manpower to workloads such that these are levelled
- monitor the man-hour used and project the amount of man-hour required to complete new contract
- prevent waste such as waiting time, rework, etc. by identifying their sources and impacts.

E.2 Productivity improvement

Improving the productivity of a shipyard is demanding a larger effort from management than automation, mechanisation or extra personnel. Labour productivity will increase, leading to reductions in production time. As long as the investment for the change is low, the affection the overall cost is evident. The effects on cost of automation and mechanisation are claimed to be less (see E.1). The improvement of the productivity can be made through a higher grade of automation, production-friendly design, optimal material flow, and other "engineering solution".

	Required effort in		Improvement in	
	Management	Investment	Productivity	Lead Time
Improve organisation	• • • •	•	• • • •	• •
Improve ship design	• •	• •	• • •	•
Improve production schedule	• •	•	• •	•
Improve production flows	•	• •	• • • •	• •
Automation and mechanisation	•	• • •	• • •	• •
Improve standardisation	• • •	• •	• • •	•
Improve prefabrication[1]	• •	• • •	• • • •	• • •
Add personnel	•	• • •		• •
Add a new equipment or workshop[2]	• • •	• • • •	•	• • • •

Table E.1: How to increase productivity

[1](Block, sections, pre-outfitting, etc. –> Group Technology)

[2]To work in parallel